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Potential Efficiency and Energy Usage in a Leachate Treatment Process

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Abstract**—**Generated leachate in landfills is often as a result of the infiltration of rain, surface or running water into waste bodies. Numerous studies have revealed the potential impacts of leachate escape from landfill disposal facilities on human and environmental health. Although much is been done in most landfills in South Africa to ensure minimal leachate escape into immediate soil, surface and groundwater reserves, much more is still required. As such, the option of leachate treatment is gradually been explored. The potential efficiency and energy usage of a landfill waste water treatment plant (WWTP) for a simple leachate treatment process is explored. The WWTP process involves the basic treatment of the leachate with subsequent sequencing batch reactors (SBR), reverse osmosis unit (RO) and evaporation for additional concentration of RO yield. The process efficiency is appraised by conductivity, chemical oxygen demand (BOD), biochemical oxygen demand (BOD) and total nitrogen (TN) measurements. Energy usage is estimated by electrical input power, motor efficiency of power-consuming units and functional hours. 2.2% of the of the WWTP total operational real power consumption is gotten for the primary treatment process with 16.7% corresponding SBR operation and 13.2% RO unit. 2 unit evaporators consumes 61.5% and 0.78% for leachate recirculation to landfill from the total energy usage. Therefore, RO is taken as the most efficient leachate treatment process as it can dispense substantial amounts of water from the landfill leachate pond whereas, the evaporators are energy demanding.

Keywords**—***Landfills, Reverse Osmosis, Leachate, Waste, Energy,*

I. Introduction

MUNICIPAL solid waste (MSW) landfills is a pronounced method of waste management system in most parts of South Africa and around the globe. The absence or ineffective recycling and reuse options in South Africa and most developing African countries implies that various generated waste types are destined to landfills [1]. In recent decades, civilisation and globalisation has warranted increased human activities to meet dire needs and challenges. This has led to diverse transformations in industries and households, resulting in massive generation of solid wastes. It has therefore become imperative as observed by [2] that these by-products of human activities are properly disposed in engineered waste containment facilities. However, in present times, recycling is the first and best option of dealing with waste before landfilling is considered in the face of handling difficulties by other methods [3]. Landfills are known to produce gases and leachates whose breakaway and eventual permeation into surrounding soil and groundwater could have detrimental human and environmental health effects. For these reasons, [4], [5] argues that leachate migration be curbed to the lowest minimum if not entirely prevented. Rain, runoffs and waste containing high moisture in landfills propel the decomposition and production of leachate contaminants by microbial actions. Hence, protecting regimes of soil and ground water resources against leachate pollution is of major interest. Generally, as recorded by [6] leachate can be is defined as a saline complex high strength wastewater rich in ammonium and organic matter. In most cases, the leachate treatment forms one of the main challenge during the design, construction and running of a landfill disposal facility. Open dumps, uncovered and/or defected operating landfills are exposed to high rainwater permeation through the waste body and consequent increased volumes of leachate generation [7]. As recorded by [8] the daily generation and disposal of more than 41,000 tons of solid waste in South Africa has attracted attention, particularly, in the Gauteng province and Johannesburg city where cumulatively, over 25,000 tons of non-hazardous waste is dumped, compacted and covered with soil daily [9]. Generally, with an average daily generation of leachate up to 180 m^3/d in most landfills around the City of Johannesburg (CoJ), the need for a treatment process is vital. A potential WWTP leachate process in landfills around the CoJ may include that shown in Figure 1. The study therefore explores the potential efficiency and energy usage of respective WWTP leachate treatment process which involves the basic treatment of the leachate, then a biological treatment, a reverse osmosis unit (RO) and evaporation for additional concentration of RO yield. The concentrate of the evaporators and the excess RO concentrate are feedback to the landfill.

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II. Conceptual and Experimental Approach

A. Testing Method

The potential treatment efficiency is often appraised using a monitoring application/software program frequently reviewed. Samples of wastewater are harvested intermittently across the respective treatment processes. The physical and chemical analyses are done in conformance to Standard Methods with

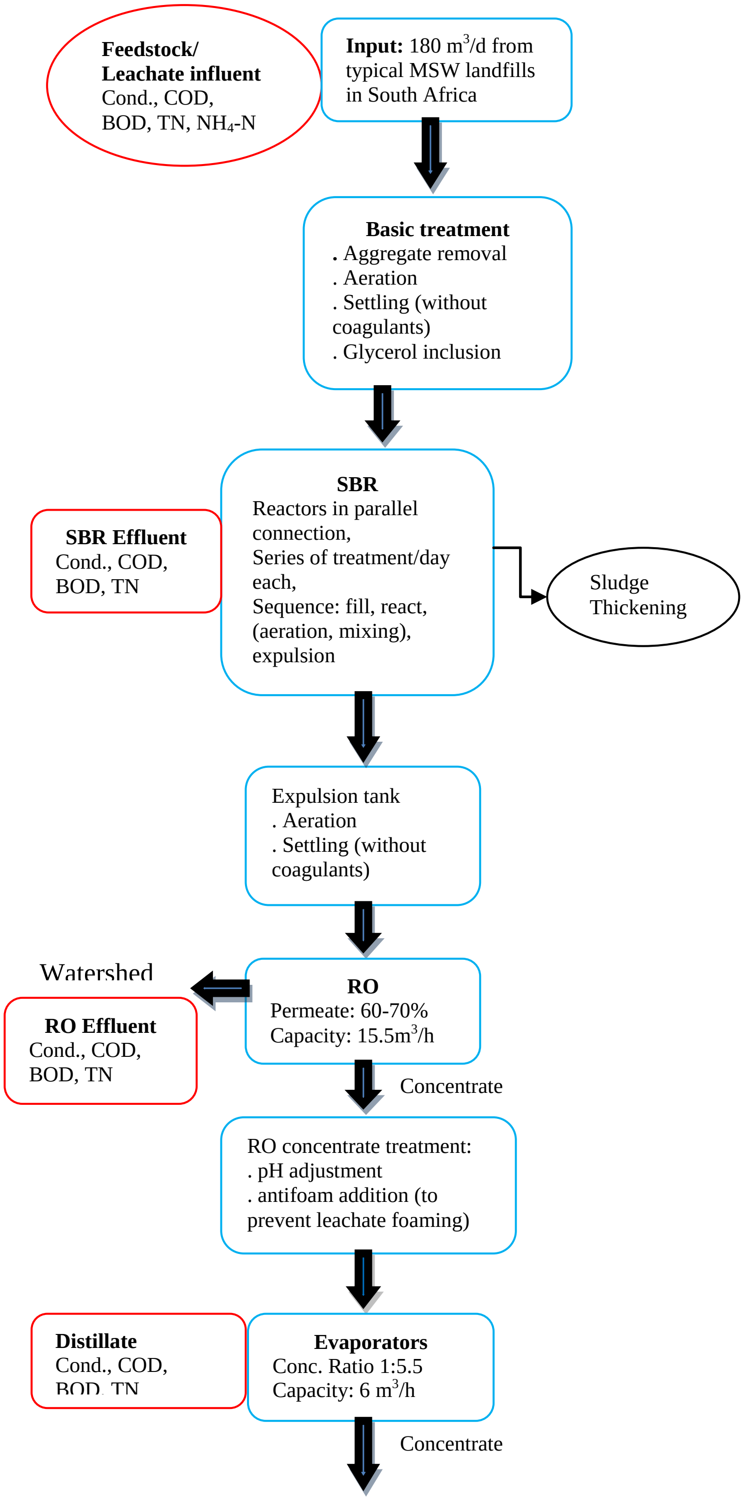

Fig. 1. Flow chart of potential efficiency and energy usage in landfill leachate treatment process

an aliquot of leachate vacuum filtered via glass fiber filters (GFF) of nominal pore size 1.0 µm and diameter 47 mm which is then applied to appraise the mixed liquor suspended solids (MLSS) concentration with other aliquots utilised to analyse conductivity, BOD, COD, TN and ammonium (NH_4-N). Respirometric measurement is done to determine the BOD using up to 25°C thermostatted sample bottles for a period of 5 days in an incubator whereas, a spectrophotometric analysis is done to determine the COD, TN and NH4-N. A probe meter was used to measure the electrical conductivity of the sample. The energy usage is accounted for by the electrical input power, the motor efficiency power-consuming devices for respective units and functional hours. As such, the sum power required by a three-phase motor includes the real power and the reactive power i.e., the redundant power triggered by magnetising current. Therefore, power factor (PF) expressed by [10] is represented in (1) as:

$$PF = \frac{P}{3^{\frac{1}{2}} \times U \times I} \tag{1}$$

Where; P = power input (W), U = 400 V, I = current (A).

As recorded by [11] the characteristic motor PF values span between 0.89-0.91. However, a PF value of 0.90 is used after [11] in the appraisal of energy usage.

III. DISCUSSION OF FINDINGS

A. Basic Treatment Process

The commencement stage of the basic leachate treatment requires raw leachate feed from landfill leachate cells/ponds by submersible pumps. Here, there is extraction and removal of sediments, pre-aeration and settlement of the feedstock/influent without the addition of coagulant or enhancers. The leachate stock and subsequent stabilisation allows for sufficient uniform and quality wastewater prior biological treatment. Conversely, as reported by [12] aeration hinders biomass from toxic inhibition because of nitrogen fluctuations in the leachate. Energy usage in the basic treatment unit is 2.2% of the WWTP sum real power usage.

B. Sequencing Batch Reactors (SBR)

SBR is basically the biological treatment conducted and it functions to extract the biodegradable compounds of the feedstock/leachate. According to [11] the feedstock is introduced to a number of parallel operating batch reactors at monitored interims where it is treated and then subsequently expelled. For every treatment series, roughly 25-35 m^3 of feedstock is added in each SBR which represents an approximate volume percentage of each reactor. Sequential treatments are formed by anoxic and aerobic phases of nitrification-denitrification processes. At the anoxic phase, [13] explains that denitrifying organisms consume feedstock organic matter while slow stirring gives total homogenised liquid to lower the oxidised nitrogen in the form of nitrite (NO_2^-) to nitrogen gas. At the aerobic phase, dissolved oxygen concentration inside the reactor maintain around 4-6.5 mg/L to oxidise the NH4-N to nitrite and then to nitrate (NO_3^-). However, where there is insufficient or low availability of biodegradable organic matter in the feedstock, glycerol which is a by-product of biodiesel production is incorporated. The introduction of glycerol provides the feedstock with a measured COD amount. As reported by [11] the 2012-2013 operational data shown in Table I gives the COD, BOD and NH_4-N average removal SBR efficiency.

TABLE I
EFFICIENCY OF WWTP LEACHATE TREATMENT PROCESS [11]

Parameters (mg/l)	Influent			SBR effluent		
	Ave.	*n	**SD	Ave.	n	SD
Cond (μS/cm)	23015	66	2973	16719	104	2117
MLSS	189	54	196	317	70	544
COD	3286	64	1910	1302	79	418
BOD	909	34	1242	90	36	50
TN	1360	54	300	747	59	210
NH_4-N	941	40	224	20	56	46
	RO effluent			Distillate		
	Ave.	n	SD	Ave.	n	
Cond	405	37	163	51	1	
MLSS	4	24	5	2	1	
COD	15	21	162	162	1	
BOD	11	14	80	80	1	
TN	20	23	24	24		

*n- number of samples; **SD- standard deviation

Nevertheless, filed observations suggest that the potential efficiency of SBR is temperature-reliant indicating higher removal rates during seasonal warm weather conditions. Also, the biological leachate treatment fosters effective RO process with the SBR operation having roughly 16.7% of the WWTP sum real power usage.

C. *Reverse Osmosis (RO)*

Here, the SBR effluent passes through an aeration tank, settles in a sedimentation tank and subsequently channels to the RO unit without the addition of coagulant or flocculating agents such that, any possible surcharge on RO process is avoided and the 1-stage RO unit having disc-tube modules operate. The partially treated feedstock as influent is pre-filtered using a sand filter which then goes through 10 μm nominal pore sized cartridge filters. RO unit capacity of 15.5 m^3/h, maximum operational pressure of 6.5 MPa with a recovery ratio ranging between 60-70% was recorded by [11]. Furthermore, insignificant solute concentrations in the output are seen in Table I. This implies that the permeate stream satisfies environmental requirements and could be appropriate for expulsion to watersheds [13]. On this note, permeate ejection will substantially decrease the storage capacity of the landfill leachate. The RO unit operation in WWTP adds up to approximately 13.2% of the sum real power usage. Table II reveals the sum real power usage for the respective power devices of a WWTP in landfill leachate treatment process after [11].

TABLE II
ENERGY USAGE OF RESPECTIVE FUCTIONAL DEVICES OF WWTP LEACHATE TREATMENT PROCESS [11]

Energy Usage of WWTP of landfill leachate treatment process					
Motor	Installed devices	Functional devices	Installed capacity of each motor (KW)	Real power usage (KW)	% of Sum energy usage
Basic Treatment Process					
Feeding from pond 1	1	1	2.20	1.98	
Feeding from pond 2	1	1	1.10	0.99	
Basic treatment feeding	2	1	3.40	3.06	
Blower	2	1	3.00	2.70	
Fast agitator	1	1	4.00	3.60	
1st slow agitator	1	1	0.80	0.72	
2nd slow agitator	1	1	0.80	0.72	
Motor regulator	1	1	0.37	0.33	
Sludge pump	2	2	1.50	2.70	
Flow jet	1	1	4.00	3.60	
Dosing pump	2	1	0.50	0.45	
Biological Treatment- Sequencing Batch Reactors (SBR)					
SBR feeder pump	8	4	2.50	9.00	
Blower	5	4	90.0	324.00	
Mixer	8	8	5.00	36.00	
Sludge pump	8	8	2.30	16.56	
Aeration/Sedimentation					
Blower	2	1	7.50	6.75	
Feeder pump	2	1	2.30	2.07	
Fast agitator	1	1	2.20	1.98	
1st slow agitator	1	1	0.80	0.72	
2nd slow agitator	1	1	0.80	0.72	
Motor regulator	1	1	0.37	0.33	
Sludge pump	2	2	0.50	0.90	
Reverse Osmosis (RO) Unit					
RO feeder pump	2	1	2.20	1.98	
Sandfilter feeding pump	1	1	3.00	2.70	
Cartridge filter feeder	1	1	4.00	3.60	

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Plunger pump	3	3	11.00	29.70
Booster module	2	2	11.00	19.80
Degassing fan	1	1	1.10	0.99
Permeate feeder pump	1	1	4.00	3.60
Evaporator Units				
Pre-treatment feeder	2	1	1.50	1.35
Pre-treatment blower	4	4	2.20	7.92
Pre-treatment recirculation pump	4	4	1.50	5.40
Vacuum blower	2	2	110.00	198.00
Recirculation pump	2	2	30.00	54.00
Evaporator pump	2	2	1.50	2.70
Evaporator pump G03	2	2	1.37	2.47
Evaporator pump G04	2	2	0.35	0.63
Evaporator pump G05	2	2	0.35	0.63
Recirculation/Feed back				
Station pump	2	1	7.00	6.30
Recirculation pump	2	1	11.00	9.90

Motor	Daily function (h/d)	Total functional hours (h/yr)	Annual energy usage (KWh/yr)	Annual energy usage of each unit (KWh/yr)	
Basic Treatment Process					
Feeding from pond 1	16.00	5840	11563		
Feeding from pond 2	16.00	5840	5782		
Basic treatment feeding	18.00	6570	20104		
Blower	20.80	7592	20498		
Fast agitator	0.00	0	0		
1st slow agitator	3.20	1168	841		
2nd slow agitator	3.20	1168	841		
Motor regulator	24.00	8760	2917		
Sludge pump	0.01	5	14		
Flow jet	16.00	5840	21024		
Dosing pump	16.00	5840	2628	86212	2.3
Biological Treatment- Sequencing Batch Reactors (SBR)					
SBR feeder pump	1.00	365	3285		
Blower	3.75	1369	443475		
Mixer	15.75	5749	206955		
Sludge pump	0.00	1	21	653736	17.5
Aeration/Sedimentation					
Blower	16.00	5840	39420		
Feeder pump	18.00	6570	13600		
Fast agitator	0.00	0	0		
1st slow agitator	0.00	0	0		
2nd slow agitator	0.00	0	0		
Motor regulator	24.00	8760	2917		
Sludge pump	0.01	5	5	55942	1.5
Reverse Osmosis (RO) Unit					
RO feeder pump	18.00	6570	13009		
Sandfilter feeding pump	24.00	8760	23652		
Cartridge filter feeder	24.00	8760	31539		
Plunger pump	24.00	8760	260172		
Booster module	24.00	8760	173448		
Degassing fan	24.00	8760	8672		
Permeate feeder pump	24.00	8760	31536	542025	14.5
Evaporator Units					
Pre-treatment feeder	16.00	5840	7884		
Pre-treatment blower	24.00	8760	69379		
Pre-treatment recirculation pump	24.00	8760	47304		
Vacuum blower	24.00	8760	1734480		
Recirculation pump	24.00	8760	473040		
Evaporator pump	16.00	5840	15768		
Evaporator pump G03	16.00	5840	14401		
Evaporator pump G04	16.00	5840	3679		
Evaporator pump G05	16.00	5840	3679	2369615	63.5
Recirculation/Feed back					
Station pump	1.00	365	2300		
Recirculation pump	8.00	2920	28908	31208	0.8

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D. Evaporation

At this point, the RO unit concentrate is additionally treated via simple evaporation. Subsequently, the pH of the concentrate is adjusted using HCl and antifoam agent is added. The antifoam agent is a treatment approach to prevent the raw pre-treated leachate from foaming. However, it is noted that the cost of antifoam agent is costly. As observed by [11] the evaporators are capable of treating pre-concentrated liquid to a concentrate having approximately 20% of total solids (TS) pumpable fluid. The nominal concentration ratio of the evaporators is 1:5.5 as could be found differently and which further adds to the decreased landfill leachate storage capacity. The instrumental functions from a study by [11] shows energy usage of 2369600 KWh/yr which tallies with the 63.4% of the WWTP sum real power usage presented in Table II. Notwithstanding, evaporators are energy intensive and as such, should be considered carefully.

E. Recirculation

As the final/end phase, the concentrated product/sludge formed due to evaporation and the excess amount of RO concentrate are reinjected into the landfill. The leachate recirculation process exhausts roughly 0.78% of the sum energy of landfill leachate WWTP process.

IV. Conclusions

The option of leachate treatment is explored un line with the potential efficiency and energy usage of a landfill WWTP for a simple leachate treatment process. The WWTP process is a basic treatment approach of the leachate with subsequent sequencing batch reactors (SBR), reverse osmosis unit (RO) and evaporation for additional concentration of RO yield. The process efficiency appraisal uses conductivity, chemical oxygen demand (BOD), biochemical oxygen demand (BOD) and total nitrogen (TN) measurements. From the results and analysis the following conclusions were reached:

- That the RO is considered as the most efficient method for the leachate treatment as it can expel substantial volume of water from the landfill leachate storage capacity.
- That the functional operation of evaporators is energy intensive and expensive thus, should be appraised with caution.
- Additionally, it is measured that the most economical and environmentally friendly approach of the entire treatment process is to decrease the leachate volume by utilising the RO process and subsequently reinjecting the concentrated product/sludge via a controlled process into the landfill.

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