Potable water reuse – a sustainable water management option

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ABSTRACT:

Direct and indirect potable reuse (DPR and IPR respectively) is needed in many cases in order to secure a sustainable drinking water supply.The Windhoek/Namibia experience shows that treated domestic sewage can be successfully used for direct potable reuse. The advanced process employed produces reclaimed water of a quality that constantly meets all the required drinking water standards. Approximately 25 % of the potable water supply consists of reclaimed water. Therefore, this source is an essential part of integrated water resource management and has contributed greatly to the social and economic development of the city.A multiple barrier strategy is employed in order to attain the highest possible safety levels. There are three types of barriers comprised by *non-treatment*, *treatment* and *operational barriers*.The main reasons for public acceptance of potable reclamation and reuse are the lack of other affordable choices and the fact that since the beginning of potable reuse, no reclaimed water related health problems have been experienced. Further important factors have been the open information policy employed from the start of the project in 1968, the excellent public education practice and the consumer confidence in both the quality management and the advanced water treatment technology employed.

In recent years, indirect potable water reuse has also been a topic in India. Operational experience from the Windhoek New Goreanagab Water Reclamation Plant (NGWRP) and results from lab scale tests conducted with municipal tertiary effluent from an Indian sewage treatment plant is used for the design of an IPR treatment train employing ozone (H_2O_2 optional), ceramic membranes, biological active carbon filters (BAC), activated carbon adsorption (GAC) and disinfection.Although the used water (tertiary effluent) under study contained large amounts of bromide (700 – 1,350 µg/L), when dosed stepwise in low concentrations, ozone can be applied without the massive formation of bromate. This is due to the fact that hardly any ozone is available for reactions with bromine species. Nevertheless, micro-pollutants are degraded by nearly 50 %. This is the result of the formation of highly reactive hydroxyl radicals during the reaction of ozone with the organic matter of the tertiary effluent.

In many water stressed regions, potable reuse (DPR and IPR)has beensustainablypracticed,and also in Indiait constitutes a great opportunity for a safe and secured drinking water supply.

INTRODUCTION

Due to severe water stress, in many regions (southern Africa, southwest USA, Australia, etc.) the practice of indirect and direct potable reuse has to be employed in order to secure the drinking water supply. The Orange County Groundwater Replenishment System and the Singapore *NEWater* scheme (blending in reservoirs)are prominent examples of indirect potable reuse (IPR). The advantages of direct potable reuse (DPR) are that no environmental buffer is needed and existing drinking water infrastructure can be used. The city of Windhoek is well known for its lengthy DPR experience (more than 50 years). The city is water stressed and several severe droughts have made DPR vital for its development. In the last rainy seasonfrom November 2018 to March 2019, the rainfall was only 107 mm (average rainfall is 340 mm), and therefore - as in the past - emergency measures had to be implemented by the city government.Additionally, the city intends to build a second DPR facility in order to deal with the increased water stress in Windhoek. In recent years, further DPR schemes have been realized in South Africa: Beaufort West(2012) and in the USA: Big Spring, Texas/USA (2013) and Wichita Falls, Texas/USA (2014). Additionally, there are IPR and DPR projects that are in the planning, approval or execution stage (e.g. San Diego, California/USA and El Paso, Texas/USA).

DIRECT POTABLE WATER REUSE (DPR) IN WINDHOEK, NAMIBIA

In Windhoek, domestic secondary effluent is used for potable water reclamation. In order to attain the highest safety levels possible for this sensitive practice, a multiple barrier approach is employed (Lahnsteiner *et al.*2018). There are three types of barriers comprised by***non-treatment, treatment*** and ***operational barriers***.An essential ***non-treatment barrier***is the strict separation of domestic and industrial wastewater, i.e. only domestic sewage is used for potable reclamation. Industrial used water (approximately 1 million m³/y), which is discharged mainly by a brewery, a tannery and a meat processing company is treated separately in a central treatment plant with an MBR as its core technology (operational since October 2014). Another crucial ***non-treatment barrier*** is the comprehensive monitoring of thesewage treatment plant inlet and outlet, as well as the extensive monitoring of the drinking water quality. The blending of the reclaimed water with other potable sources (treated Von Bach Dam water and borehole water, maximum 35% reclaimed water) is also worthy of mention as a further important *non-treatment barrier*. Only blended water is distributed to consumers.***Treatment barriers***are formed by purification systems that are in constant operation, i.e. the Gammams STP (nutrient removal plant), maturation ponds and the New Goreangab Water Reclamation Plant (NGWRP, Fig.1).

Figure 1. New Goreangab Water reclamation Plant (NGWRP)

Operational barriersrepresent additional treatment options or operational measures that can be used on demand. An additional treatment option is powdered activated carbon, which can be dosed if the adsorption capacity of the GAC is too low or the organic load of the reclamation plant inlet is too high. One example of an operational measure involves switching to the recycle mode when the water quality fails to meet the online monitoring “absolute” values set for the different process units.

The NGWRPtransforms secondary domestic effluent (maturation pond effluent) into high-quality drinking water by means of an advanced multi-barrier system. It produces a maximum of 21,000 m^3/d of drinking water that is constantly controlled in order to ensure its suitability and safeness for human consumption.The plant was started up in mid-2002 and officially inaugurated in December 2002. The treatment train includes the following single *treatment barriers*: powdered activated carbon (PAC) dosing (optional), pre-ozonation, enhanced coagulation and flocculation, dissolved air flotation (DAF), dual media filtration, main ozonation, biological activated carbon (BAC) filtration, granular activated carbon (GAC) adsorption, ultrafiltration (UF) and disinfection with chlorine and stabilization with caustic soda (NaOH) (Fig. 2).

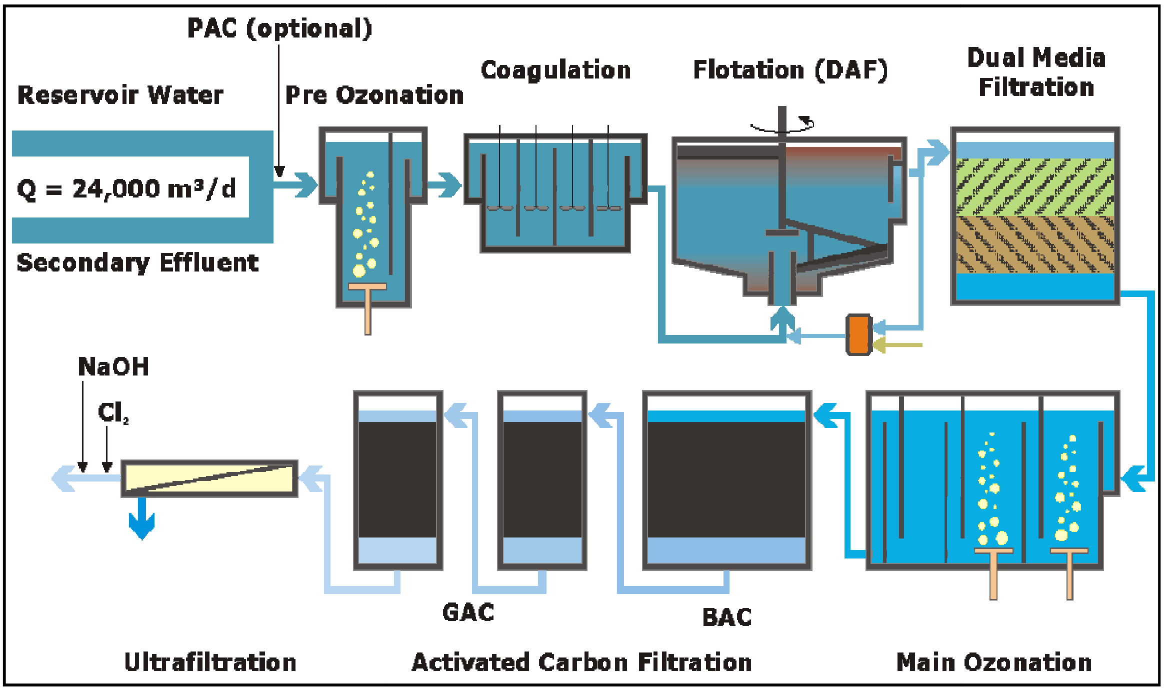

Figure 2. Process flow diagram - New Goreangab Water Reclamation Plant for direct potable reuse (DPR)

The process is automated based on a monitoring supervisory control and data acquisition (SCADA) systemwhich is operated by local staff (Fig. 3).

Figure 3. NGWRP - supervison of the process by local staff

Operational results

The New GoreangabWater Reclamation Plant (NGWRP) produces continuously good water quality that consistently meetsthe required final water specifications (van der Merwe et al. 2008, du Pisani&Menge 2013, Lahnsteiner et al 2007, 2013 and 2018). Table 1 shows the final water specifications and typical operational results (50 and 95 % tile). The final water specifications were derived from the following standards: the *1993 WHO Guidelines*, the *1996 Rand Water Guidelines Potable Water Quality Criteria* and the *1998 Namibian Guidelines for Group A Water*. New Namibian drinking water quality standards were drafted in 2012, but have yet to be implemented. As part of their latest DPR project, the City of Windhoek has conducted a review on the standards, monitoring requirements and final water quality requirements with a view to implementing any changes required at the NGWRP.

Table 1. Reclaimed water specification and quality

Parameter	Units	Final Water Specification	Actual Operational Results	
Physical and Organic			**50% tile**	**95% tile**
Chemical and Oxygen Demand	mg/L	10 – 15	6.6	11
Colour	mg/L	8 – 10	0.5	0.5
Dissolved Organic Carbon(aDOC)*	mg/L	3	1.7	2.8
Total Dissolved Solids	mg/L	1,000 max or 200 above incoming	838	938
Turbidity	NTU	0.1 – 0.2	0.05	0.10
UV_{254}	abs/cm	0.00 – 0.06	0.015	0.027
Inorganic				
Aluminium	Al mg/L	0.15	0.005	0.05
Ammonia	N mg/L	0.1	0.05	0.18
Iron	Fe mg/L	0.05 – 0.10	0.01	0.03
Manganese	Mn mg/L	0.01 – 0.025	0.005	0.0015
Microbiological				
Heterotrophic Plate Count	per 1 mL	80 – 100	0	4
Total Coliforms	per 100 mL	0	0	0
Faecal Coliforms	per 100 mL	0	0	0
Chlorophyll	µg/L	1	0.27	2.58
Giardia	per 100 L	0 count/100 L or 5 log removal	0	0
Cryptosporidium	per 100 L	0 count/100 L or 5 log removal	0	0
Disinfection by-products				
Trihalomethanes	µg/L	20 – 40	35	57

If the major parameters of turbidity, DOC, THM and UV_{254} in the water from the NGWRP and the Von Bach Dam (treated dam water) are compared, the reclaimed water shows superior quality to that from the dam(Table 2).

Table 2. Comparison of reclaimed and treated dam water quality

Parameter	Unit	Treatment Plants NGWRP median	Treatment Plants Bach Dam WTP median
Turbidity	NTU	0.05	0.6
DOC	mg/L	1.7	3.6
THM	µg/L	35	73
UV_{254}	abs/cm	0.015	0.05
TDS	mg/L	871	161

Antimicrobial Resistance

An emergingtopicin water management is antimicrobial resistance (AMR), i.e. antibiotics resistant bacteria (ARBs) and genes (ARGs).AMRisconsidered as a serious global health concern (e.g. by the World Health Organisation).It is not an isolated clinical issue, but an ecological/environmental issue. The major sources are human and veterinary medicine (therapeutic use) and pharmaceutical production (release from antibiotic production plants). In the environment, AMR is detected in soil, in freshwater bodies (rivers, lakes, reservoirs, aquifers) and used water (municipal and industrial wastewater). Therefore, AMR is also an issue in drinking water production by both conventional treatment (e.g. river water purification) and potable water reuse (reclaimed water from treated municipal effluents). Analysis conducted along the process units of the New Goreangab Water Reclamation Plant showed that ARBs and ARGs are removedcompletely by the advanced multi barrier treatment employed.

Public Acceptance

Reclaiming drinking water from domestic secondary effluent is not generally acceptable to the human race of 2019 and requires public and psychological barriers to be broken down. This is very difficult if potable reuse is not the only viable option. In Windhoek, the main reasons for public acceptance are the lack of affordable alternatives and the fact that since the beginning of potable reuse in 1968, no health problems have been experienced or verified in epidemiological studies with regard to reclaimed water. Additional reasons are the candid information policy implemented from the beginning in 1968 and the persistent and intelligent marketing contained in the aforementioned education programs. Over the years, acceptance has been further strengthened by the excellent water quality policy (multiple barrier approach including comprehensive monitoring programs) and from 2002 onwards, by the trust in the advanced technology of the New Goreangab Water Reclamation Plant(Fig. 1). In fact, there have been practically no consumer complaints relating to reclaimed water.

For the city of Windhoek, the future is unmistakably tied to intensified water reuse to a point at which the motto of “every drop counts” becomes a reality to each and every citizen. Building on the success attained by past generations, the planning of an additional direct potable reclamation facility is currently ongoing in an effort to secure medium-term water supply as an economically feasible alternative.

DESIGN OF AN INDIRECT POTABLE WATER REUSE (IPR) FACILITY IN INDIA

In recent years, indirect potable water reuse has also been a topic in India and in the following the design of an Indian IPR facility is described. Operational experience from the Windhoek NGWRP (Lahnsteiner 2018) and results from lab scale tests conducted with municipal tertiary effluent from an Indian sewage treatment plant is used for the design of an IPR treatment trainemploying ozone (H_2O_2 optional), ceramic membranes, biological active carbon filters (BAC), activated carbon adsorption (GAC) and disinfection (Fig. 5).

Bromate formation during ozonation (by oxidation of bromide) can be a limiting factor in such multiple barrier systems. The bromate standard has been set at 10 µg/L (EU, US-EPA and WHO).The source water is tertiary effluent from a large municipal used-water treatment plant including phosphorous and nitrogen removal. The bromide concentration of this source water is rather high (700 – 1,350 µg/L). This is above the upper end of bromide concentrations typically found in fresh water resources (10 - 1000 µg/L) (von Gunten 2003). Therefore, special emphasis has been laid on ozone design and on the avoidance of bromate formation.

The lab scale tests were conducted at the University of Duisburg-Essen (UDE) in co-operation with IWW Muelheim/Ruhr Germany (Koti et al 2016). For that purpose three 10 L samples of the tertiary effluent were sent from India to UDE and used for a comprehensive series of tests with regard to the ozone consumption of the source water (tertiary effluent), the evaluation of bromate formation depending on different ozone and ozone/H_2O_2 concentrations. In that context, also the degradation of the ozone resistant compound 4-chlorobenzoic acid (pCBA) was monitored, as indicator for OH-radicals. Ozonation experiments were performed at room temperature. For ozone dosage, an aqueous stock solution was prepared by purging ice cooled pure water with gaseous ozone. This ozone stock solution was dosed to aliquots of the wastewater samples using glass syringes. Free ozone in the wastewater was determined according to Bader and Hoigné(Bader and Hoigne 1981). The degradation of pCBAwas determined by HPLC-UV.

In Figure 4 and 5 typical lab scale test results with regard to ozone consumption and bromate formation are presented.

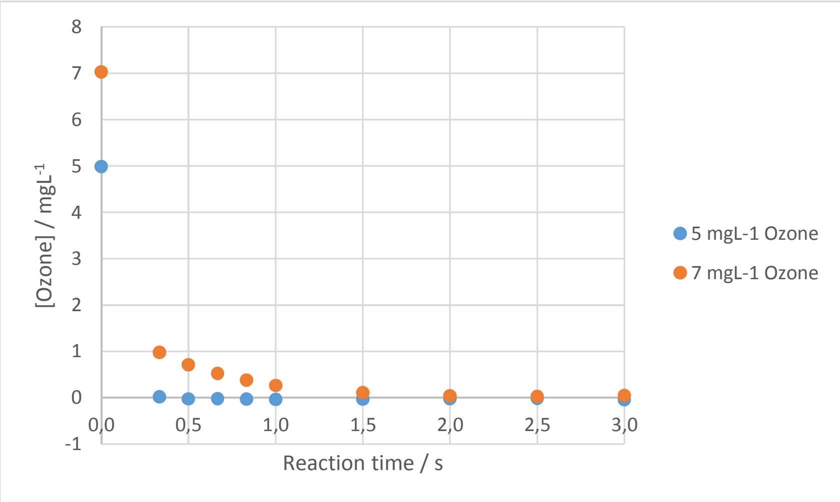

Figure 4. Ozone consumption at 5 and 7 mg O_3/L

Figure 4 shows the ozone concentration over time after dosage of 5 and 7 mg/L ozone. Due to the high dissolved organic carbon concentration (7.3 mg/L) of the used water, ozone is rapidly consumed in both cases in the first few seconds. However, it becomes obvious that the ozone stability at 7 mg/L ozone is markedly higher compared to the dosage of 5 mg/L. This has an effect on the formation of bromate (Figure 5).

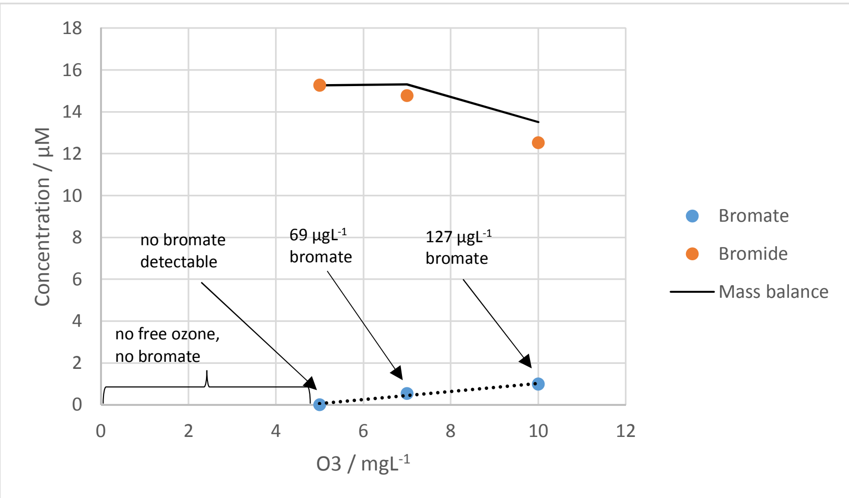

Figure 5. Oxidation of bromide and formation of bromate at 5, 7 and 10 mg O_3/L, [DOC] = 7.3 mg/L, [Bromide] = 1,200 µg/L

Figure 5 shows the formation of bromate at different ozone dosages. It can be seen that despite the high bromide level in the wastewater (1,200 µg/L) hardly any bromate is formed at an dose of 5 mg/L ozone, which coincides with the absence of free ozone (see above). Once free ozone is present at dosages > 5 mg/L bromate formation sets in.

Therefore, the ozonation process unit consists of two stages. The first ozonation stage is formed by a conventional, baffled ozone reaction tank (Fig. 5) with two or three dosing points for pre-disinfection and pre-oxidation. On the basis of the lab test results, the ozone dosage into the first compartment will be max. 5 mg O_3/L. A lower dosage (e.g. 3 mg/L) will be applied in the second compartment, as the main ozone consumption already occurs in the first compartment. The free ozone concentration is held at a minimum (< 0.1 mg/L) in order to avoid bromate formation. The second ozonation stage is formed by the volume of the ceramic membrane modules (Fig.6). The dosing point is located directly at the ceramic membrane inlet (dosing into the feed pipe, Fig. 5). This second application (preliminary assumption: 5 mg O_3/L) is also for oxidation (of e.g. micro-pollutants) and disinfection, as well as for the continuous chemical cleaning of the ceramic membrane.

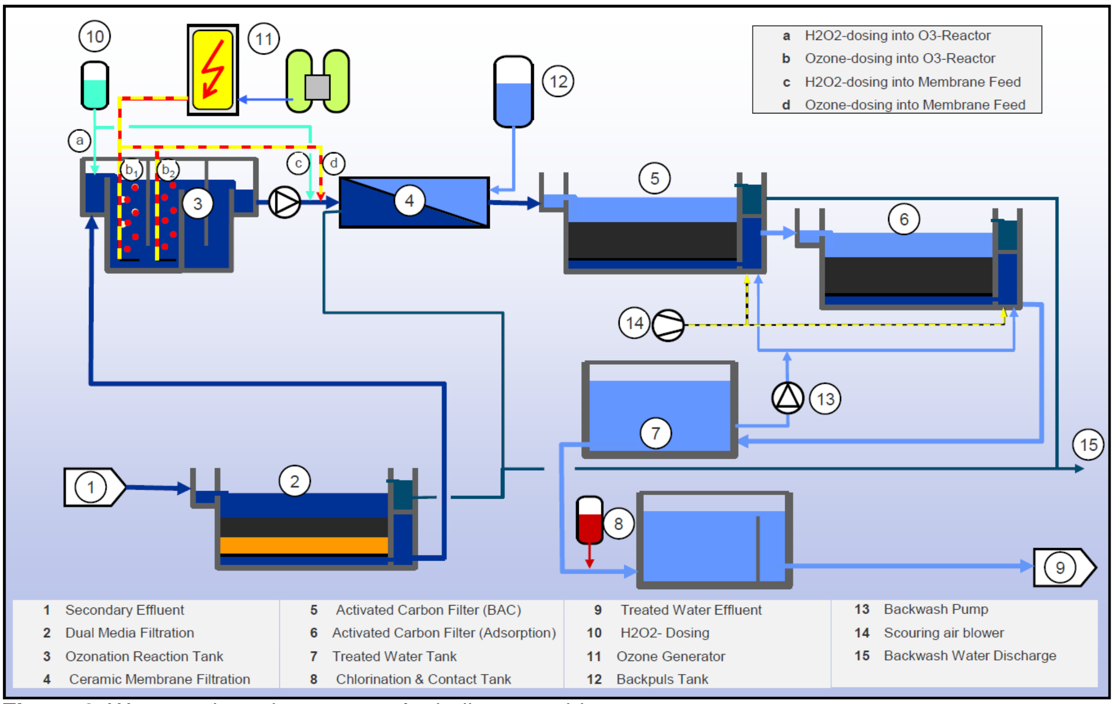

Figure 6. Water reclamation process for indirect potable reuse

The reaction of ozone with the organic matter in used water (wastewater) produces highly reactive hydroxyl radicals (Nöthe et al. 2009), hence pollutants can be degraded even in absence of free ozone (Figure 7).

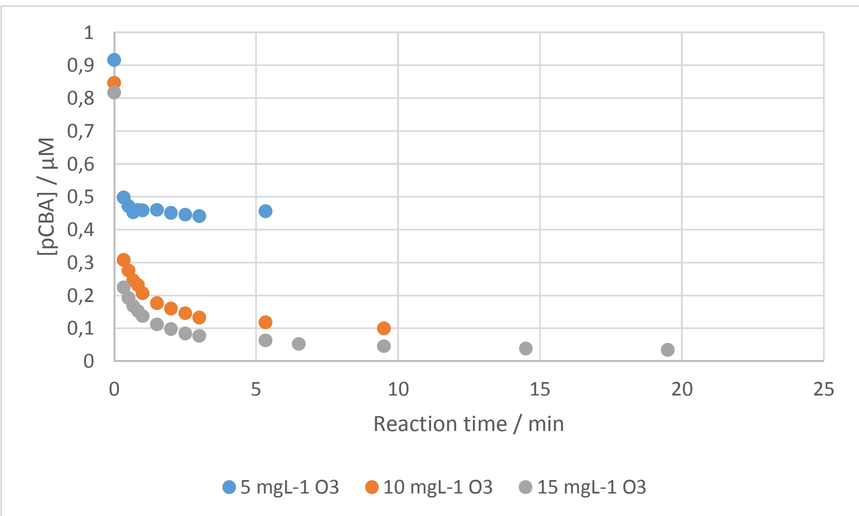

Figure 7.4-Chlorobenzoic acid elimination by ozone

Figure 6 shows the degradation of para-Chlorobenzoic acid (pCBA; 4-Chlorobenzoic acid) at different ozone dosages. Even though ozone is strongly consumed by the water matrix at a dosage of 5 mg/L ozone, the model pollutant pCBA is distinctively degraded. pCBA barely reacts with ozone but fast with hydroxyl radicals. This points to hydroxyl radicals as reactive species available for pollutant degradation. Hence, pollutant degradation was possible without massive bromate formation at low ozone dosages. The effect of $H_2O_2$was investigated in further experiments. In these experiments H_2O_2 was dosed in different stoichiometric proportions towards ozone (0.25-2.5 mol of H_2O_2 per mole of ozone). However, the addition of H_2O_2 did not improve pollutant degradation nor bromate mitigation. This can be explained by the strong scavenging of ozone by the organic matrix preventing direct reactions of ozone with H_2O_2. Surprisingly, H_2O_2 had also no positive effect on bromate formation. This observation is currently under study.

CONCLUSIONS

Both the Windhoek/Namibia experience and the other potable reuse installations (IPR and DPR)demonstrate that treated domestic and municipal used water can be utilized successfully (safely and economically) for potable reuse. The multiple barrier approaches employed guarantee reclaimed water of a quality that constantly meets all the required drinking water standards and is superior to that of conventional sources. The major challenges facing the promotion of potable reuse are reclamation process optimization (increased sustainability) and the attainment of greater public acceptance. In Windhoek, the inhabitants have accepted DPR, as there are no other affordable choices and since the beginning of potable reuse 50 years ago, no DPR-related outbreaks have been experienced. In general, it can be stated that there appears to be no reason why DPR should not become a common and widely used water management option within the next 5 to10 years.

In water-stressed India, indirect potable reuse (IPR) is under discussion as a possibility for megacities and large conurbations. In order to be prepared an advanced and robust process for the augmentation of drinking water by reclaimed water (indirect potable reuse), has been developed based on both the Windhoek experience and experimental results conducted with tertiary effluent from a large sewage treatment plant in an Indian megacity.Finally, it can be concluded that potable reuse constitutes a great opportunity for a safe and reliable drinking water supply - a sustainable solution for a better life.

REFERENCES

Bader, H. and Hoigne, J. (1981) Determination of ozone in water by the indigo method. Water Research 15(4), 449-456.

duPisani, P. and Menge J. 2013 Direct potable reclamation in Windhoek: a critical review of the design philosophy of new Goreangab drinking water reclamation plant. *Water Science &Technnology: Water Supply***13.2**, 214-226

Koti M., Lutze H., Panglisch S. and Lahnsteiner J. (2016), ***InternalReport*** Ozonisation and AOP of Municipal Used Water as Basis for the Evaluation of a Potential Ozone – Membrane Contact Process.

Lahnsteiner J., van Rensburg P. &Esterhuizen J. (2018) Direct potable reuse - a feasible water management option *Journal of Water Reuse and Desalination* 08.1, 2018, 14 - 28.

Lahnsteiner J., du Pisani P. L., Menge, J. and Esterhuizen, J. 2013 More than 40 years of direct potable reuse experience in Windhoek, Namibia. In: *Milestones in Water Reuse. The Best Success Stories.* Edited byV. Lazarova, T. Asano, A. Bahri and J. Anderson, IWA Publishing, London, UK, 351-364

Lahnsteiner J. and Lempert G. 2007 Water Management in Windhoek, Namibia. *Water Science & Technology***55**, (1 – 2), 441-448.

Nöthe, T., Fahlenkamp, H. and Von Sonntag, C. (2009) Ozonation of wastewater: Rate of ozone consumption and hydroxyl radical yield. Environmental Science and Technology 43(15), 5990-5995.

van der Merwe, B., du Pisani P., Menge J. and Koenig E. (2008) Water reuse in Windhoek, Namibia: 40 years and still the only case of direct water reuse for human consumption. In: *Water Reuse – An International Survey of current practise, issues and needs* edited by B. Jimenez and T. Asano IWA Publishing, ISBN13: 97818443390893, 434-454.

vonGunten U. (2003) Ozonation of drinking water: Part II. Disinfection and by-product formation in presence of bromide, iodide or chlorine. *Water Research***37**, 1469-1487

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