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Full Length Research Paper

Evidence based review of *Legionella* elimination in building water systems

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Legionnaires disease can be acquired through exposure to *Legionella pneumophila*, a gram-negative bacteria ubiquitous in both natural and engineered water systems. Over the years, a number of disinfection techniques notably, chlorination, ozonation, thermal, UV and copper-silver ionization have been employed across different kinds of engineered water systems with diverse measures of success. Available evidence portends, most of the aforementioned techniques often have to be combined to achieve long-term efficacy. Remarkably, albeit the extensive research and reportage on Legionnaires outbreak in the developed world, very few studies have been carried out with regards to Africa. We reviewed existing literature on the application of the aforementioned techniques in buildings. Our study concurs with earlier studies; most of the disinfection techniques will have to be combined to achieve the desired efficacy. We found very scanty studies on Legionella or reportage of its outbreak within Africa. Our study also found very little in terms of any of the techniques been applied with the specific aim of reducing Legionella proliferation in engineered water systems within Africa. This is alarming, especially, on a continent where several communities have little or no access to quality water and healthcare. In light of the above, stronger measures such as sensitization, properly managed water distribution systems, as well as policies aimed at enforcing national and international guidelines on Legionella control is recommended.

Key words: Legionnaires disease, water disinfection, engineered water system, Africa.

INTRODUCTION

Legionnaire's disease first commanded attention in 1976 during an American Legion convention in Philadelphia (Swanson and Hammer, 2000). Whilst initial documentation on Legionnaires was related to cooling towers, a study by Tobin et al. (1981) was one of the earliest to demonstrate *Legionella* could be found in water distribution systems of hotels and hospitals. Their study demonstrated infected water systems could be linked with cases of Legionnaires in the absence of air-conditioning equipment. Legionnaires is largely caused by Legionella *pneumophila* a pathogenic bacteria for free living, ubiquitous, freshwater, and soil amoebae of the

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genera Acanthamoeba and Naegleria (Rowbotham, 1980). The disease is characterized by pneumonia, often afflicting the elderly or immunosuppressed individuals (Parry et al., 1985; Kümpers et al., 2008; Hilbi et al., 2010). Although *Legionella* is a genetically diverse species, L. *pneumophila*, one of the many *Legionella* species, is common in natural and engineered water systems and its single serogroup, L. *pneumophila* Sg1 accounts for almost 84% of Legionnaire's cases reported world wide (Cold Spring Harbor Laboratory, 2008). Though several disinfection modalities have been tested and approved over the years, the dilemma in choosing an efficacious technology still lingers. The application and draw backs of most of the contemporary techniques employed continue to be evaluated whilst new techniques or devices aimed at *Legionella* control in water systems are still being experimented. Perhaps, this is because each of the techniques presents distinct characteristics (Marchesi et al., 2011). Over the last two decades, most of the notably documented techniques (e.g. superheating, copper-silver ionization, ozonation, Ultra violet light and hyper chlorination) have undergone evaluation and review in literature elsewhere (Kim et al., 2002a; Campos et al., 2003; Lin et al., 2002; Muraca et al., 1987; Muraca et al., 1990; Lin et al., 1998, 2011). Despite the above, these reviews along with documented efficacies often do not include Africa. While *Legionella* sampling in water systems is almost a routine in developed nations. Legionnaires disease is barely a subject in most African countries. Most patients are sub optimally treated for other diseases such as Tuberculosis in the face of likely symptoms. Owing to the fact that *Legionella* is ubiquitous in both natural and manmade water systems (CDC, 2016), the aforesaid is particularly disturbing considering the fact that piped-in water is non-existent in the poorest 40% of households in rural sub Saharan Africa (UNDESA, 2014). In this study, we review literature on some of the most commonly used techniques in *Legionella* control in engineered water systems. Keen attention is paid to water quality as well as the application of the respective techniques on the continent.

METHODS

The documented efficacy, advantage, disadvantage and effect on water quality of a number of disinfection modalities aimed at *Legionella* control and elimination was carried out. Thermal disinfection, hyper-chlorination, copper-silver ionization, ozonation and UV light were selected, taking into consideration similar reviews of the afore listed along with other techniques (Kim et al., 2002a; Campos et al., 2003; Lin et al., 1998). With the exception of copper silver ionization, the techniques were also selected based on existing evidence of their application across Africa for regular water treatment. Copper silver ionization was however added based evidence of its “positive” reviews in other literature. Finally, the review also sought to put together, documented efficacy in hospitals, hotels and water distribution networks; uncharacteristic of majority of such reviews.

CLASSIFICATION OF WATER DISINFECTION TECHNOLOGIES IN LEGIONELLA CONTROL

Water disinfection employed in *Legionella* control is varyingly classified. In certain literature, the techniques are classified as “localised methods” or point of use e.g. ozonation, UV lights and “systemic” e.g. thermal disinfection or copper silver ionization (Peiró Callizo et al., 2005). Other literature also groups the techniques as systemic or emergency disinfection (Lin et al., 2011). Emergency techniques such as thermal disinfection often employed during outbreaks have been reported to lack residual effects over longer periods (Stout et al., 1986; Chen et al. 2005; Mouchtouri et al., 2007), while disinfection techniques such as copper-silver ionization which have been linked with long term *Legionella* control are still under evaluation albeit being implemented (Cachafeiro et al., 2007).

THERMAL DISINFECTION (“HEAT AND FLUSH”)

Method

Water temperature greater than 60°C inhibits the survival 19 and growth of L. *pneumophila in vitro* (Muraca et al., 1987, 1990; Campos et al., 2003). Although one of the earliest in *Legionella* control, available literature suggests it is inefficacious unless repeatedly applied alongside faucets chlorine disinfection (Stout et al., 1986; Mouchtouri et al., 2007). Nonetheless, the temperature range for proliferation (20°C to 43°C) as well as inactivation (>44°C, < 20°C) are well documented (Konishi et al., 2006; Schulze-Robbecke and Buchholtz, 1992). Though varying forms of implementing this technique exists, the basic principle involves elevating the temperature of water in a storage tank above 70°C while ensuring temperatures at distal fixtures are not below 60°C. Distal fixtures may then be run at respective time intervals for days and monitored in accordance with required standards or regulations.

Characterization of efficacy, advantages and disadvantages

In a review, Campos et al. (2003), described thermal disinfection as a temporal control strategy as bacteria colonization is often evident months after implementation. Perhaps, due to ‘repository biofilm’ which provide protective mechanism for survival and re-colonization, complete elimination of *Legionella* in water systems remains farfetched (Mouchtouri et al., 2007). The above is evident in a study by Steinert et al. (1998), who observed re-colonization of two *Legionella* strains, three months after implementing the technique (70°C) in a hospital water system (Figure 1). A study by Chen et al. (2005), also observed regrowth’s, two months after implementing the technique at a medical centre (Figure 1). Other studies have also reported insignificant reduction in *Legionella* contamination counts within the first months of its implementation (Marchesi et al., 2011). In terms of its edge over other disinfection techniques, thermal disinfection does not require any special equipment’s aside the use of devices that register water temperature. It can be implemented expeditiously in cases of outbreaks or emergencies. On the other hand, the possibility of scalding and the amount of work involved in monitoring distal sites could be time consuming. Challenges with its application in larger buildings e.g. hotels or hospitals where stable temperature may be difficult to attain along entire water networks is also noteworthy (Chen et al., 2005; Mouchtouri et al., 2007). In view of the afore-stated, routine implementation could be challenging especially as such facilities (Hotels or hospitals) will have to be unoccupied at best. Finally, dead legs, operation at deliberate low temperatures per concerns of scalding, as well as its implementation in old water

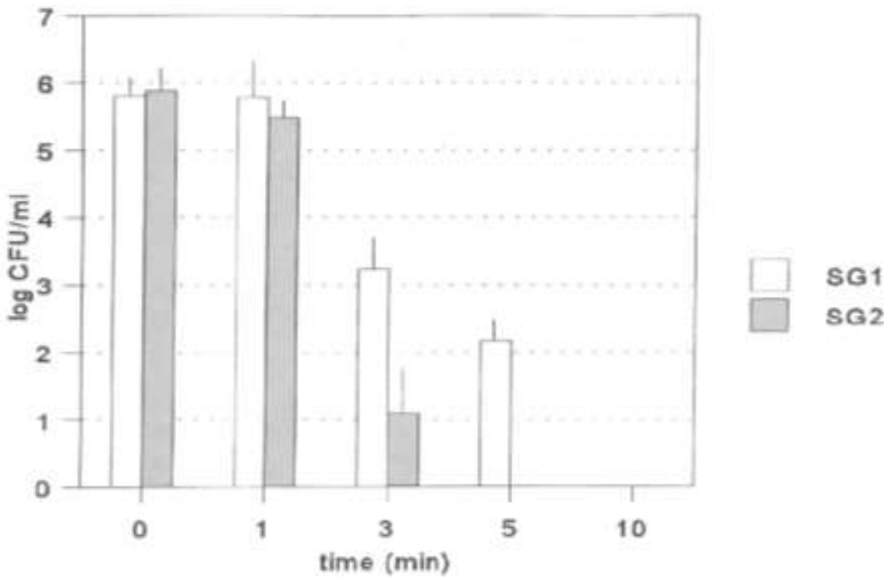

Figure 1. Comparison of the heat resistance of *L. pneumophila* serogroup 1 (SG1) and serogroup 2 (SG2). The heat resistance was determined by plotting the number of survivors (CFU/ml) versus period of exposure at 60°C. Data are expressed as the means of 5 independent experiments. Source: Steinert et al. (1998).

distribution networks are also noteworthy inhibitions (Groothuis et al., 1985; Plouffe et al., 1983).

Effect of thermal disinfection on water quality and its application in Africa

The overall effect of thermal disinfection on water quality remains conspicuously better than other water disinfection technologies especially due to lack of biocidal effect of chemicals as may be the case in other disinfection modalities. Minus "circulation" through the water distribution network along with "special devices" that monitor water temperature at distal sites, the technique is almost synonymous to boiling which remains perhaps, one of the default household water treatment methods in the developing world (Rosa and Clasen, 2010). Evidence of easy contamination after cooling coupled with economic and environmental unsustainability in its application (Luby et al., 2000; Gilman and Skillicorn 1985; Parikka, 2004) perchance, remains the defining reason why the technique is not used as a routine water disinfection modality. Interestingly, boiling remains relatively rare in Africa (4.5%) even though other African countries such as Uganda (39.8%) and Zambia (15.2%) report significantly high rates of its application (Rosa and Clasen, 2010). Nonetheless, whereas boiling will serve the same purpose of *Legionella* inactivation (> 70°C), evidence of literature on boiling or heat treatment specifically aimed at *Legionella* control is almost nonexistent. Boiling is however largely documented as a household water treatment method.

HYPER CHLORINATION

Method

Hyper chlorination involves the addition of chlorine to water with existing chlorine residue. So far, two ways of implementing the technique has been documented: (1) Shock hyper chlorination, which involves the pulse injection of chlorine into a given water system (range of 20 to 50 mg/l), and (2) continuous chlorination which involves continuous injection of chlorine in a form of gas, liquid or solid. The treated water is later drained and fresh water introduced to reduce chlorine concentration to about 0.5 to 1 mg/l. Typically, the installation involves, mounting chlorine injectors in highly pressured water supply lines with venturi orifice which create a vacuum; consequently, drawing chlorine gas into the water stream. Overall, adequate contact time and mixing is required to achieve desired efficacy.

Characterization of efficacy, advantages and disadvantages

Although the technique represents the decisive treatment for bacteria control and elimination in most water systems most especially in old water distribution networks (Schoenen, 2002; Orsi et al., 2014), *Legionella* is reported to be more tolerant to chlorine than other bacteria including *Escherichia coli* (World Health Organization (WHO), 2007). Evidence of the presence of biofilm is reported to be a key element in its ability to offer such resistance. As described by Cooper and Hanlon (2010), continuous growth and survival of L. *pneumophila* biofilms (1-2 month old at 50 mg/L over an hour) were observed despite high levels of chlorine. An earlier study by Kuchta et al. (1983) also showed different *Legionella* strains were more resistant to chlorine compared to other coliform bacteria; even more resistant at low chlorine dosages. In terms of its long term efficacy, an environmental surveillance study by García et al. (2008), showed *L. pneumophila* sero-group 1 survived despite successive episodes of hyperchlorination for 10, 5 and 17 years in a hotel, fishing boat and hospital water system respectively. By far, available studies continue to suggest, hyper chlorination appears to be only effective in its initial stages with bacteria levels often exceeding pre-treatment levels after a short while (Marchesi et al., 2011) (Figure 2). There is also evidence of facilities (e.g. hospitals) switching to other disinfection techniques having previously implemented hyper chlorination (Lin et al., 2011).

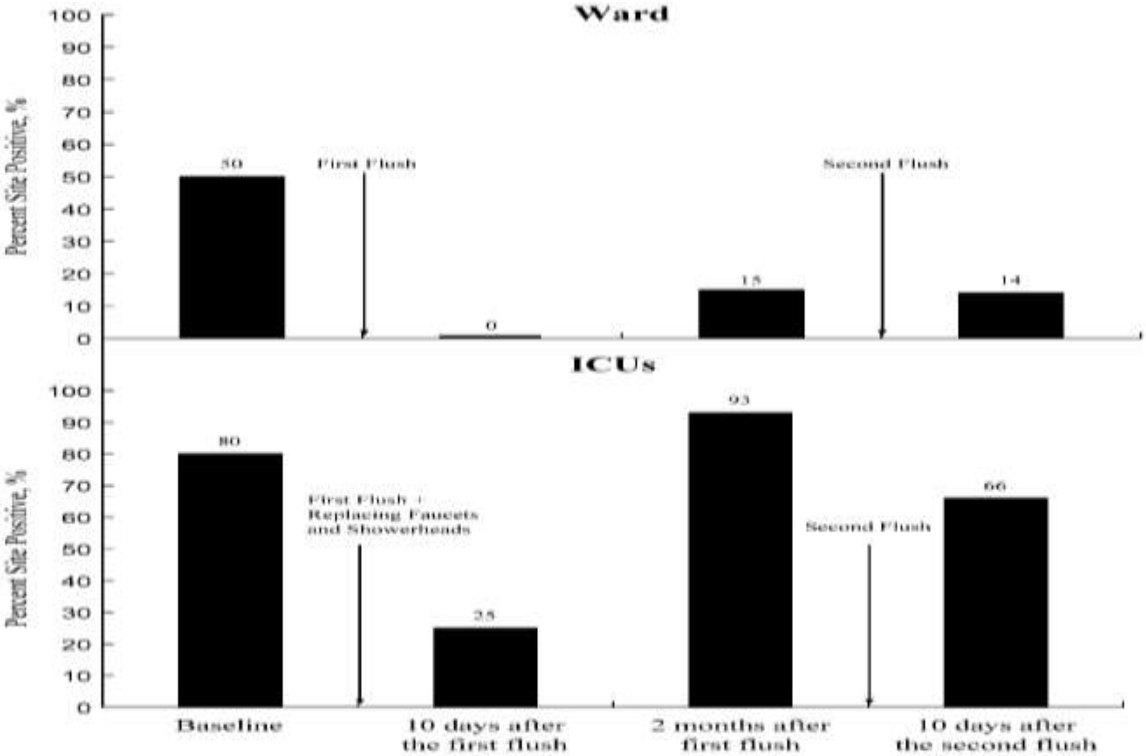

Figure 2. Short duration of superheat and flush failed to eliminate the site positivity for Legionella in patient ward and intensive care units (ICUs). Source: Chen et al. (2005).

Thus, hyper chlorination is inadequate for long term disinfection and only suitable for emergencies or during commissioning (DOH, 2009). Coupled with the above, the after effects of its application e.g. corrosion of pipping material over longer periods and the associated health effects of chlorine by-products such as trihalomethanes linked to cancer is also noteworthy (Gopal et al., 2007; USEPA, 2001; Miller, 2008; DOH, 2009; Mcdonnell et al., 1999). Finally, it has been suggested varying residual concentration due to changes in water flow rates may result in inadequate residual quantity at distal fixture, this, may in the long run have no significant effect on bacteria present (DOH, 2009).

Effect of hyper chlorination on water quality and its application in Africa

Although the use of chlorine eliminates water odour (Wajon et al., 1988), water quality is reduced (organoleptic and chemical) often, as a result of chlorine levels (>0.5 < 1.0 mg/L) (Orsi et al., 2014). In terms of health, an increased risk of bladder cancer also appears to be associated with the consumption of chlorinated water (Cantor, 1997) along with other illnesses such as asthma and dermatitis which have also been reported (Gorchev and Ozolins, 2011; Fawell, 2003). Within Africa, available literature shows hyper chlorination is used extensively. Albeit reports of its effect on human health in countries such as Algeria (Benhamimed and Moulessehoul, 2010), hyper chlorination has been documented as an emergency technique during a Legionnaires outbreak in South Africa (NICD, 2016). Its application in conflict areas or disasters zones e.g. Kenya during Cholera outbreaks, alongside the promotion of hygiene and safe food preparation has also been reported (UNICEF, 2011). More so there is documented evidence on its use in the control of Hepatitis E outbreak in northern Uganda. These, reports show, higher concentration of residual chlorine is often required to facilitate control of the virus (IFRC, 2008). Overall, the use of chlorine within drinking water networks either as centralised or point of use is quite extensive in many African countries e.g. Angola, Cameroon, Ethiopia, Guinea, Kenya, Madagascar, Malawi, Mozambique, Nigeria, Rwanda, Tanzania, Uganda, and Zambia (Peletz and Mahin, 2009; Walfer, 2013).

COPPER-SILVER IONIZATION

Method

Copper-silver ionization involves passing water through a device which applies low potential electricity to electrodes of silver and copper, consequently, dissolving and distributing smaller ions (Cachafeiro et al., 2007). The Copper ions (Cu^{2+}) present, form electrostatic bonds with the negatively charged cell walls of microorganisms (*Legionella* inclusive) resulting in the disruption of cell wall permeability (Muraca et al., 1990; Lenntech, 2011). On the other hand, the silver ions bond with the DNA and RNA of the microorganism, leading to immobilization and cell death (Lenntech, 2011). Overall, the concentration of ions and the nature of the water system must be carefully evaluated, in order to achieve eradication of *Legionella.*

Characterization of efficacy, advantages and disadvantages

Despite the conventional argument that most disinfection techniques cannot be used in isolation, there is evidence to

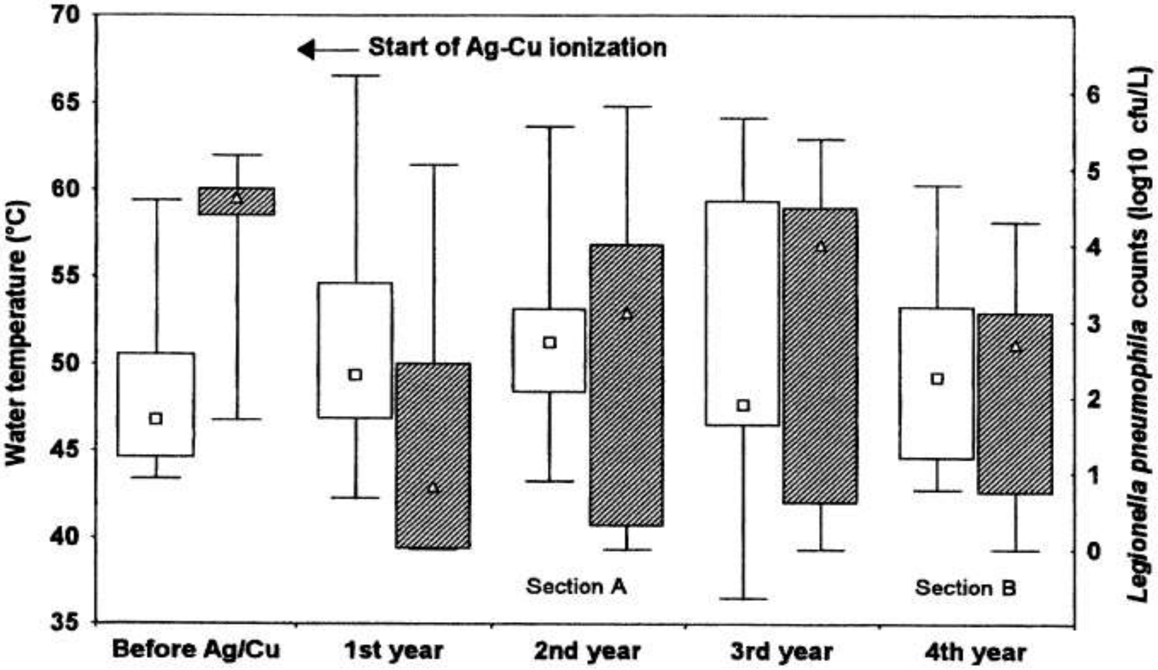

Figure 3. *Legionella pneurnophila* counts (cfu/L; shaded bars) and water temperature (°C; white bars) in hot water system of a university hospital, with use of silver-copper ionization in the year before ionization, 3 years with first ionization unit (Section A), and 1 year with a new ionization unit (Section B; fourth year). Box plot: Median, 25 to 75th percentile, minimum to maximum. Source: Rohr et al. (1999).

suggest, copper-silver ionization continues to gain popularity across the globe as an effective and safe technique so long as ions are monitored according to requisite standards (Cachafeiro et al., 2007). In terms of its effect, its application leads to lysis and cell death by "distortion of cellular permeability coupled with protein denaturation" (USEPA, 2001). Its ability to kill as opposed to suppression or control of bacteria is also well documented (Lin and Vidic, 1996; Lin et al., 1998; DOH 2009). With respect to other microorganism aside *Legionella*, States et al. (1998) argue, copper silver-ionization is ineffective against amoeba and other non-Legionellaceae bacteria. Nonetheless, there is evidence the technique is efficacious against other waterborne pathogens such as *Pseudomonas aeruginosa*, *Stenotrophomonas maltophilia* and *Acinetobacter baumannii* (Huang et al., 2008). Its application in both hot and cold water point of entry is also reported (Chen et al., 2008).

A survey by Stout and Yu (2003) across 16 US hospitals over a 5 to 11 year period, observed copper-silver ionization was most effective compared to other previously implemented disinfection techniques. They reported 0% positivity for *Legionella* for 50 and 43% of the hospitals as of 1995 and 2000 respectively. This was against 7 out of 15 of the hospitals reporting 30% *Legionella* positivity at distal fixtures prior to application. Only a single incidence of Legionnaires was reported after the technique had been implemented. A study by Rohr et al. (1999), also showed copper silver ionization achieved a reduction *in Legionella* counts from 40,000 to 7 cfu/L during the first year of disinfection (average silver ion concentration <10 ug/L). Nevertheless, an increment of 10,000 cfu/L was observed in the third year over a four-year period (Figure 3). Thus, the study concluded, the effect of the technique was only suitable for short-term applications and influenced by factors such as water temperature and content of silver ions in water (>45°C, up to 66.6°C).

Following the concentration of nontuberculous mycobacteria and legionellae for three and four years respectively on the influence of the technique, Kusnetsov et al. (2001), reported electronically released copper and silver ions were inefficacious at taps and showers of a hospital water system despite an increase in ion concentration in the circulating water. Mòdol et al. (2007) in an evaluation of the impact of the technique after the implementation of other techniques, reported a significant decrease in *Legionella* counts as well as reduction in nosocomial legionellosis (2.45 to 0.18 cases per 1000 patient discharges)

Overall, although advantages such as ease of installation and maintenance have been reported, difficulty in monitoring residual levels, formation of insoluble hydroxides and the need for periodic cleaning of electrodes are also noteworthy (Lin et al., 2011; Campos et al., 2003). A review by Kim et al. (2002a), on studies conducted by other authors suggests the use of metal ions, "*either copper alone or both copper or silver*" is a good option for *Legionella* control especially in hot water recirculation systems. Nonetheless, its long term effect is yet to be listed as a major advantage. There are also studies on its application in swimming pools although peer reviewed literature on its efficacy is rarely been reported (Abad et al., 1994; Beer et al., 1999).

Effect of Copper-Silver Ionization on water quality and its application in Africa

According to Mcdonnell et al. (1999), the oral consumption of ions through the use of copper-silver ionization is often limited as ions are only added to recirculating lines in hot water systems. Largely, copper-silver ionization poses very minimal potential safety hazards compared to other chemical disinfection techniques even though its continuous use is however barely encouraged (Zheng et al., 2012).

Table 1. Water and swab samples obtained before control measures, during ozonation, and during ozonation and increased temperature (65°C).

Periods	Control measures	Water samples			Swabs	
		No. of positives/no. performed (%)	p	Cfu/ml (mean of positives) (SD)	No. of positives/no. performed (%)	P
1993-1995	None	66/100 (66)		10.9G17	Not done	
1996-1998	Ozonation	67/120 (56)	0.12	5.2G97	56/106 (53)	
1999-2001	Ozonation and increased temperature (55°C)	23/79 (29)	0.0004	7.6G16	54/169 (32)	0.006

Source: Blanc et al. (2005).

In a study on the technique, Lin et al. (2002), found variations in water quality as a cause of its inefficacy as on-site pH measurement were high (8.9). There are also reports on the effect of water type (hard or soft) on the efficacy of the technique (TARN-PURE Ltd, 2016). Within Africa, there seem to very little or non-existent literature on the application of the technique in *Legionella* control. There are however some studies related to copper and silver metals. In Swaziland, Varkey (2010) reported on the antibacterial effect of copper and silver metals on Coliform and E. *Coli* through immersion of the metals in water. Paper filters containing AgNP and CuNP were tested on water sourced from contaminated streams in Limpopo South Africa resulting in marked reduction in coliform bacteria and *E. coli* counts and in the incorporation of a copper mesh in the design of clay pot water filters (CPWFs), E. *coli* and coliforms concentrations in contaminated water were reported to have reduced markedly (Varkey and Dlamini, 2012; Dankovich and Gray, 2011).

OZONATION

Method

Ozone is an unstable potent biocide and oxidizing agent which must be produced on site due to its short half-life especially as rising temperature can results in increase in decomposition (NRC, 1980). Ozone can be produced in a number of ways notably phosphorus contact, silent discharge, photochemical reactions, and electrochemical reactions (Wei et al., 2016). Generated electrically by exciting oxygen O_2 to a tri-atomic state O_3 , ozone can be injected to an allowable quantity but should be maintained at a residual dosage.

Characterization of efficacy, advantages and disadvantages

Comparably, ozone is more effective in L. *pneumophila* control compared to other oxidizing biocides (Dominique et al., 1988). In a review, Kim et al. (2002b) reported there is an appreciable use of ozone across Europe although its better complimented with other disinfectants such as chlorine. In light of it being unstable, ozone does not stay in water sufficiently long to provide the residual effects often required in the control of pathogenic bacteria (Kim et al., 2002b; WHO, 2007; Blanc et al., 2005). Ozone is reported to somewhat more effective at a lower temperature, with a potential of faster destruction of microorganisms at higher pH (Botzenhart and Tarcson, 1993)

In terms of efficacy, Edelstein et al. (1982) documented, ozone reduced L. *pneumophilla* counts in one wing of an unoccupied hospital with average ozone concentration of 0.79 mg/L.

Blanc et al. (2005) however reported no significant reduction in *Legionella* counts after the application of just ozonation. Appreciable reduction in *Legionella* counts were however observed after the complimentary implementation of thermal eradication (Table 1).

Overall, ozone generation consumes a significant amount of energy and thus require a lot of monitoring in order to ensure power is optimized while achieving disinfection targets (Casey et al., 1998). Additionally, its requirement of onsite generation and the use of special equipment as opposed to other disinfection modalities make it less favourable. Based on its quick decomposition characteristics and its lack of residual effect, a growing body of reviews and independent studies show ozonation is best implemented as a secondary disinfection technique (Campos et al., 2003; Kim et al., 2002a; Blanc et al., 2005). Reports of of its instantaneous effect in bacterial inactivation, rapid decomposition and on site generation are however listed as major advantages (Casey et al., 1998; Campos et al., 2003).

Effect of ozonation on water quality and its application in Africa

A varying body of literature shows, ozonation significantly improves water quality either in building water systems or even when used in aqua culture (Davidson et al., 2011; Von Gunten, 2003). A study by Von Gunten, (2003) reported ozone as an excellent disinfectant in the inactivation of protozoa compared to other very conventional disinfectants. In terms of water quality, ozonation has been documented to result in a significant increase in ultraviolet transmittance as well as a reduction in carbonaceous BOD and colour (Davidson et al., 2011). By combining ozonation with UV treatment, available literature has shown the potential for minimizing bromate as well as the oxidation or micro pollutants in water (Meunier et al., 2006). Practically, studies have also shown the application of ozonation for disinfection has a positive impact on distribution water system, reducing both levels of disinfection by products and complaints about the taste and odour of water (Dyksen et al., 2016). Essentially, it is evident problems in water quality that are often addressed with peroxide, chlorine etc. can also be addressed through ozonation (Eagleton, 1999). Within Africa, there is extensive evidence on the application of ozonation although much of its use is not directly aimed at the elimination of L. *pneumophillia*. The post-ozone plant at Wiggins waterworks which was commissioned in 1984 in South Africa is one such example. The purpose of the plant has been to properly disinfect water by eliminating viruses in raw water pumped from the polluted lower Umgeni river (Rencken, 1994). There is also evidence on the application of ozonation in industrial waste water and drinking water treatment plants in parts of South Africa (Van der Merwe et al., 2012). Its use at the Midvaal water company Durban Water Recycle

Plant and Magalies Water plant are also documented (Rajagopaul et al., 2008; Morrison et al., 2012).

UV IRRADIATION

Method

UV disinfection can be applied in two ways: (1) Positioning UV lights at specific points within a given water distribution system that service a designated area or (2) installation of a UV-sterilizers for the disinfection of incoming water. Monochromatic low pressure UV lamps and polychromatic medium pressure lamps are some of the lamps used (Oguma et al., 2004).

Characterization of efficacy, advantages and disadvantages

In terms of efficacy, available literatures shows UV radiation kills bacteria by hampering DNA replication through the production of “thymine dimers” (Gavdy and Gavdy, 1980 as cited in Hambidge, 2001). Typically, there are different types of UV lamb systems although low pressure UV bulb systems are almost an industry standard supplying monochromatic irradiation specific to 254 nm wavelength (Summerfelt, 2003). Its efficacy against other microorganisms is documented elsewhere (Harris et al., 1987; Hijnen et al., 2006; Chevrefils et al., 2006). On the other hand, the use of UV alone in a persistently colonised hospital water distribution system (“point of use application”) showed it was ineffective in the elimination of *Legionella* (Liu et al., 1995). The concurrent application of other disinfection techniques e.g. Superheat/Flush and shock chlorination however achieved some reduction in *Legionella* counts. In a study by Franzin et al. (2002) a reduction in *Legionella* counts (L. *pneumophila* sero-group 3) was achieved even at distal sites using UV light. The authors therefore concluded UV disinfection could be suitable in small areas of water system. In Hall et al. (2003), UV was efficacious in preventing *Legionella* contamination over a 13 year period. Overall, despite reports of the extensive application of UV in both cold and hot water systems (Liu et al., 1995; Kim et al., 2002a), its limitations include maintenance against the formation of scales, likelihood of malfunctions, lack of residual protection beyond points of application and turbidity (Muraca et al., 1990; USEPA, 2001; Campos et al., 2003). The use of filters in minimizing the accumulation of scale on UV quatz sleeves has also been reported (Liu et al., 1995). In terms of other advantages, UV light is easy to install (Campos et al., 2003). Conspicuously, continuous monitoring as may be the case in other disinfection modalities is also limited. Finally, although the energy used in typical UV disinfection system in an average size home is comparable to the energy used by a 40 watts bulb (UV Dynamics, 2016), the energy cost associated with technique cannot be ignored.

Effect of UV irradiation on water quality and its application in Africa

Overall, the application of Ultraviolet light (UV-Lamp) is an established and increasingly popular alternative to chemicals for the disinfection of water distribution systems. Interestingly, the quality of water is one of the many defining factors in its application (Wright and Cairns, 1998). Amid it being a cost effective disinfection technology, there is evidence, UV provides no residual effect in water towards the protection against post treatment contamination (Clancy et al., 2000; Said and Otaki, 2013). A study by Choi and Choi (2010) has shown the technology has an effect on dissolved organic matter structure (DOM) in distribution systems including an increase in biodegradability (Frimmel, 1998; Drikas et al., 2004). By far, the aforementioned remains the most documented effect on water quality across an existing body of research (Kruithof et al., 1992; Oppenheimer et al., 1997). Within Africa, a study on a device (UV light 254 nm) that utilizes the technique to disinfect community drinking water demonstrated efficacy for close to 4.5 months; delivering water that meets WHO and USEPA bacteria standards (USEPA, 2001; Gadgil et al., 1998). At the Durban Metro Water and hospice for infants, the application of a UV unit also achieved a reduction in E. *coli* and total coliforms concentration per local standards (Gadgil et al., 1998). Largely, there is no literature on the application of this technology specifically aimed at *Legionella* control. There is however extensive publication on its application as a regular water disinfection technology coupled with the proliferation of numerous devices or units that utilize the technology for disinfection (Brahmi and Hassen, 2014; Gadgil et al., 1997). Perhaps, Solar Water Disinfection (SODIS) which is appears to be highly patronised due to the conspicuously low cost implication associated with it compared to the conventional use of UV lamps, positions the use of UV- light as somewhat unpopular. Reports on the efficacy of SODIS and application in developing nations is been reported (Mosler et al., 2013; Murinda and Kraemer 2008; Altherr et al., 2008; Conroy et al., 2001). Nevertheless, its limitations such as the need for sufficient solar radiation, relatively clear water and difficulty in treating large volumes cannot be overlooked (Mintz et al., 2001).

DISCUSSION

This work provides further knowledge on an already explored area of comparing different water disinfection techniques in *Legionella* control and elimination. Additionally, the study also attempts to identify cases of Legionnaires reportage in Africa as well as the application of some selected disinfection techniques in *Legionella* control within the continent. The overall aim of the fore going, is to provide an update on some of the most commonly used water disinfection techniques employed in *Legionella* control so as to provide a pool of evidence based options (locally and internationally) in the event of Legionnaires outbreak within Africa.

Globally, reports on the outbreak of Legionnaires occur almost every year; often reported by the developed countries. Countries such as the United States through the Centre for Diseases Control (CDC) are known to document almost 5,000 cases of Legionnaires’ annually (Dooling et al., 2015). This is no different in Europe. Well-regulated surveillance programmes across almost 35 countries within Europe, exist with the mandate to collect and provide information with regards to the disease (Heuner and Swanson, 2008). The European Surveillance Scheme for Travel Associated Legionnaires Disease now known as EWGLINET, is known to be instrumental in recommending standards for Legionnaires surveillance (Ricketts and Joseph, 2005). The case is however very different in the African context. With the exception of a handful African countries e.g. South Africa, there is very little in terms of institutions or organizations aimed solely at monitoring Legionnaires on the national scale or on the continent at large. The lack of statutory notification of Legionnaires, coupled with clearly defined health based standards is evident in the lack of academic literature or studies related to Legionnaires on the continent, as may be the case in Europe. For instance, there are very few studies or reports on particular water disinfection techniques aimed at *Legionella* control or evidence of them being applied during an outbreak as shown in this review. Perhaps, political importance, clinical impact or rareness of disease (Heuner and Swanson, 2008) that are motivating factors in paying attention to most infectious diseases is minimal.

Unfortunately, the argument cannot be made that reportage or studies related to *Legionella* are very little because proliferation, infection or outbreaks rarely occur. L. *pneumophila* is known to grow and survive over a wide range of temperature (20, 40 and 50°C) (Rogers et al., 1994; Konishi et al., 2006) and these temperatures are typical in a greater part of sub Saharan Africa. Moreover, there is evidence to suggest temperature increase over land regions across the continent is consistent with anthropogenic climate change (Aalst et al., 2014), thus, the implication of the foregoing are favourable temperature for bacteria proliferation in already precarious water distribution networks across the continent. More so, at the root of the many challenges with water supply are the poor maintenance and servicing culture of already deteriorated pipe networks (Marin, 2009). Many of the water distribution networks are faced with massive leakages, irregular supply and low water pressure; these factors create avenue for easy water contamination (Marin, 2009). Implicitly, much of the water prior to being consumed at distal sites are already contaminated with pathogenic bacteria; a challenge that must be avoided from the onset as a step in achieving *Legionella* control (Borella et al., 2005; Rangel et al., 1999; WHO, 2007).

On the other hand, evidence of a single most consistent and permanent method at *Legionella* control is barely been established globally. Our review noted most of the disinfection techniques often had to be combined to achieve long term efficacy; consistent with literature elsewhere. For instance, while techniques such as thermal disinfection record some measure of efficacy, the lack of residual effect days after application, often require the application of other techniques e.g. chlorination. Thus, the application of such methods have demonstrated efficacy only in the short term. Additionally, it would also seem somewhat challenging to flush entire water systems of heavily occupied hotels or hospitals especially as occupancy and monitoring at distal sites are significant in achieving success. In terms of Chlorination, evidence of re-colonization as shown in this review, suggests it can arguably be placed under the category of short term or emergency techniques notwithstanding its residual effect. Moreover, the role of biofilm and *Legionella* resistance to Chlorine as reported in other literature (Kuchta et al., 1983; Cooper and Hanlon, 2010) imply, larger doses of chlorine are often required to achieve complete elimination. In view of the fact that chlorination is already used extensively as a common water disinfection technique within Africa (Whitacre, 2010), it seems at best, one of the most accessible disinfection techniques to be employed in the event of an outbreak. Chlorine dosage will however have to be based on local regulations or known international standards.

Copper silver ionization appears the most efficacious compared to the other techniques in this review. In addition to its ease of installation, evidence of its application even in hot and cold water systems with keen consideration to ion quantities, provides the basis for arguing, the technique can be employed during outbreaks and over longer periods. Additionally, its ability to kill as opposed to suppression, proves copper-silver ionization will be the most suitable disinfection modality in heavily colonised water distribution networks. The afore highlights, coupled with findings in other literature (Marchesi et al., 2011; Lin et al., 1998) therefore positions copper silver ionization, conceivably as one of the best alternatives for *Legionella* control.

With Ozonation, albeit, its extensive use within Europe and Africa as shown in this report, the need for onsite generation and special equipment could be challenging in most domestic installation or small public buildings in rural areas; heavily colonised by bacteria. Additionally, its lack of residual effect, energy consumption and need for monitoring, implies the technique will be difficult to apply in colonised water systems in places with less manpower or electricity. Nevertheless, its rapid destruction of microorganism at higher pH (Botzenhart and Tarcson, 1993) along with its ability to compliment other disinfection techniques, positions the technique as a viable option in *Legionella* control within Africa.

Finally, on the grounds of challenges such as maintenance against the formation of scales, lack of residual effect, use of filters for scale prevention and the need to combine with other disinfection techniques as already evidenced in this report, UV cannot be considered a “singular disinfection method“. Albeit its ease of installation, the lack of evidence of its efficacy in large-scale water systems, suggests UV should be considered in less colonised water systems or systems with little water volume, where greater water quantity can be exposed at point of contact. On the hand, the use of Solar Water Disinfection (SODIS) in Africa as suggested in the earlier part of this study will serve the greater advantage of bacteria control in rural areas especially in the absence of the commonly “advanced technologies” in water disinfection. A foreseeable challenge to this measure will be its inability to be implemented in large scale water systems where treating large volumes of water will pose a challenge (Mintz et al., 2001).

Overall, while all the aforementioned techniques have their respective disadvantages, their proven reliability across different types of buildings and water systems, suggest they can all be described as efficacious in one way or the other. Their implementation will therefore vary on a number of factors such as cost, ease of installation, maintenance, age and design of plumbing system, availability of electricity (for certain techniques), as well as the measure of colonization of the water system under consideration. An overall consideration should however be the prevention of contamination from the onset as reported elsewhere as well as effective monitoring of water system towards the identification of colonization at the early stages. The need for sensitizing the general population about Legionnaires, symptoms as well as factors that can lead to contamination in water distribution networks is also important within Africa.

Conflict of Interests

The authors have not declared any conflict of interests.

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