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Field hospital wastewater treatment scenario

Nadeem Ahmad Khan[1*], Sirajuddin Ahmed[1], Sergij Vambol[2], Viola Vambol[2], Izharul Haq Farooqi[3]

[1]Jamia Millia Islamia, New Delhi, India
[2]Public Agency "National Scientific and Research Institute of Industrial Safety and Occupational Safety and Health", Kiev, Ukraine,
[3]Aligarh Muslim University, Uttar Pradesh, India
[*]email: er.nadimcivil@gmail.com

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Abstract. In extreme situations with a large number of victims, field hospitals are deployed to provide patients with medical treatment. The large number of patients with different types of medications used generates the problem of hospital waste accumulation, including hospital wastewater (HWW). Wastewater is water having compromised characteristics that adversely affect the environment. Many countries do not have strict regulations regarding the disposal of hospital effluent, which contains pathogens, toxic chemicals and radioisotopes. The disposal of such substances poses a serious threat to public health and the environment. This paper discusses the possibilities of field hospital wastewater management development. Micropollutants, including pharmaceuticals, are found in different ecosystem elements, like soil, surface and ground water, drinking water as well as treated effluent from conventional wastewater treatment plants. Wastewater discharged from different health facilities, with varying concentrations of pharmaceuticals, is often mixed with municipal sewage, thus remains untreated even after passing through conventional treatment plants. Extensive experience in the application of different types of HWW treatment methods allows the development of an optimal treatment scenario for field hospital wastewater problem resolution, including the combination of Microbiological Reactor and Fenton Process technologies. They are applicable in the case of low wastewater flow rate values, specific for field hospital conditions.

Key words: environment, pollution, waste management, disposal, pharmaceutical micropollutants.

1. Introduction

One of the most important tasks to be resolved at zones of liquidation of extreme situations is providing rescue work and emergency medical care to victims (Bar-On et al., 2013; Sokolov et al., 2018). For such purpose the rescue units are supplied with mobile hospitals having ability of fast delivery and deployment at needed location. Primary task of mobile hospital is to evaluate patient's state of health. Depending on the evaluation result, they must provide patient with urgent care right at place and send him to stationary health facility for definitive treatment.

Extreme situations with large number of victims and wide spreading territory like natural disasters such hospital should be transformed into field one to provide definitive treatment right at place (Bar-On et al., 2013; Halpern et al., 2003; Naor et al., 2017). Multiple patients with different sorts of medications used bring up the problem of hospital wastes accumulation including hospital wastewater (HWW) (Halpern et al., 2003; Naor et al., 2017; Vambol et al., 2018; Vambol et al., 2019). Nowadays these emerging pollutants are still not being regulated neither for stationary hospitals nor for field or mobile ones.

In any health facility, the water is used in various places like wards, surgery, laboratories, kitchens, etc. During consumption, its characteristics change drastically (Fekadu et al., 2015). The types of HWW are presented in Figure 1.

In comparison with domestic sewage the hospital effluent raises much higher danger as it contains wide variety of toxic substances like antibiotics, radionuclides, and disinfectants (Chonova et al., 2016; Santos et al., 2013; Verlicchi et al., 2012a; ICRP, 2004). In certain study (Verlicchi et al., 2010b) they have highlighted that the range of such micropollutant is much higher than the one of domestic sewage by 4-150 times. Presence of drug's residues is caused mainly due to undigested drugs excreted with human excreta (Maheshwari et al., 2016). Yet the hospital effluent in general terms should be considered as the breeding ground for pathogenic bacteria. As field hospitals have higher use of antibiotics for treatment of patients the rate of environmental pollution for them is much more critical.

2. Methodology

This paper covers some aspect about the HWW treatment scenarios toward effluent discharge that are most suitable nowadays for field hospital wastewater treatment. The investigation was carried out using analytical analysis.

2.1. Hospital wastewater occurrences

Common micropollutant occurrence including pharmaceuticals are found in different elements of ecosystem like soils, surface and ground waters, drinking water as well as treated effluent from conventional wastewater treatment plants (Kümmerer, 2009a, b). There are various possible routes for exposure in an ecosystem. But most expected source is through the consumers consumption and excretion, which is transported to sewers (Kümmerer, 2009a, b). There might be another route like leaking from treatment units, application of biosolids in fields, leaking from septic tanks or even lack of any treatment equipment (Jones-Lepp et al., 2009, 2010, 2012; Jones-Lepp & Stevens, 2007; Kümmerer, 2010).

The assessment of drugs and its residues in HWW can be done either with predicted or measured concentration (Verlicci & Zambello, 2016). Predicted concentration value is based on water consumption per bed, excretion percent etc., whereas measured concentration value is found by sample collection and laboratory analysis. Predicted and measured concentrations may provide different information due to influence of time scale selected. Predicted concentrations are calculated on yearly basis while measured concentration is found for specific period of time. But in some aspect predicted concentration is better for evaluation of discharge of drugs and their residues through longer period (Hermann et al., 2015).

Too many pharmaceuticals are available so prioritization strategies need to be adopted considering various parameters like ecotoxicity, risk, biological and physicochemical characteristics and resistance towards treatment (Al et al., 2014; Kümmerer & Helmers, 2000). The mounting evidence about the resistant genes, genetic lesions and impact had made to rethink about this HWW discharging to streams (Boxall et al., 2012; Brodin et al., 2013; Cizmas et al., 2015; Galus et al., 2013a, b; Parolini et al., 2013).

2.2. Regulation standards around the globe

The regulation pattern is variable depending upon the various factors in different countries. The margin between the

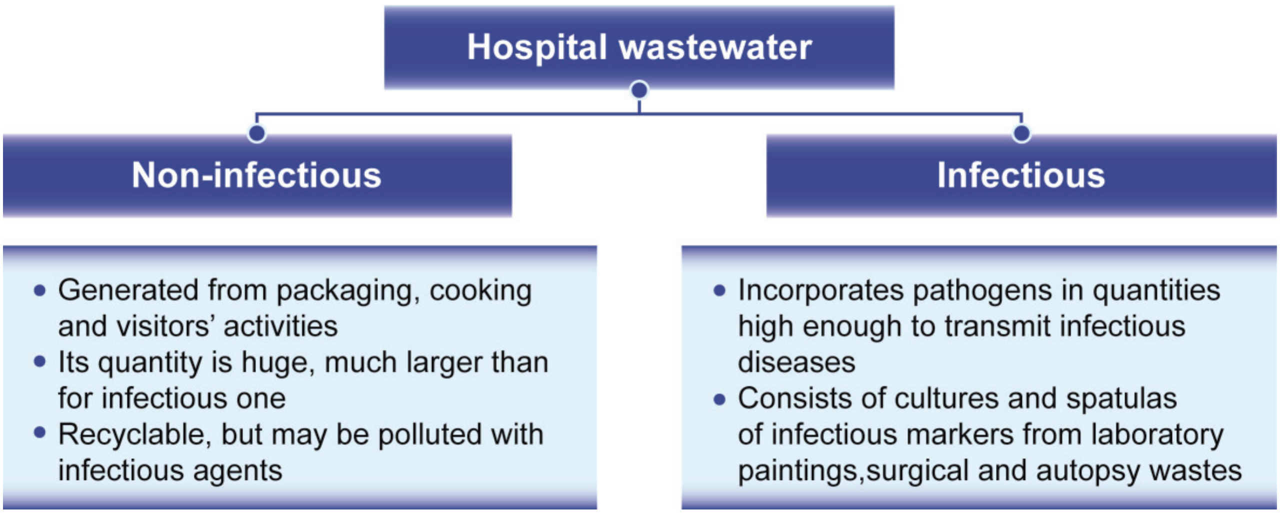

Figure 1. Schematic diagram showing types of hospital wastewater

disposal of sewage and wastewater having active pharmaceutical ingredients is very narrow and is a debatable issue. No clear boundary definition makes confusion towards legislative norms about the HWW in terms of management (Ministry of Environment and Forest, Government of India, New Delhi, 1986).

If we look around, we will see that even Europe lacks behind specific guidelines in managements of such wastewater except some directives (EU, 1991; EU, 1998). They generally consider collection and treatment of effluent for population greater than 2,000, secondary treatment of all discharges and advance treatment for population greater than 1,000, pre-authorization discharge from various industries and monitoring the efficiencies of existing treatment systems (EU, 2008).

Due to non-existence of specific guidelines in European Union, its members have adopted their own regulations on evaluation and disposal criteria for HWW. In Germany, HWW is considered as domestic wastewater, thus no prior authorization is needed (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany, 2004). In some case, if HWW meets certain characteristics with respect of sewage then they discharge it to water treatment plant without any further consideration (Carraro et al., 2016). In Italy, if health facility capacity is less or equal to 50 beds then HWW is discharged as sewage without certain analysing. Such HWW is treated along with domestic sewage in conventional treatment plants (Italy, 2011).

In China, HWW is considered as industrial effluent. Then they take F-coliform bacteria as indicator of ecotoxicity for 50 bed health facility (China, 1998).

In Vietnam, they have specific legislation regarding management and treatment of HWW (The Socialist Republic of Vietnam, 2014). The law indicates that hospital needs to collect and treat effluent according to the treatment standards. On the other hand, the law was made to regulate the HWW collection in water bodies.

The World Health Organization guidelines are much more clear (Chartier et al., 2014). It clearly states collection and disposal of healthcare wastewater divided into three heads: (1) Blackwater having high pollutant load with faecal matter; (2) Greywater as diluted form generated from washing, bathing, laboratories, x-rays film cleaning, etc.; (3) Storm water, which is actually not a form of wastewater but represents rainfall collection on ground surface. They can be utilized in different forms but HWW might contain different levels of contamination in relation with service level and tasks of medical facilities. The main risk associated with HWW in developing countries where unmonitored disposal schemes were in practice, which might pollute both ground and underground aquifers. The best way of HWW management is to treat it on-site. The document also provides details about sludge disposal, possible reuse, including the application of new and innovative HWW treatment technologies. It also provides guidance for minimum approach for HWW management in developing countries where patients do not have proper sanitation facilities.

In USA, Clean Water Act is governing law regarding discharges (Clean Water Act, 1972). It also considers the local pre-treatment schemes and regulations including discharge permits. The discharging unit has to follow these local regulations as well as the technology-based standards set up on national level. Medical facilities discharges HWW into sewer line are considered to be indirect discharges. Direct discharges are those put directly into rivers, ponds, etc. These regulations were reviewed annually with technological advancement in the treatment field. The main objective is to modify current disposal standards, categories of discharge for law framing and identifying new indirect discharges for pre-treatment standard development (EPA, 2016). Health facilities are designated by local sewer authority as significant industrial user, who has to submit its discharging effluent characteristics report twice to the authority.

Any health facility making direct discharges into natural water bodies has to follow national discharge standards. Their requirements are quite strict as compared to indirect standards. Generally they are not met by in-field mobile hospitals because they are not being monitored or treated by municipal systems.

2.3. Hospital wastewater treatment scenarios around the world

Multiple researches were carried out in this field (Adamcza et al., 2012; Batelaan et al., 2013; Beyene & Redaie, 2011; Duong et al., 2008; Göbel et al., 2007; Gracepavithra et al., 2017; Grundfos BioBooster A/S, 2015; Kosma et al., 2010; Lien et al., 2016; Liu et al., 2010; Mahvi et al., 2009; Martins et al., 2008; Prabhasankar et al., 2016; Prado et al., 2011; Shrestha et al., 2001a; Sim et al., 2013; Tambosi et al., 2009; Verlicchi et al., 2010a; Yu et al., 2013). However, they mostly deal with exploring different characteristics, compositions and the risk imposed with HWW and their residues in comparison with domestic sewage.

Conventional treatment plants efficiencies are investigated same as new technologies to be applied. However, the past studies were concentrated only on some of the chemical effluents leaving behind most of them, which are nowadays commonly used in health facilities. The main cause of this limitation is the lack of detection techniques and consumption pattern data.

The micropollutant removal efficiency depends on biodegradability, physicochemical properties, solubility, adsorption ability, pH, temperature and retention time. The characteristics of HWW effluents are dependent on topography and some physical, chemical, biological and microbiological parameters. Maximum values of these parameters, detected in different studies (Carraro et al., 2016; Verlicchi et al., 2010b, 2012b; Lenz et al., 2007; Daouk et al., 2016; El-Ogri et al., 2016), are mentioned in Table 1.

HWW physicochemical characteristics are comparable with the domestic wastewater. Nowadays the presence of micropollutants in HWW is mainly focused on due to their low biodegradability, antibiotic-resistant genes and associated factors like cancer, mutagen ones, etc. Till date, there are hardly any norms for the concentration of pharmaceuticals in wastewater.

The methods to be applied to organic contaminants of HWW during sewage and industrial effluent treatment (Rogers, 1996) are presented in Figure 2.

Different technologies based on enlisted methods are in use acting as primary, secondary and tertiary steps of HWW treatment scenarios. The type of sequences adopted for the combination of various treatments related to HWW depends on the economic condition of the country. The most widely used technology is Conventional Activated Sludge (CAS) followed by Membrane Biological Reactor (MBR). Micropollutants removal efficiency values vary from higher for some drugs to lower for another ones. But there are no specific technology considered as proper solution for HWW problem. Table 2 indicates different treatment scenarios adopted globally on full scale.

In Table 3 the results of comparison of adopted single stage HWW treatment schemes are represented.

Table 1. Characteristics of hospital wastewater

No.	Parameters observed	Maximum value detected
1.	Chemical oxygen demand, g/m^3	7,764
2.	Dissolved organic carbon concentration, g/m^3	130
3.	Total organic carbon concentration, g/m^3	180
4.	Biochemical oxygen demand, g/m^3	2,575
5.	Biochemical and chemical oxygen demands ratio	0.4
6.	Adsorbable organic halides concentration, mg/m^3	10,000
7.	Chlorine concentration, g/m^3	400
8.	Nitrite concentration, g/m^3	0.6
9.	Nitrate concentration, g/m^3	2
10.	Total suspended solids, g/m^3	3,260
11.	E. coli presence measure, most probable number per 100 cm^3	106
12.	Total coliform presence measure, most probable number per 100 cm^3	107
13.	Gadolinium concentration, mg/m^3	300
14.	Mercury concentration, mg/m^3	8
15.	Copper concentration, mg/m^3	230
16.	Nickel concentration, mg/m^3	71
17.	Lead concentration, mg/m^3	19
18.	Zinc concentration, mg/m^3	670
19.	Naproxen concentration, mg/m^3	11
20.	Diclofenac concentration, mg/m^3	15
21.	Ciprofloxacin concentration, mg/m^3	125
22.	Erythromycin concentration, mg/m^3	83
23.	Norfloxacin concentration, mg/m^3	44
24.	Ofloxacin concentration, mg/m^3	35
25.	Penicillin G concentration, mg/m^3	5
26	Tetracycline concentration, mg/m^3	4
27.	Carbamazepine concentration, mg/m^3	2
28.	Glibenclamide concentration, mg/m^3	11
29.	Penciclovir concentration, mg/m^3	0.01
30.	Cyclophosphamide concentration, mg/m^3	2
31.	Doxifluridine concentration, mg/m^3	0.08
32.	Tamoxifen concentration, mg/m^3	0.17
33.	Tegafur concentration, mg/m^3	0.09

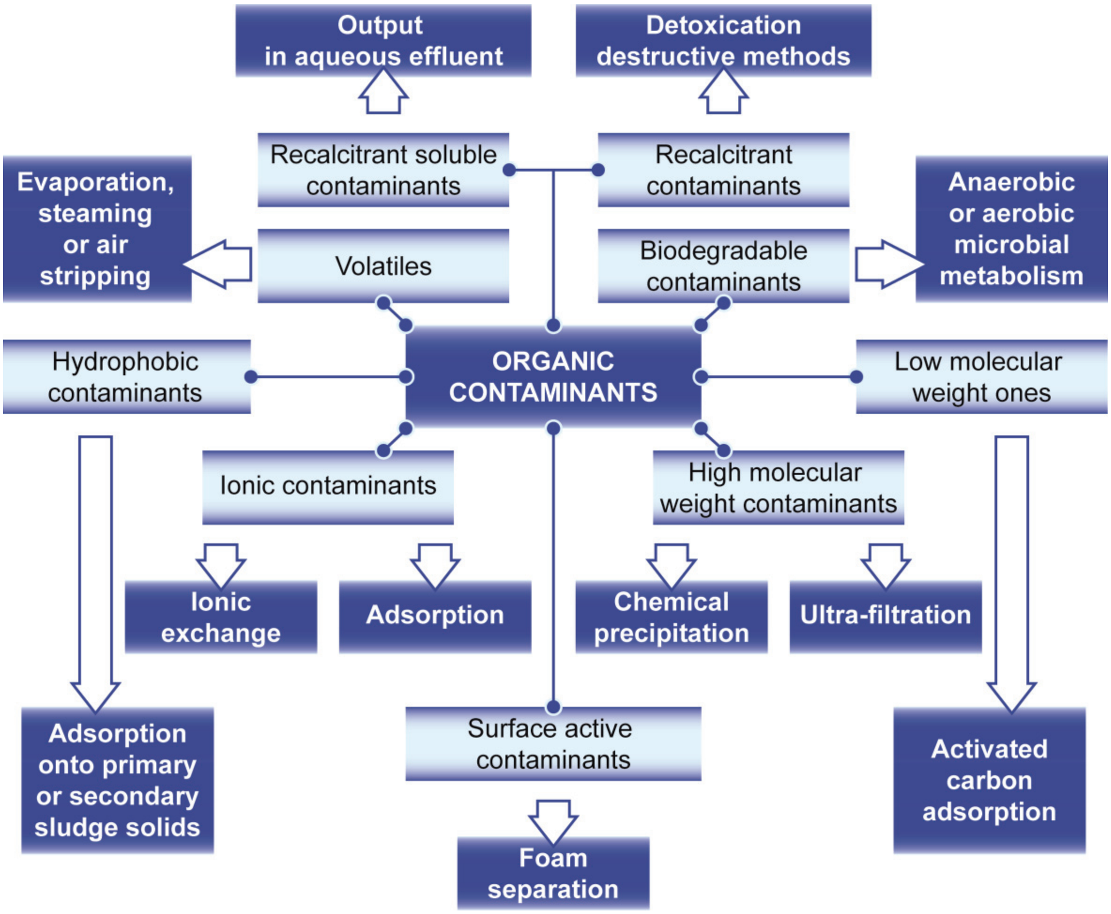

Figure 2. Methods of hospital wastewater organic contaminants neutralization during sewage and industrial effluent treatment

Table 2. Hospital wastewater treatment scenarios adopted globally on full scale

No.	Country	Treatment schemes	References
1.	China	MBR + Chlorination CAS + MBR	(Liu et al., 2010; Yu et al., 2013)
2.	Ethiopia	Ponds	(Beyene & Redaie, 2011)
3.	India	CAS + Sand filtration	(Prabhasankar et al., 2016)
4.	Iran	CAS + Chlorination	(Mahvi et al., 2009)
5.	Nepal	Septic tank + horizontal subsurface flow + vertical subsurface flow	(Shrestha et al., 2001b)
6.	Vietnam	CAS	(Duong et al., 2008)
7.	Republic of Korea	Flocculation + activated carbon Flocculation + CAS	(Sim et al., 2013)

As it may be seen, the most effective single stage method is Ozonation Process (OP) providing up to 91 % efficiency of pharmaceuticals removal. In this method, ozone oxidizes micropollutants directly or indirectly on hydroxyl radical acting as strong oxidizing agent. Ozone reaction pathway is shown in Figure 3.

However, OP method has certain practical complexities for in-field application. First of all, its cost is high. In addition, ozone is a toxic gas, which means necessity of strict safety control application and corresponding qualification level of those who use it. Thus in most cases they use MBR treatment method as the biological stage of combined removal process.

Table 3. Single stage HWW treatment schemes comparison

No.	Treatment adopted	Single stage removal efficiency	References
Biological treatment adopted			
1.	MBR	39–60 %	(Göbel et al., 2007)
2.	Filtration + CAS	59–76 %	(Lien et al., 2016)
3.	Flocculation + CAS + Activated Carbon	80 %	(Sim et al., 2013)
Physicochemical treatment adopted			
4.	OP	91 %	(Gracepavithra et al., 2017)

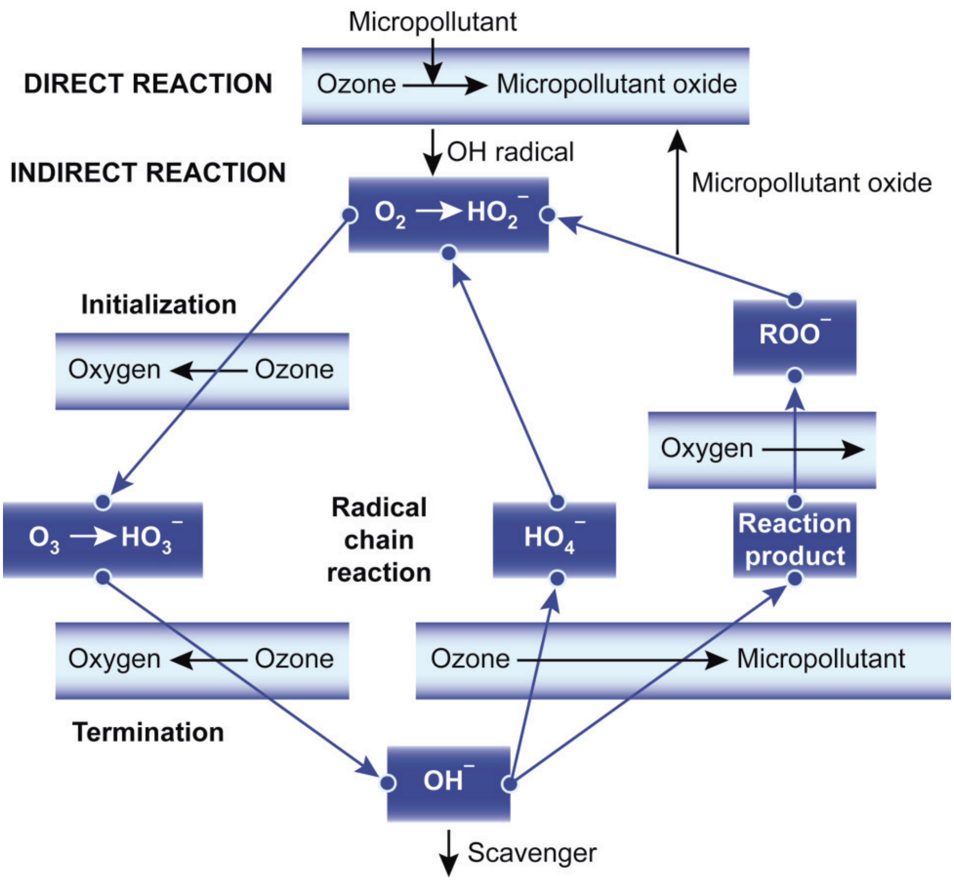

Figure 3. Ozone reaction pathway

In Table 4 the results of comparison of adopted combined HWW treatment schemes are shown. The basic biological stage of HWW treatment scenario is formed by one of four methods including MBR, Septic tank application, Upflow Anaerobic Sludge Blanket (UASB) and CAS. Various physical and physicochemical methods are considered in studies, including CAS, Granulated Activated Carbon (GAC), Powdered Activated Carbon (PAC), Ultraviolet (UV) radiation, OP, Fenton Process (FP), Chlorination, Anaerobic filters and Wetlands application.

Selection of physicochemical treatment depends upon characteristics of treated wastewater (Hancock, 1999) shown in Figure 4.

Adsorption using activated carbon is quite an old method of treatment of pollutants. In adsorption, molecular-level attraction leads to binding of the soluble and gaseous chemical substances on the adsorbing surface. Activation of carbon results in a porous structure, which enhances the adsorption capabilities. The types and uses of activated carbon are shown in Figure 5.

Fenton treatment process involves the reaction of hydrogen peroxide with iron to produce its radical.

Photo-Fenton process is a promising treatment opportunity in the elimination of a various type of pharmaceuticals. As in HWW treatment, the main challenge is to treat micropollutant effectively considering the cost aspect. Fenton process is not only used in the elimination of various microcontaminants dissolved in water or wastewater but is also simpler method.

New approach is economical as the chemical rate for hydrogen ion requires great attention for modification, mainly for the procedure of treatment process. Pre-treatment of effluent enables Photo-Fenton Process (see Fig. 6) act at lower costs, decreased reactor size and amount of reagents required.

3. Results and Discussion

3.1. The lack of hospital wastewater treatment regulations

The lack of specific laws for HWW is that it is considered as domestic waste in some cases and as industrial one in another. For field hospitals specific HWW management guidelines are to be developed indicating certain characteristics that can be represented to specify its nature.

The HWW discharge to the natural water bodies are considered to be the most important risk due to the generation of antibiotic resistant genes in bacteria and the raise of

Table 4. Combined hospital wastewater treatment schemes comparison

No.	Biological treatment	Physicochemical treatment	Combined removal efficiency	References
1.	MBR	OP + GAC	up to 70 %	(Batelaan et al., 2013)
2.		OP + PAC + Sand filtration PAC + Sand filtration	up to 80 %	(Adamcza et al., 2012)
3.		OP + UV	50–90 %	(Verlicchi et al., 2010a)
4.		GAC + OP/FP + UV	up to 90 %	(Grundfos BioBooster A/S, 2015)
5.		GAC + UV	up to 90 %	(Grundfos BioBooster A/S, 2015)
6.		Chlorination	95 %	(Liu et al., 2010)
7.		FP/UV	12–100 %	(Tambosi et al., 2009)
8.	Septic tank	Oxidation ponds	54 %	(Beyene & Redaie, 2011)
9.		Anaerobic filters	65 %	(Martins et al., 2008)
10.		Wetlands	up to 77 %	(Shrestha et al., 2001b)
11.	UASB	Anaerobic filters	64 %	(Prado et al., 2011)
12.	CAS	Chlorination	65–92 %	(Göbel et al., 2007; Kosma et al., 2010; Shrestha et al., 2001a)

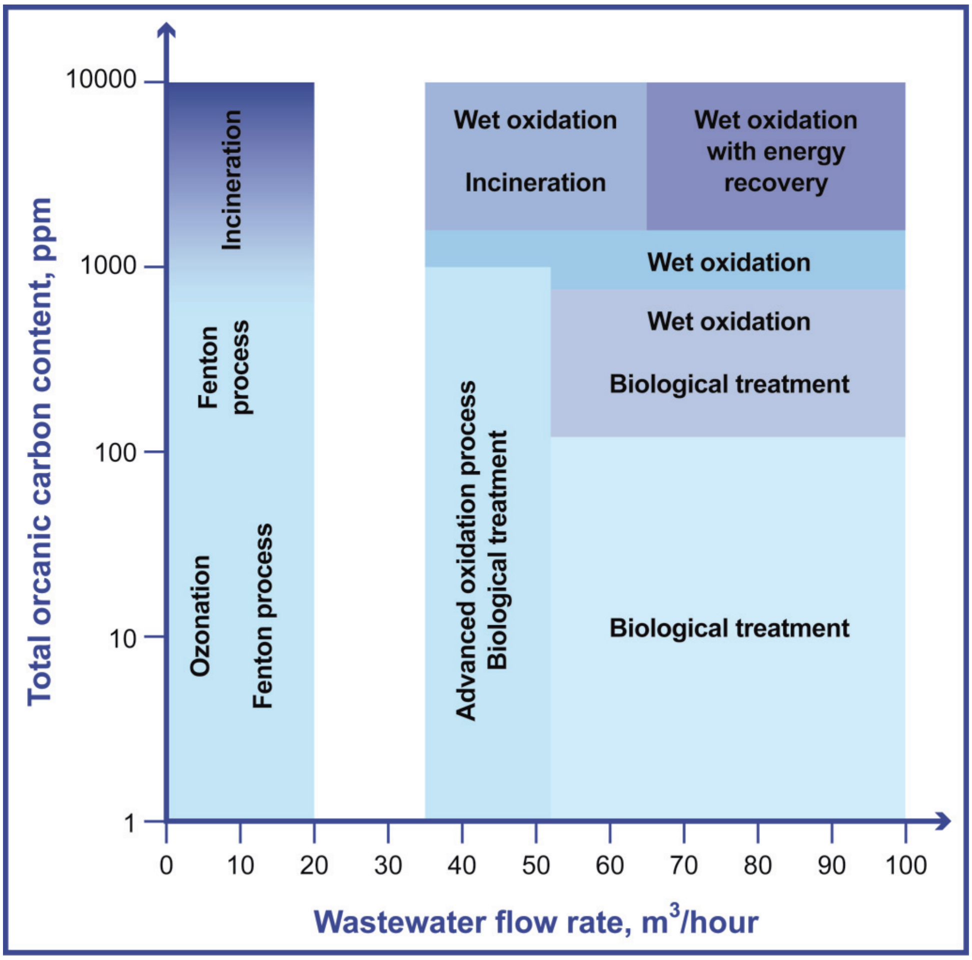

Figure 4. Physicochemical treatments application depending upon Total organic carbon content and Wastewater flow rate

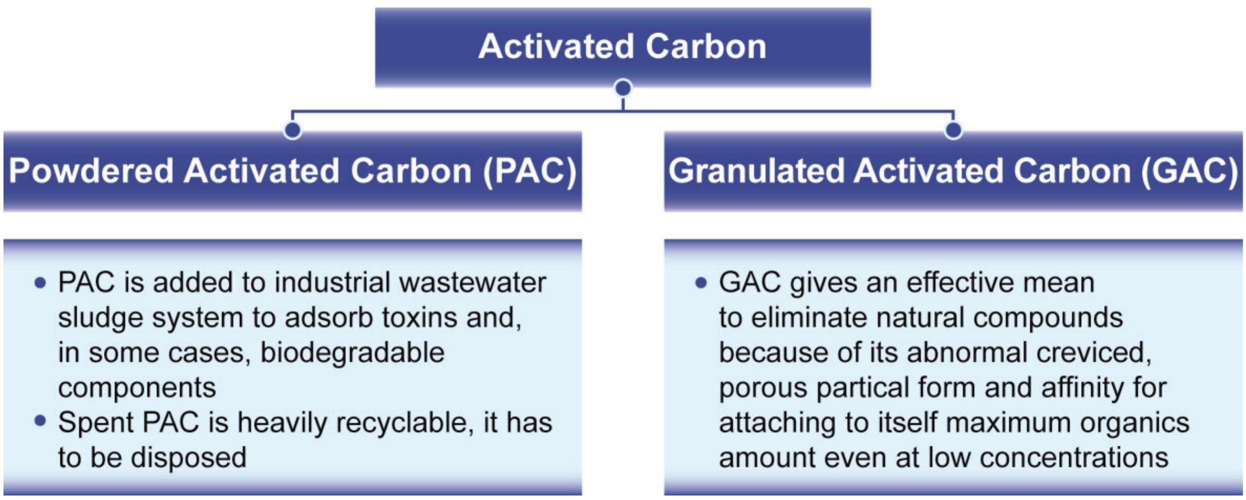

Figure 5. Activated Carbon types and uses

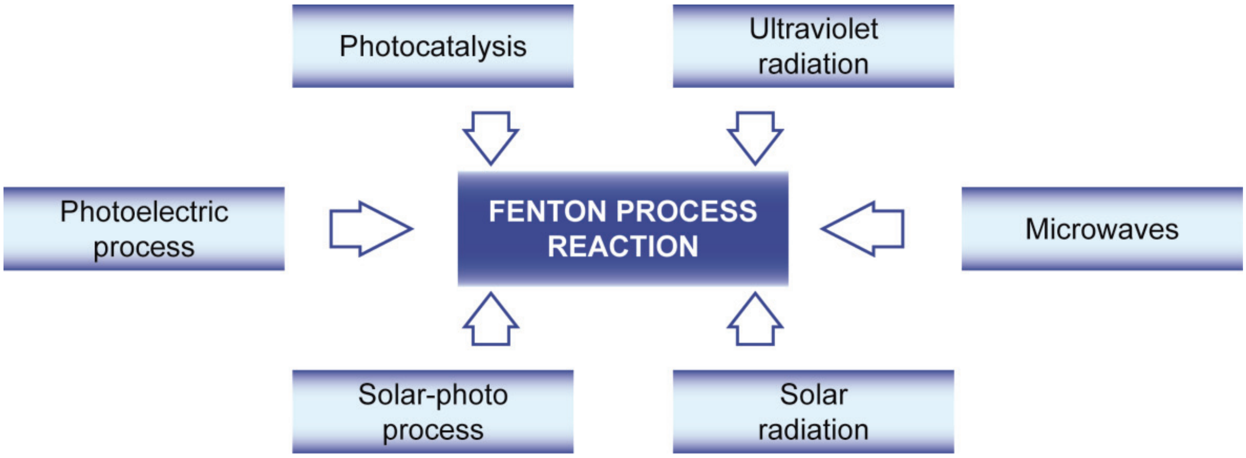

Figure 6. Technologies to be used for improvement of Fenton Process

ecotoxicity in the environment. These problems are quite prominent in developing countries due to unrestricted discharge of HWW.

3.2. Adopted hospital wastewater treatment scenarios

The HWW were subjected to various treatment schemes in different countries but due to lack of separate, onsite treatment facilities they remain a problem of resistant gene development around the globe. As there are no specific treatment schemes available hence combination of treatment is tried in different countries. European countries are in progress to develop and upgrade the centralized HWW treatment facilities.

Multiple parameters in designing of waste treatment technology are considered like characteristics, temperature conditions and economic feasibility of HWW. Different technologies are employed for HWW treatment including pre-treatment, MBR and other advanced oxidation processes. Due to uneven nature of HWW, different removal mechanisms would be needed. By considering the risk associated with field hospital wastewater management, its provision will be available by adopting sustainable, most economic and less energy required technologies.

3.3. Optimal field hospital wastewater treatment scenario

Wide application of different types of HWW treatment methods gives an opportunity to create an optimal treatment scenario for field hospital wastewater problem resolution. Experience of currently adopted HWW treatment scenarios application gives an opportunity to create combined double stage HWW treatment scenario for field hospital usage.

Biological stage of HWW treatment should be represented with MBR technology due to its simplicity and low cost. Physicochemical stage of HWW treatment should be represented with FP technology. It is applicable for low wastewater flow rate values. In addition it may be improved using effluent pre-treatment to lower cost, decrease reactor size and amount of reagents required.

3.4. Contribution of the findings to the field and any potential applications

By considering the criticality of hospital effluent there is no specific legislation regarding its discharge in environment. Yet wide variety of tasks to be resolved here in addition to neutralization of selected pharmaceutical compounds. In addition we should mention that developed foreground scenarios and their options will need to be adopted globally for HWW treatment. Arising HWW management and detection issues are wastewater sampling mode, observation frequency, spatial and temporal micropollutants concentration, allowable detection accuracy, reliability of results and predictions, etc.

Obtained results allow developing and implementing global field hospital wastewater treatment scenario both in legislation and technical spheres. Further technological advancement can henceforth produce a viable implication and make a strong national policy with proper legislation towards production and disposal of HWW. Their longer-term risk due to acute and regular exposure needs to be considered with proper metabolic pathways determination.

4. Conclusions

As a result of analytical research we have:

1. Hospital wastewater occurs widely in field hospitals used at extreme situations. It is characterized with high risk because in comparison with domestic sewage the hospital effluent contains wide variety of toxic substances like antibiotics, radionuclides, and disinfectants.

2. Based on currently adopted HWW treatment scenarios application the optimal field hospital wastewater treatment scenario includes combination of MBR and FP technologies. It will lower cost, decrease reactor size and amount of reagents required for HWW treatment.

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