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Fresh Water Savings Through the Use of Municipal Effluents in Concrete Pavement

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Abstract: Wastewater reuse presents a promising solution to the growing pressure on the world's water resources. The use of municipal wastewater effluents for concrete production in the construction industry would result in energy and water savings leading to conservation and sustainability of our water resources. In this research, to promote and increase the reuse of wastewater in construction industry, both chemical and bacteria analyses were performed to ensure the recommended quality for concrete mixing water and the compressive strength of concrete specimens made with wastewater effluents was investigated and compared to specimens made with fresh water. Statistical analysis of the strength results showed that at 95% confidence interval, the compressive strengths of the control specimens and those of test specimens are not statistically different.

Keywords: Wastewater, Reuse, Effluents, Concrete, Sustainability

Introduction

Wastewater reuse presents a promising solution to the growing pressure on the world's water resources (de Graaf *et al*., 2014). Billions of gallons of wastewater effluent are discharged to rivers and lakes every year around the world while the demand on potable water for residential, commercial and industrial applications continue to increase (Muthukumaran *et al*., 2011). Furthermore, the increasing population levels, expanding economies, rapid urbanization and the increase in living standards of most communities have greatly increased the demand for energy (Huang, 2014). The opportunities for energy conservation are becoming more available in almost all applications such as homes, offices, schools, commercial and industrial settings (Chang *et al*., 2011) and (Rahman *et al*., 2012). According to the United States Environmental Protection Agency (USEPA, 2014a), some of these settings have already received benefits from the cost and energy-saving innovations such as reuse of wastewater for agriculture, public works, power plants and refineries cooling and toilet flushing. The reuse of wastewater provides the opportunity to save water, energy and money. Unfortunately, the large-scale applications for energy savings may often be hindered by the technical, legal, social and economic challenges at community levels especially the upfront investment and/or operating costs (Mizyed, 2013). According to the USEPA (2014a), the most successful wastewater reuse has been in decentralized facilities around the country; however, there is a need to maximize wastewater reuse by investing in large industrial, commercial and residential applications.

Quality of Concrete Mixing Water

The main parameters used to determine the right mixing water are those that may have an effect on the strength, durability and workability of the concrete. There are several standards with guidelines that set the maximum concentrations of certain chemicals. The most important chemicals that are controlled in concrete production include sulfates and chlorides. According to Zuquan *et al*. (2007; Zhang *et al*., 2013), the chlorides promote corrosion when the concrete is reinforced with steel bars and high sulfate concentration leads to reduced strength in concrete. It is therefore very important to examine the mixing water for these types of pollutants in order to ensure the durability of concrete when using waste water effluents for concrete production.

Wastewater Effluents

Wastewater effluent or discharge is the final product from a wastewater treatment plant and the composition varies by location and standard of living. In order to effectively make use of the effluent for concrete purposes, it is important to understand the chemical and bacteria constituents of the wastewater and determine the concentration levels to see if they are within acceptable standards. It is also important to note that actual effluents concentrations will vary from one treatment plant to another. However, most developed countries like the United States of America have regulations that specify the maximum concentrations of chemicals and bacteria in wastewater effluents and this research is focused on effluents discharged in the United States for use in construction industry to produce concrete for specific concrete works.

Wastewater Chemicals

The wastewater effluent contains various chemicals that are discharged from domestic, municipal and industrial sources. Some of these chemical include compounds of nitrogen, phosphorus, barium, copper, zinc, nickel, manganese, sodium, magnesium and lead. However, most of these are usually in small concentrations unless the treatment plant processes wastes from chemical industries and even then by the time the wastewater becomes the effluent, the concentration is significantly reduced. The chemical or parameters of concern in wastewater management are nitrogen and phosphorus compounds which are considered nutrients for plant growth, biochemical and chemical oxygen demand which are the measurement of organic matter in the wastewater and the amount of oxygen needed to decompose the organics (Gardner *et al.*, 2012).

Wastewater Bacteria

The wastewater is contaminated with a number of pathogens such as bacteria and viruses. These pathogens can cause harm to human and animal life and are therefore monitored and eliminated from the wastewater before discharge to the streams and rivers. According to the USEPA (2014b), members of two bacteria groups, coliforms and fecal streptococci, are used as indicators of possible sewage contamination because they are commonly found in human and animal feces. Total coliforms, fecal coliforms, *Escherichia coli* (*E. coli*), fecal streptococci and enterococci are the most commonly tested fecal bacteria. Total coliforms are the large collection of bacteria found everywhere in the natural world. Fecal coliforms are a subset of the total coliform bacteria that generally live in the digestive tracks or intestines of humans and warm-blooded animals. *E. coli* is a species of fecal coliform bacteria. Fecal streptococci, like the fecal coliforms, generally occur in the digestive systems of humans and animals; and enterococci are a subset in the fecal streptococcus group (USEPA, 2014b).

Suitability of Municipal Effluents for Concrete

The use of wastewater in the construction industry, specifically for concrete production, is very possible with the right treatment to make sure the mixing water standards are met. Treating wastewater to meet the mixing water standards for concrete can be quite costly and many concrete applications in the construction industry find it cheaper to use tap water which is potable and in almost all cases meets the mixing water standards. The wastewater effluent may not be safe for human consumption but it can be safe for concrete use.

Significance of Research and Objectives

This research addresses our current water crisis around the world and presents a promising solution to our water shortage. The research presents an additional low-energy source of almost unlimited water supply for non-potable usage and hence provides an option to save fresh water which results in energy savings from the collection, treatment and distribution of water from surface and ground sources. Unlike previous researcher that have focused on general comparisons of concrete properties when using wastewater, this research uses a specific mix design for concrete pavement application. This research furthermore promotes the reuse of wastewater in construction industry and provides a water-savings assessment for the city of Greensboro through the use of its municipal effluents for concrete applications. The main objectives of this research are to investigate and compare the compressive strength of concrete specimens for roadway concrete pavement using treated and untreated secondary municipal wastewater effluents to specimens made using potable water and to investigate the bacteria hazards when using untreated secondary municipal wastewater effluents for concrete production.

Literature Review

The continuous and growing ground extraction and surface withdraw of fresh water has resulted in the depletion of available water sources especially in industrial surrounding areas. Because of the increasing water demand, water intensive industries such as the chemical, petrochemical, pulp and paper, textile, steel, food and beverage, agricultural and construction industries especially in developed countries have already started to move towards wastewater reclamation and reuse.

Reuse in Construction Industry

Treated effluent is not only used in irrigation and industrial cooling systems but also used for concrete mixing, curing and washing aggregates (El-Nawawy and Ahmad, 1991). According to El-Nawawy and Ahmad (1991), treated effluent has been used in the Arabian Gulf by cities like Dubai especially for plain concrete production (concrete that do not need steel reinforcement). In addition to the use of wastewater effluent for plain concrete, several researchers have conducted experiments to investigate the effects of wastewater effluent use in various high strength concrete applications. Some of these studies are as follows:

Noruzman *et al*. (2012) conducted a research study to determine the feasibility of using treated effluents as alternatives to freshwater in mixing concrete. They collected samples from three effluent sources: Heavy industry, palm-oil mill and domestic sewage. The chemical and physical properties of the treated effluents were investigated and used to correlate with the standard requirements and then samples were prepared using the wastewater for testing and using freshwater to establish control samples. With the exception of total solids and pH, all the physical and chemical properties investigated were found to fall within the established testing standards limits. The test samples were evaluated with regard to the setting time, workability, compressive strength and permeability. The results from the testing showed that samples made from heavy industry and domestic sewage effluents performed well for all the parameters investigated. Furthermore, they found that the strength of the concrete made using heavy industry effluents was better than that of the control concrete. The high compressive strength associated with the heavy industry effluent samples could be the result of the chemical and physical composition of the effluent as the presence of fine solids in mixing water could fill voids in the concrete matrix which have significant impact on concrete strength (Noruzman *et al*., 2012). Another research was conducted by Al-Ghusain and Terro (2003) to determine the suitability of using wastewater for mixing concrete. This team made concrete specimens using tap water (for control samples), primary treated wastewater, secondary treated wastewater and tertiary treated wastewater. The results from their testing showed that the type of mixing water used for the mixing did not affect the slump and density of the concrete. Their results also showed that concrete setting times increased with the deteriorating quality of mixing water; and the samples made from primary and secondary effluents showed slower strength development compared to the tertiary effluent and tap water specimens. Furthermore, they found that the possibility of steel corrosion increased with the use of secondary and primary effluents as mixing water for the specimens reinforced with steel. There are several other researchers who have investigated the feasibility of using wastewater effluents for concrete production such as Shekarchi *et al*. (2012; Al-Jabri *et al*., 2011). In order to determine the suitability of using wastewater for concrete production, most researchers have to investigate the chemical and physicals properties of the wastewater for correlation with the established maximum allowable concentrations in standards.

Treatment and Energy Savings through Wastewater Reuse

The wastewater can be treated to meet the water quality requirements of a planned application and this reuse of wastewater offers a number of financial and resource savings in many industries (USEPA, 2014c). The reuse of wastewater for landscape irrigation for instance requires less treatment and energy than reusing wastewater for drinking purposes; and according to the USEPA (2014c), there has not been any documented case of human health problems reported due to contact with recycled water that has been treated to standards, criteria and regulations.

According to the United States Department of Energy (USDOE, 2014), there are several projects around the world that have achieved significant water and energy savings through the use of treated wastewater such as the U.S. Army's Fort Carson training facility in Colorado Springs, CO. This facility has successfully reclaimed the wastewater effluent from its treatment plant for irrigation and has been operating a large vehicle wash facility that uses the treated effluents for more than 30 and 20 years respectively yielding an approximate conservation of 1.14 billion liters (300 million gallons) of potable water per year (USDOE, 2014). Furthermore, Fort Carson facility saves about US $682,000 per year (2008 rates). The Texas Water Development Board (2014) gives examples of companies such as American Airlines, Freescale and Frito-Lay that have instituted significant water conservation measures and have reaped both financial and environmental benefits as follows: American Airlines Maintenance Base in Fort Worth implemented a program that allowed them to reuse treated wastewater and resulted in reduction of total water usage by 24 to 36% and reduced costs by almost US $1 million; Freescale in Austin implemented a rigorous reuse and recycling program and since 2006 the company has reduced wastewater production by more than 50% and potable water consumption by more than 51% as a result of reuse and recycle of the majority of process water leading to savings of more than 340 and 605 million liters (90 and 160 million gallons) of potable water and wastewater respectively in 2007; and finally the Frito-Lay plant in San Antonio recycles the water used to make potato and corn snacks and has reduced potable water use by 35 to 50% leading to savings of 3.78 billion liters (1 billion gallons) of water annually since 1999.

The treatment level of wastewater depends on the concentrations of constituents such as Biochemical Oxygen Demand (BOD), Checmical Oxygen Demand (COD), Total Solids, micro-organic pollutants, trace elements, nutrients and pathogenic microorganisms (Haruvy, 1997). There are several treatment methods with varying effectiveness that are utilized in municipal wastewater as well as industrial wastewater (Chan *et al.*, 2009). Traditional anaerobic-aerobic systems that uses ponds or lagoons have been highly utilized in both industrial and municipal wastewater for many years; and recently high-rate integrated anaerobic-aerobic bioreactors have been used increasingly especially for wastewater high in COD (Ahn *et al.*, 2007; Del Pozo and Diez, 2003; Castillo *et al.*, 1999). Because of the highly operational simplicity, low energy and chemical consumption, low sludge production and high potential for energy recovery through production of biogas during anaerobic treatment, the anaerobic-aerobic treatments have received great attention over the years compared to other wastewater treatment methods (Ranade and Bhandari, 2014; Gupta and Ali, 2013; Chan *et al.*, 2009). According to the USEPA (2014d), the municipal wastewater treatment is generally defined as primary, secondary and tertiary and is based on the extent of pollutant removal and the removal mechanism: Physical, biological, or chemical. Primary treatment uses physical processes such as screening, settling/sedimentation and skimming that remove significant amounts of organic and inorganic solids from wastewater; Secondary treatment uses biological actions to remove fine suspended solids, dispersed solids and dissolved organics through volatilization and biodegradation; and Tertiary or advanced treatment consists of a variety of physical, biological and chemical treatment methods to eliminate or significantly reduce the wastewater nutrients, organics and pathogens before discharge to receiving water bodies (USEPA, 2014d).

The cost of wastewater treatment depends on the established required level of treatment before disposal or minimum constituent concentrations in effluent for a given wastewater reuse application; and can also vary in different areas around the world (Haruvy, 1997). For instance, the cost of wastewater treatment at the Columbia Boulevard Treatment Plant in Portland Oregon is about US $0.01 per gallon [3.78 liters] (COP, 2014). According to the COP (2014), this treatment facility utilizes mainly primary and secondary treatments of wastewater. The T.Z Osborne Water Reclamation Facility in Greensboro NC utilizes primary, secondary and tertiary treatment of wastewater; and according to the City of Greensboro (COG) (2014), the treatment facility spends about US $0.11 per 3.78 liters (1 gallon) for wastewater treatment.

Wastewater Treatment Chemicals and Effects on Concrete

There are several treatment methods and chemicals used for wastewater treatment and their application depends on the level treatment required and the cost of the method or chemicals (Gogate and Pandit, 2004a; 2004b; Bhatti *et al.*, 2011). According to Gombos *et al.* (2013), chlorine, sodium hypochlorite, chlorine dioxide, ozone, hydrogen peroxide or the combination of these chemicals are the most common oxidizing/disinfecting reagents used in water and wastewater treatment.

Potassium Peroxymonosulfate (commercial name Oxone) has a high oxidation potential making it a strong chemical oxidant for municipal wastewater treatment such as the decomposition of dyes and organic compounds in influents (Legros *et al.*, 2001; Renganathan and Maruthamuthu, 1986). A study conducted by Sun *et al.* (2009) to investigate the use of oxone and Fenton (iron and hydrogen peroxide) oxidation processes in treatment of wastewater from landfill (leachate) showed that the oxone oxidation process demonstrated higher degradation efficiencies of COD, suspended solids and color than that by Fenton oxidation process. Oxone use as an oxidant has rapidly increased due to its stability, simple handling, non-toxic nature, versatility and the low costs (Woźniak *et al.*, 1998; Travis *et al.*, 2003; Parida and Moorthy, 2014; Lou *et al.*, 2014). Oxone can oxidize hydrogen sulfide (odor causing compound) and cyanide in addition to organics and bacteria in wastewater (Anipsitakis *et al.*, 2008). Literature also shows that oxone has high removal efficiencies of typical carcinogenic contaminants such as 2,4-dichrolophenol and atrazine compared to traditional methods (Anipsitakis and Dionysiou, 2003).

Even though the oxidation potential of potassium permanganate is less than that of oxone, potassium permanganate is also a highly effective oxidant and literature shows that in addition to treatment of organic loading and pathogens, it is effective in oxidizing some heavy metals of concern in water and wastewater treatment such as arsenic, iron and manganese (Sorlini and Gialdini, 2010; Fan *et al.*, 2013; Zhang *et al.*, 2013). Furthermore, potassium permanganate has been widely used in water and wastewater treatment to control taste and odor, remove color, control biological growth in treatment plants, remove polycyclic aromatic hydrocarbons which have a carcinogenic and/or mutagenic potential (de Souza e Silva *et al*., 2009; Rodríguez *et al*., 2007); and potassium permanganate has several additional advantages such as easier to handle, readily soluble and higher efficiency in water and soil treatment over other oxidants (Xu *et al*., 2005; Yan and Schwartz, 1999). Unlike oxone, potassium permanganate gained momentum over a century ago and has increased in use due to its eco-friendly water/wastewater treatment applications around the world as well as its low cost (Dash *et al*., 2009; Kao *et al*., 2008).

Potassium Permanganate is an inorganic water-soluble compound with purple crystals and a molecular formula of $KMnO_4$. This compound has potassium, Manganese and oxygen chemically bonded together; and when mixed in contaminated water, the permanganate ion in the compound oxidizes the organic contaminants to innocuous compounds such as water, oxygen and carbon dioxide (Schnarr *et al*., 1998; Ahmed, 2014). According to Schnarr *et al*. (1998), the manganese settles out as brown precipitates after the reactions are complete. Oxone is a water-soluble white granular compound which is present as a component of a triple salt with a molecular formula of $2KHSO_5.KHSO_4.K_2SO_4$. The active ingredient of oxone is potassium peroxymonosulfate ($KHSO_5$) which is also known as potassium monopersulfate (Yin *et al*., 2012; Zhiyong *et al*., 2013). When oxone is added to wastewater, the peroxymonosulfate ion (HSO5-) oxidizes the contaminants like the permanganate ion but more efficiently (Sun *et al*., 2009; Shukla *et al*., 2010). Literature show that both oxone and potassium permanganate are capable of removing most contaminants from wastewater by oxidizing them into harmless or less harmful compounds but none show the effects of by-products on concrete applications.

Methodology

Materials and Methods

Agricultural wastewater treated by a constructed wetland for secondary treatment was collected from a local swine farm (Greensboro, NC). Wastewater samples were collected using sterile 1-liter bottles with lids from a lagoon that received secondary treatment through a constructed wetland. The samples were tested for total coliform, *E. coli* and enterococci levels within one hour of sample collection. In cases when the testing could not be done within a couple of hours, the samples were refrigerated at 4°C or less to slow down the biochemical reactions. Colilert Assay Kits (IDEXX Laboratories, Westbrook, Maine) were used for total coliform and *E. coli* concentrations in the wastewater. Enterolert Assay Kits (IDEXX Laboratories, Westbrook, Maine) were used for Enterococci analyses.

Chemical, Physical and Biological Wastewater Tests

A HACH DR3900 Benchtop Spectrophotometer (Hach Company, Loveland, Colorado) was used for the chemical analyses. Protocols for the DR3900 and the Hach TNTplus Assays were used to analyze chloride, sulfate, free and total chlorine, phosphorus and nitrogen concentrations in the wastewater using US EPA compliant procedures. TNTplus HACH kits were purchased from Hach Company for the Mercuric Thiocyanate Method, Sulfate Turbid metric TNTplus Method, Total and Free Chlorine TNTplus Method, Total Nitrogen Persulfate Digestion TNTplus Method and Phosphorus TNTplus Method for analysis. The total solids concentration was determined according to the American Society for Testing and Materials (ASTM) Standard C1603.

The pH and Alkalis content of the sample was determined using the Fisher Scientific Accumet Excel (XL) 600 Benchtop Meter. Alkalis content was determined using a method adapted from ASTM Standard C114-19 (2013) by measuring sodium and potassium levels and then converting these ions to alkali equivalent. The built-in Direct Reading with Standards Method was used. The standards used for sodium measurements were 25, 50, 100 and 200 mg L^{-1} sodium chloride solutions and those for potassium measurements were 12.5, 25, 50 and 100 mg L^{-1} potassium iodide solutions. The 200 mg L^{-1} sodium standard was prepared by mixing 127.1 mg sodium chloride in deionized water and then using serial dilutions to make the lower concentration standards. Potassium standards where prepared in a similar manner by mixing 74.2 mg potassium iodide in deionized water for the 100 mg L^{-1} standard.

The wastewater effluent samples were treated using the two chemical oxidants: Oxone and potassium permanganate. Varying amounts of potassium permanganate (Fisher) and Oxone®, potassium peroxymonosulfate, (Sigma-Aldrich) in 0.5 g increments up to 2 g where used to determine the effectiveness of bacteria treatment with respect to the amount of oxidant used. Furthermore, the concentration of bacteria was determined every 2 h for 8 h to determine the length of time required for complete bacteria treatment. To test the mobility of bacteria in finished concrete pavement, the specimens of 24 h -hardened concrete made using 100% secondary-treated wastewater effluent were put in deionized water and then the water was tested for presence of bacteria after 24 h.

Measurement of Sulfate after Oxone treatment

Because Oxone contains sulfate compounds as part of the chemical structure, the Oxone-treated effluent samples were reanalyzed for sulfate concentration in order to determine if this method of treatment increases the sulfate concentration in the sample wastewater effluent.

Concrete Mix Design

The North Carolina Department of Transportation (NC DOT) concrete pavement design was used in this research as a reference for wastewater reuse in concrete applications since this research was conducted in Greensboro, NC. The Mix Design was based on Section 1000 of the NC DOT Standard Specifications for Roads and Structures (NC DOT, 2012). As the widely accepted mix design method in the United States, the American Concrete Institute (ACI) Absolute Volume Method was used in this research. The NC DOT recommends the use of 150×300 mm (6×12 inch) specimens; however, it permits the use of 100×200 mm (4×8 inch) specimens as long as the Nominal Maximum Size Aggregate is 25.4 mm (1 inch). The specifications from NC DOT pertaining to this design are listed in Table 1. The cement, sand and stones, together with the material properties shown in Table 2, were provided by Chandler Concrete Company in Greensboro NC. Using the information provided in Table 1 and 2, as well as the ACI Table A1.5.3.6 and a target trapped air content (not entrained) of 5% of total volume, the absolute volumes of the mix design were calculated. The design weights were then found by multiplying the absolute volumes by the specific gravities and then by the unit weight of water. The absolute volumes and suggested quantities of the concrete constituents for 0.765 cubic meters (1 cubic yard) of concrete are reported in Table 3.

The experimental design included the making of trial samples, control samples and test samples. Trial samples using the maximum w/c ratio (0.559) and a w/c ratio of 0.500 were made and tested for strength and workability at 7 and 14 days. Next the control samples using potable tap water were made in triplicates for 3-, 7-, 14-, 21- and 28-days curing time for testing. Similar combinations (15 samples each set) were then made for the test samples using 100% wastewater effluent, 100% oxone-treated wastewater effluent and 100% potassium permanganate-treated wastewater effluent. Finally the hardened test samples using 100% wastewater effluent were used to test for bacteria mobility in finished concrete pavement.

Table 1. NC DOT concrete pavement specifications

Parameter	Value	Units
Minimum cement content:	313 (526)	g/L (lbs/cy)
Maximum W/C ratio:	0.559	
Nominal maximum size aggregate:	25.4 (1.00)	mm (in)
Air content:	4.50 - 5.50	%
Maximum slump (hand place):	76.2 (3.00)	mm (in)
Min. 28-day compressive Strength:	31 (4500)	MPa (psi)

Table 2. Material properties

Parameter	Value	Units
Fineness modulus of Sand:	2.75	
Specific gravity of Sand:	2.64	
Specific gravity of Stone:	2.89	
Dry-Rodded unit weight of stone:	1.63 (101.6)	g/L (lbs/ft^3)
Specific gravity cement:	3.15	

Table 3. Concrete mix design quantities

Volumes and weights of concrete mix design				
	Volume		Weight	
Constituent	m^3	ft^3	Kg	lbs
Portland cement	0.076	2.68	239	526
Water	0.133	4.71	133	294
Air	0.038	1.35	0	0
Coarse aggregate (stones)	0.291	10.3	840	1852
Fine aggregate (sand)	0.226	7.99	597	1317

The triplicate samples were prepared specimen by specimen to minimize segregation of the concrete constituents and the batches were hand-mixed. Because each batch is to provide sufficient concrete for one specimen, a 100×200 mm (4×8 inch) cylinder with volume of 1.65E-3 cubic meters (5.818E-2 cubic feet), the design volume of 0.765 cubic meters (27 cubic feet) was reduced using a ratio of specimen-volume to design-volume. Using a waste factor of 1.5% for each batch, the resulting design volumes and weights were calculated. The different sets of specimens were then made using the same design volumes and weights and according to ASTM Standard C31/C31M (2012a). The specimens were cured in limewater for 24 h and removed from the molds using air pressure. The measurements of the specimens were taken and then the specimens were put into the curing boxes for the intended period of time. The use of limewater for concrete curing is preferred over fresh water to prevent diffusion of the lime in the concrete to the surrounding curing water because the lime in the concrete is needed for the hydration process to develop strength. Before the strength testing, the ends of concrete specimens were capped with sulfur mortar according to ASTM Standard C617 (ASTM International, 2012a; 2012b) in order to provide uniform loading of the compression machine. The concrete specimens were finally tested for unconfined compressive strength according to the ASTM Standard C39/C39M (ASTM International, 2014). Other ASTM Standards used in this research included the ASTM C150/C150M-12 (2012c), ASTM C143/C143M-12 (2012d) and ASTM C1602/C1602M-12 (2012e) for Standard Specification for Portland Cement, Standard Test Method for Slump of Hydraulic-Cement Concrete and Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete respectively.

Statistical Analysis

The statistical analysis of this research included the determination of the mean, variance, standard deviation and 95% confidence intervals of the compressive strength of the specimens. Furthermore, to compare the compressive strength results of control specimens to test specimens, the F-Test and t-Test were used to determine the variance and mean comparison respectively.

Results and Analysis

Bacteria Test Results

From the Enterolert and Colilert biological assays, it was found that despite treatment through the constructed wetland, the wastewater effluents continued to have high concentration of bacteria. The Most Probable Number (MPN) of *E. coli*, Enterococci and Total Coliform bacteria was 1000 MPN, 2000 MPN and 14600 MPN per 100 mL of wastewater respectively. Due to the concentration of bacteria in the wastewater at levels dangerous for human contact, the wastewater effluent was treated with oxidants for disinfection. Disinfection of the wastewater prior to mixing with concrete was performed to yield water that no longer posed a biological hazard to workers during concrete production. Treatment of the water using 0.5 g of either potassium permanganate or Oxone was sufficient to reduce the *E. coli* and Total coliform bacteria concentrations by 2-log within 2 h. Oxone at 0.5 g reduced the concentration to 8.4 MPN per 100 mL with in 2 h where as 0.5 g of potassium permanganate took about 8 h to reduce the concentration to 52.1 MPN per 100 mL. The use of 2.0 g of each oxidant resulted in complete inactivation of total coliform and *E. coli* bacteria. Oxone used at 2.0 g was more effective at treating enterococci bacteria to non-detectable levels than potassium permanganate over the 8 h period.

Table 4 summarizes the bacteria reduction based on oxidant dose and time. The results in Table 4 show that the effectiveness of bacteria treatment increases with time and the amount of oxidant used. For instance, 0.5 g and 2.0 g of potassium permanganate reduced the Enterococci bacteria to 344 MPN and 82.8 MPN respectively within 2 hours; and 177 MPN and 42.4 MPN of Enterococci bacteria were measured after 2 and 8 h of treatment with 0.5 g of potassium permanganate respectively. Results show that Oxone is more efficient in treating Enterococci bacteria than potassium permanganate. Potassium permanganate appears to be more efficient in treating coliform groups of bacteria than Oxone.

The bacteria mobility from hardened test specimens using secondary-treated wastewater effluents were investigated to determine if bacteria at the maximum concentration would have cell regrowth on the surface and the potential to serve as a bacteria source. It was found that after the concrete hardens, there was no bacteria leaching from the specimens or present on the surface of the specimens. It can be theorized that either the bacteria get trapped in the hardened concrete and without any source of nutrients the bacteria die off rapidly, or that the bacteria get killed due to the toxicity of the lime in the cement. In either case, the bacteria in secondary-treated effluents do not pose a health problem to the finished concrete product based on the results in this research. The wastewater effluent infested with bacteria may therefore be used as long as the workers observe safety rules by wearing personal protective equipment if concrete is mixed by hand as opposed to mechanical mixers.

Table 4. Bacteria reduction based on oxidant dose and time

			MPN per 100 mL of water			
		Amount (g)	2-h	4-h	6-h	8-h
Total Coliform[A]	Oxone	0.5	42.5	37.7	35.5	24.3
		1.0	33.2	30.1	27.2	18.7
		1.5	18.3	13.4	12.0	6.3
		2.0	1.0	0.0	0.0	0.0
	$KMnO_4$	0.5	43.7	14.4	10.9	4.1
		1.0	22.8	0.0	0.0	0.0
		1.5	0.0	0.0	0.0	0.0
		2.0	0.0	0.0	0.0	0.0
E. coli[B]	Oxone	0.5	28.4	14.2	13.0	10.6
		1.0	9.4	8.5	7.4	6.2
		1.5	6.1	5.1	4.1	3.0
		2.0	1.0	0.0	0.0	0.0
	$KMnO_4$	0.5	3.0	2.0	0.0	0.0
		1.0	0.0	0.0	0.0	0.0
		1.5	0.0	0.0	0.0	0.0
		2.0	0.0	0.0	0.0	0.0
Enterococci[C]	Oxone	0.5	8.4	5.2	4.1	0.0
		1.0	5.2	4.1	3.0	0.0
		1.5	4.1	3.0	2.0	0.0
		2.0	3.1	1.0	0.0	0.0
	$KMnO_4$	0.5	344.0	153.0	74.3	52.1
		1.0	177.0	93.2	67.8	42.4
		1.5	103.0	85.6	61.3	32.7
		2.0	82.8	52.1	21.4	15.3

A: Control samples for Total Coliform = 14600 MPN per 100 mL sample
B: Control samples for *E. coli* = 1000 MPN per 100 mL sample
C: Control samples for Enterococci = 2000 MPN per 100 mL sample

Chemical Test Results

Table 5-1 shows the concentrations of sodium and potassium ions measured to calculate the alkali content of the wastewater effluent. There is no explicitly established maximum permissible effluent concentration of potassium and sodium ions in literature and water quality limitations. This may be due to the fact that both sodium and potassium are not considered as pollutants of concern in wastewater effluents. However, research has shown that potassium and sodium concentrations in municipal wastewater effluents range from 13 to 20 mg L^{-1} and 50 to 250 mg L^{-1} respectively (Arienzo *et al*., 2009). The alkali content of the wastewater effluent used in this research was well below the established limit for concrete mixing water.

Table 5-2 reports the measured chemical concentrations with the ASTM Standard Limits. The concentration of total solids was found to be 384 mg L^{-1}. This concentration was also below the 50,000 mg L^{-1} limit for concrete mixing water. Furthermore, the amount of solids in the effluents used in this research did not appear to have any negative effects on the appearance of cured concrete specimens. The concentrations of chloride (48 mg L^{-1}) and sulfate (105 mg L^{-1}) are also well below the concrete mixing water limits of 500 and 3000 mg L^{-1} respectively. According to Zuquan *et al*. (2007; Zhang *et al*., 2013), chlorides promote corrosion when the concrete is reinforced with steel bars and high sulfate concentration leads to reduced strength in concrete. The concentrations of chloride, sulfate and total solids satisfy the effluent limitations and are not expected to have a significant impact on concrete specimens.

The pH of the wastewater effluent was measured to be about 8.95 which is an acceptable value because the cement paste is highly basic. This pH will not significantly alter the pH of the concrete as it hardens. Because the concentrations of chemicals of concern were very low, it was not necessary to investigate the effluent treatment for chemical removal in this research. The concentration of sulfates present in the water after treatment but before mixing into the concrete was 992 mg L^{-1}. This sulfate concentration is below the established limit of 3000 mg L^{-1} for concrete. Table 6 reports the other chemicals measured to determine the quality of the wastewater effluents.

Table 5-1. Concentration of Ions used for Alkali Content

Ion	Concentration (mg/L)	Average
Sodium	21.20	21.7
	21.10	
	22.70	
Potassium	7.28	7.25
	7.26	
	7.20	
Alkali content	35.00	

Table 5-2. Measured concentrations and optional chemical limits for mixing water

Chemical name	Concentration (mg/L)	Limits (mg/L)
Chloride (Cl-)	48.0	≤500
Sulfate (SO_4^{2-})	105.0	≤3000
Alkalies as (Na_2O + 0.658 K_2O)	35.0	≤600
Total solids	384.0	≤50,000

Table 6. Concentrations of other Chemicals and pH in wastewater effluent

Chemical name	Concentration (mg/L)
pH	8.95
Free Chlorine (Cl_2)	1.96
Total Chlorine (Cl_2)	1.97
Reactive Phosphorus (as PO_4^{3-})	219.00
Total Phosphorus (as PO_4^{3-})	352.00
Total Nitrogen (N)	186.00
Sodium	27.10
Potassium	7.25
Alkali Content	35.00

Concrete Specimens Results

Trial samples were made to ensure that the slump of the concrete is within the range of the mix design requirements. Because the mix design of the concrete was based on the size of the specimen, concrete constituents for the trial samples were tripled in weight in order for the trial batch to have enough concrete for the slump test. Table 7-1 shows the trial batches data using w/c ratios of 0.500 and 0.559 and the resulting slump. The concrete slump for the water-cement ratio of 0.500 was 12.7 mm (0.5 inches) and that of 0.559 was 38.1 mm (1.5 inches). Both water-cement ratios satisfy the concrete slump conditions. Because the concrete was hand-mixed, the 0.559 water-cement ratio was used for the control and test specimens to obtain a better homogenous mix of the materials.

Table 7-2 shows the summary of the compressive strength results for the control specimens. The compressive strength of control specimens increased from 23 to 35 MPa (3,358 to 5,008 psi) between 3 and 28 days of curing. Table 7 also shows that the strength of concrete at 14 days surpasses the minimum strength requirement of 31 MPa (4500 psi) at 28 days. This further shows the effectiveness of the mix design that was chosen in this research. These results also show that the compressive strength of concrete increases as the curing time increases. The detail results of the control specimens are presented in Tables A-1 and A-2.

The average compressive strengths of all control and test specimens at different curing days are reported in Table 8. The compressive strength of the test specimens using 100% wastewater as mixing water also increased as the curing time increased. The average compressive strengths after 3 days, 14 days and 21 days of curing were slightly lower than that of the control specimens. However, the average compressive strengths at 7 days and 28 days were slightly higher than that of the control specimens. Although all the specimens were made the same way, it is difficult to produce specimens with identical amount of mix and compaction. The small differences in the actual quantities of the materials in each specimen results in different unit weights of the specimens and these differences may lead to small variations in the compressive strengths. However, the compressive strength results for both types of specimens for most curing days were within the same range. For instance, the compressive strength results for the 3-day curing of both control and test specimens were between 21 and 24 MPa (3100 and 3500 psi). The detail results of the test specimens using untreated wastewater as mixing water are presented in Table A-3 and A-4.

Table 7-1. Data for trial batches

Batch No.	Material	Quantity	Units	Date	Time	W/C Ratio	Slump [mm] (in)
1	Cement	2312.59	g	6/25/2014	4:40 PM	0.5	12.7 (0.5)
	Sand	5792.2	g				
	Stone	8144.34	g				
	Water	1157	mL				
2	Cement	2313.53	g	6/25/2014	3:30 PM	0.559	38.1 (1.5)
	Sand	5792.19	g				
	Stone	8143.88	g				
	Water	1293	mL				

Table 7-2. Compressive strength of control specimens

Curing time (days)	Compressive strength	Average compressive strength	Units
3	3396	23.2 (3358)	Mpa (psi)
3	3180		
3	3498		
7	3967	27.3 (3960)	Mpa (psi)
7	3804		
7	4110		
14	4605	31.2 (4532)	Mpa (psi)
14	4480		
14	4510		
21	4679	33.8 (4898)	Mpa (psi)
21	5102		
21	4915		
28	5108	34.5 (5008)	Mpa (psi)
28	4819		
28	5097		

Table 8. Compressive strength of concrete produced with untreated and treated water (Mpa)

Curing time (days)	Concrete produced with fresh tap water Average (psi)	Concrete produced with untreated wastewater Average (psi)	Concrete produced with Oxone treated wastewater Average (psi)	Concrete produced with $KMnO_4$ treated wastewater Average (psi)
3	23.2 (3358±162)	22.6 (3281±49)	23.7 (3435±101)	22.5 (3267±15)
7	27.3 (3960±153)	29.6 (4294±125)	28.3 (4100±134)	29.5 (4281±90)
14	31.2 (4532±65)	30.9 (4488±71)	31.7 (4594±181)	32.9 (4771±81)
21	33.8 (4898±211)	32.6 (4729±31)	33.4 (4850±163)	34.3 (4989±246)
28	34.5 (5008±164)	35.8 (5194±151)	35.2 (5106±213)	34.4 (4992±213)

Table A-1. Testing results for 3-Day, 7-Day and 14-Day control specimens

Specimen No.	Date	Time	Compressive force in KN (lbs.)		Compressive Failure type	Average strength in Mpa (psi)		strength (psi)
1C-3-Day	7/2/2014	2:55 PM	190	(42675)	4	23.4	(3395.97)	23.2 (3358)
2C-3-Day	7/2/2014	3:15 PM	178	(39966)	4	21.9	(3180.39)	
3C-3-Day	7/2/2014	4:45 PM	196	(43960)	2	24.1	(3498.23)	
1C-7-Day	7/9/2014	4:30 PM	222	(49853)	4	27.4	(3967.18)	27.3 (3960)
2C-7-Day	7/9/2014	4:45 PM	213	(47797)	4	26.2	(3803.56)	
3C-7-Day	7/9/2014	5:00 PM	230	(51653)	4	28.3	(4110.42)	
1C-14-Day	7/31/2014	9:26 PM	257	(57862)	4	31.7	(4604.51)	31.2 (4532)
2C-14-Day	7/31/2014	9:31 PM	250	(56300)	4	30.9	(4480.21)	
3C-14-Day	7/31/2014	9:36 PM	252	(56676)	4	31.1	(4510.13)	

Table A-2. Testing results for 21-Day and 28-Day control specimens

Specimen No.	Date	Time	Compressive Force in KN (lbs.)		Failure type	Compressive strength in Mpa (psi)		Average strength (psi)
1C-21-Day	7/20/2014	9:00 PM	262	(58792)	4	32.3	(4678.52)	33.8 (4898)
2C-21-Day	7/20/2014	9:00 PM	285	(64111)	2	35.2	(5101.79)	
3C-21-Day	7/20/2014	9:00 PM	275	(61758)	2	33.9	(4914.55)	
1C-28-Day	7/28/2014	7:00 PM	286	(64190)	2	35.2	(5108.08)	34.5 (5008)
2C-28-Day	7/28/2014	7:10 PM	269	(60552)	2	33.2	(4818.58)	
3C-28-Day	7/28/2014	7:20 PM	285	(64052)	4	35.1	(5097.1)	

Table A-3. 3-Day, 7-Day, and 14-Day testing results for 100% wastewater specimens

Specimen No.	Date	Time	Compressive force in KN (lbs.)		Failure type	Compressive strength in Mpa (psi)		Average strength (psi)
1T-3-Day	7/18/2014	7:00 PM	186	(41726)	2	22.9	(3320)	22.6 (3281)
2T-3-Day	7/18/2014	7:10 PM	184	(41429)	4	22.7	(3297)	
3T-3-Day	7/18/2014	7:20 PM	180	(40539)	2	22.2	(3226)	
1T-7-Day	7/18/2014	7:00 PM	236	(53116)	4	29.1	(4227)	29.6 (4294)
2T-7-Day	7/18/2014	7:10 PM	236	(52998)	4	29.1	(4217)	
3T-7-Day	7/18/2014	7:20 PM	248	(55766)	4	30.6	(4438)	
1T-14-Day	7/24/2014	2:55 PM	247	(55608)	4	30.5	(4425)	30.9 (4488)
2T-14-Day	7/24/2014	3:02 PM	250	(56221)	4	30.8	(4474)	
3T-14-Day	7/24/2014	3:10 PM	255	(57348)	4	31.5	(4564)	

Table A-4. 21-Day and 28-Day testing results for 100% wastewater specimens

Specimen No.	Date	Time	Compressive force in KN (lbs.)		Failure type	Compressive strength in Mpa (psi)		Average strength (psi)
1T-21-Day	8/1/2014	2:19 PM	266	(59860)	2	32.8	(4764)	32.6 (4729)
2T-21-Day	8/1/2014	2:25 PM	264	(59266)	4	32.5	(4716)	
3T-21-Day	8/1/2014	2:30 PM	263	(59148)	4	32.5	(4707)	
1T-28-Day	9/26/2014	9:25 AM	289	(64942)	4	35.6	(5168)	35.8 (5194)
2T-28-Day	9/26/2014	9:30 PM	283	(63558)	4	34.9	(5058)	
3T-28-Day	9/26/2014	9:35 PM	299	(67315)	4	36.9	(5357)	

The average compressive strength results of specimens using oxone-treated effluents for all curing periods were slightly higher than those of control specimens except for the 21-day curing period average strength results. For the potassium permanganate-treated effluents, the average compressive strengths for the 3-days and 28-days curing periods were slightly lower than those of control specimens. However, like the strength results of the specimens using 100 percent wastewater, these results were within the same range. For instance, the 28-days strength results for all specimens were between 33 and 37 MPa (4800 and 5400 psi) which are all well above the minimum design strength at 28-days of curing. Table 8 shows that the average compressive strength results of all test specimens are not significantly different from those of control specimens. Furthermore, ASTM Standard C1602 requires that the compressive strength of test specimens at 7 days of curing should be at least 90 percent of the control specimens. The 7-days average compressive strengths of all test specimens are in fact greater than the 7-days average compressive strength of control specimens. The detail results for test specimens using oxone-treated and potassium permanganate-treated effluents as mixing water are presented in Tables A-5 to A-8 respectively. Figure 1 shows a comparison of these results and it can be seen that the average strength increases with curing time.

Statistical Analysis of Compressive Strength of Concrete Specimens

The statistics of the compressive strengths of all concrete test specimens at different curing days were computed in order to compare and contrast the strength results. For the 3-day curing time, the strength results ranged from 22 to 24 MPa (3,180 to 3,541 psi) with a mean of 23 MPa (3,335 psi) and standard deviation of 0.76 MPa (110 psi). The strength results for the 7-day curing time ranged from 26 to 31 MPa (3,804 to 4,438 psi) with a mean of 29 MPa (4,159 psi) and a standard deviation of 1.2 MPa (180 psi). The 14-day curing time had strength results that ranged from 31 to 34 MPa (4,425 to 4,861 psi) with a mean of 32 MPa (4,596 psi) and a standard deviation of 1 MPa (147 psi). For the 21-day curing time, the strength results ranged from 32 to 36 MPa (4,679 to 5,226 psi) with a mean of 34 MPa (4,867 psi) and a standard deviation of 1.3 MPa (184 psi). The strength results for the 28-day curing time ranged from 33 to 37 MPa (4,819 to 5,357 psi) with a mean of 35 MPa (5,075 psi) and a standard deviation of 1.2 MPa (181 psi). The standard deviations of the data sets are relatively small for the given strength values and hence show that the strength results for each curing time are relatively close to each other.

The most important test results are the compressive strengths of concrete specimens at 28 days of curing as these results help decide on whether or not the design requirement of strength has been met. The strength results at 28 days of curing were tested for normal distribution before proceeding with tests of significance. The Cumulative Distribution Plot in Fig. 2 shows that 50% of the data is above the mean and the other 50% below the mean. This is a characteristic of a normal distribution curve where half the data is on the right and the other half on the left. The original 28-day strength data almost coincides with the expected data as shown in the

Normal Probability Plot in Fig. 3. Because of how close the predicted data is to the original data, the compressive strength results are likely to be of normal distribution and hence this type of distribution was assumed for the statistical difference and similarity tests between the control and test concrete specimens. The data used to create the Cumulative Distribution and Normal Probability Plots is presented in Table A-9.

In order to show the 95% confidence intervals in more clear graphs, the time and strength data were both linearized and then graphs were created for the analysis. Figure 4 to 6 show the 95% confidence intervals of control specimens and the test specimens using 100% untreated effluents, test specimens using oxone-treated effluents and test specimens using $KMnO_4$-treated effluents respectively. The confidence intervals in Fig. 4 to 6 are relatively narrow in relation to the predicted compressive strengths and hence the estimated value is relatively stable. In other words, the repeated testing of concrete specimens would give approximately the same results. There is therefore a 95% probability that the true linear regression line of the compressive strength data will lie within the confidence interval of the regression line that is calculated from the sample data.

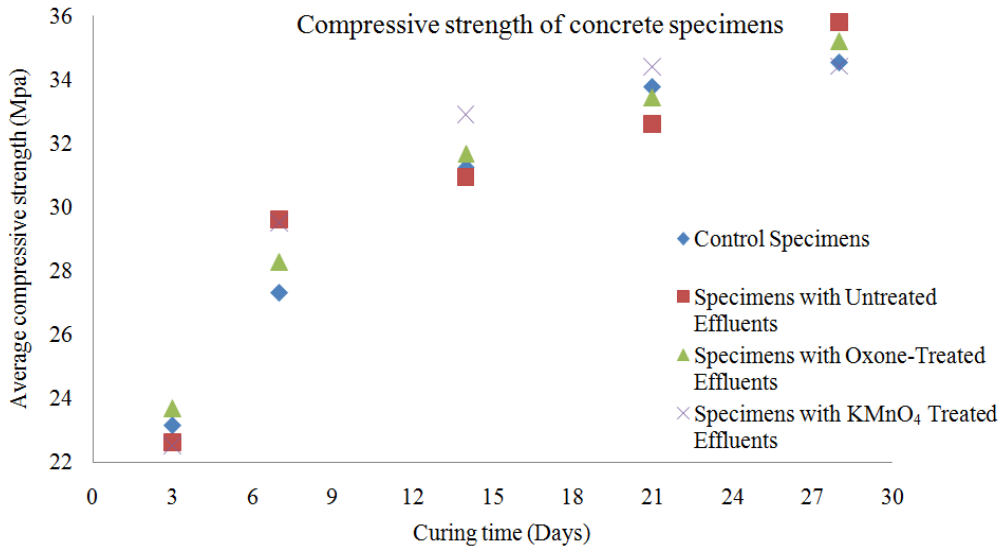

Fig. 1. Compressive strength of tests specimens with untreated wastewater and treated wastewater

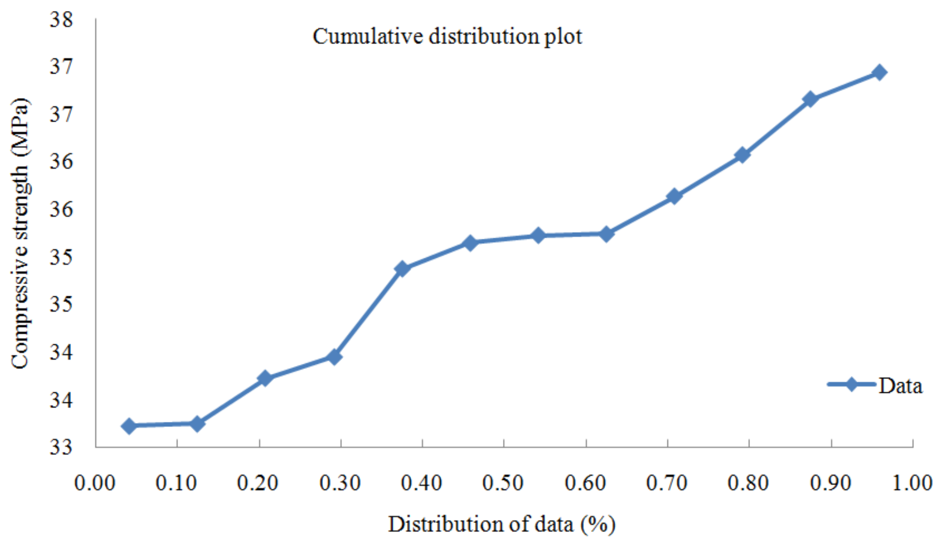

Fig. 2. Cumulative distribution plot of 28 days testing results

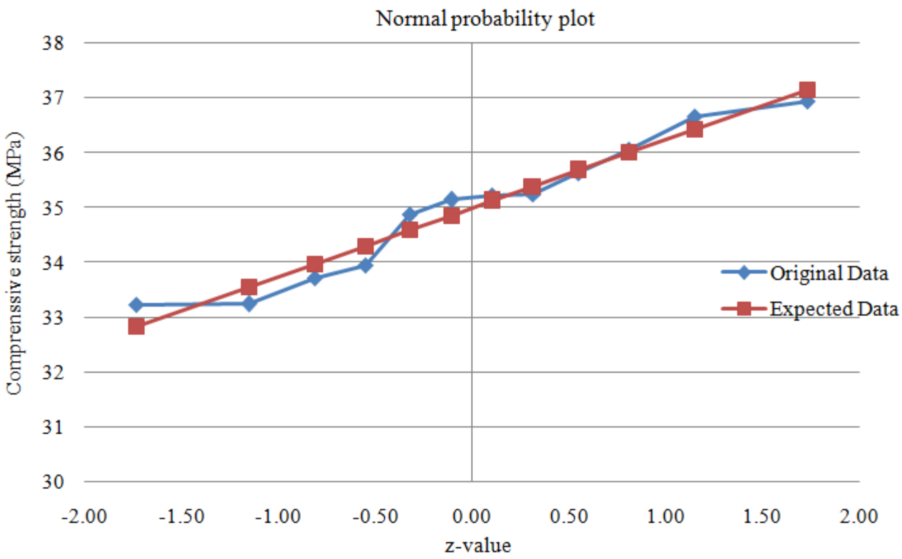

Fig. 3. Normal probability plot of 28 days testing results

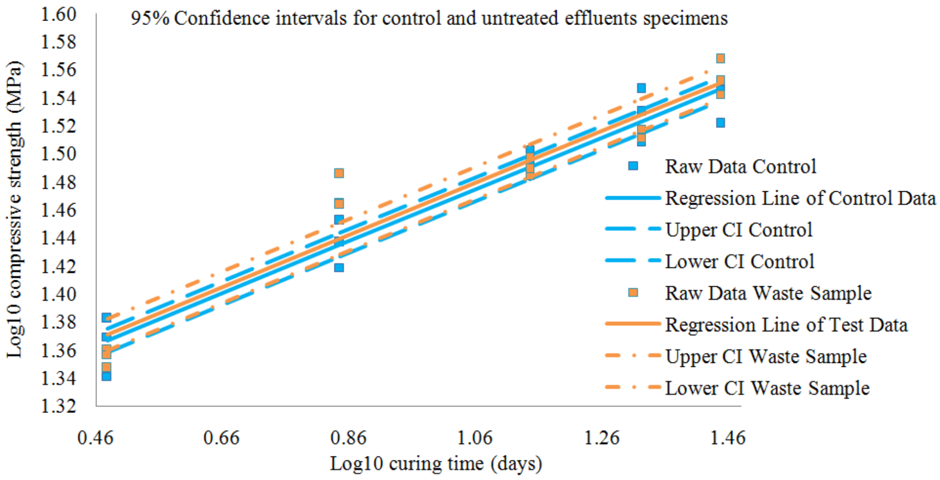

Fig. 4. Confidence intervals for control and untreated effluents specimens

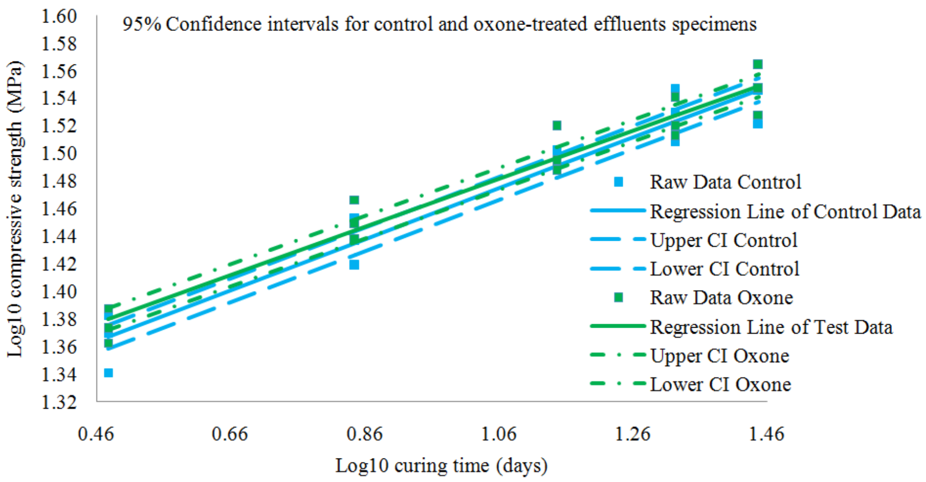

Fig. 5. Confidence intervals for control and oxone-treated effluents specimens

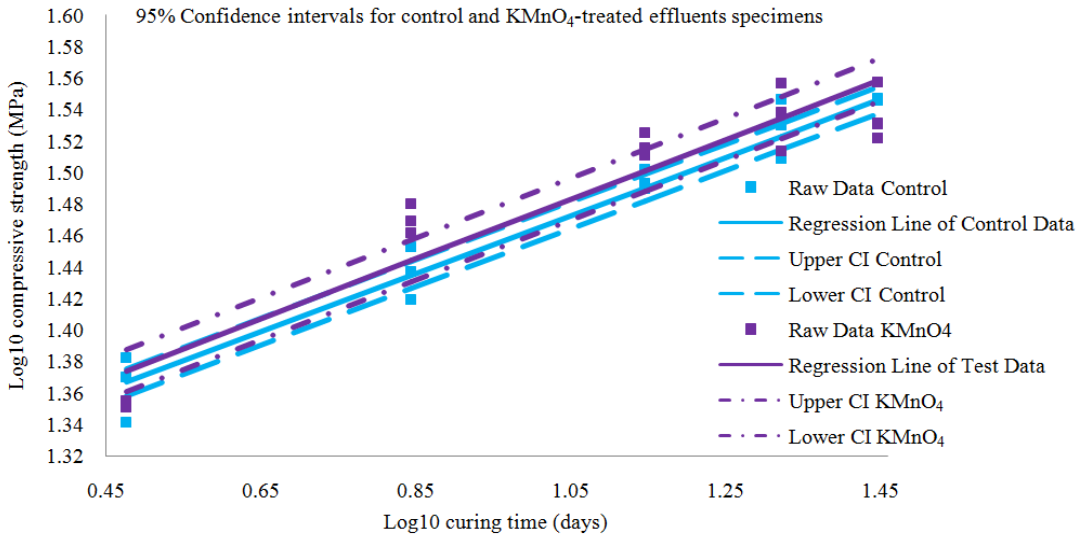

Fig. 6. Confidence intervals for control and KMnO4-treated effluents specimens

Table A-5. 3-Day, 7-Day and 14-Day testing results for oxone-treated wastewater specimens

Specimen No.	Date	Time	Compressive force in KN (lbs.)		Failure type	Compressive strength in Mpa (psi)		Average strength (psi)
1T-3-Day	8/22/2014	6:08 PM	198	(44494)	4	24.4	(3541)	23.7 (3435)
2T-3-Day	8/22/2014	6:15 PM	187	(41983)	4	23.0	(3341)	
3T-3-Day	8/22/2014	6:25 PM	191	(43011)	4	23.6	(3423)	
1T-7-Day	8/22/2014	6:37 PM	237	(53314)	4	29.3	(4243)	28.3 (4100)
2T-7 Day	8/22/2014	6:41 PM	222	(49992)	2	27.4	(3978)	
3T-7-Day	8/22/2014	6:45 PM	228	(51277)	2	28.1	(4080)	
1T-14-Day	8/29/2014	2:30 PM	249	(55984)	2	30.7	(4455)	31.7 (4594)
2T-14-Day	8/29/2014	2:40 PM	253	(56913)	2	31.2	(4529)	
3T-14-Day	8/29/2014	2:50 PM	268	(60295)	4	33.1	(4798)	

Table A-6. 21-Day and 28-Day testing results for oxone-treated wastewater specimens

Specimen No.	Date	Time	Compressive force in KN (lbs.)		Failure type	Compressive strength in Mpa (psi)		Average strength (psi)
1T - 21 - Day	9/13/2014	12:10 AM	281	(63241)	4	34.7	(5033)	33.4 (4850)
2T - 21 - Day	9/13/2014	12:15 AM	268	(60295)	4	33.1	(4798)	
3T - 21 - Day	9/13/2014	12:20 AM	264	(59306)	4	32.5	(4719)	
1T - 28 - Day	10/7/2014	2:56 PM	273	(61461)	2	33.7	(4891)	35.2 (5106)
2T - 28 - Day	10/7/2014	2:02 PM	286	(64230)	2	35.2	(5111)	
3T - 28 - Day	10/7/2014	2:10 PM	297	(66801)	4	36.7	(5316)	

Table A-7. 3-Day, 7-Day and 14-Day testing results for KMnO4-treated wastewater specimens

Specimen No.	Date	Time	Compressive Force in KN (lbs.)		Failure type	Compressive strength in Mpa (psi)		Average strength (psi)
1T - 3 - Day	9/19/2014	7:16 PM	183	(41053)	4	22.5	(3267)	22.5 (3267)
2T - 3 - Day	9/19/2014	7:20 PM	183	(41251)	4	22.6	(3283)	
3T - 3 - Day	9/19/2014	7:25 PM	182	(40875)	4	22.4	(3253)	
1T - 7 - Day	9/19/2014	7:30 PM	239	(53630)	4	29.4	(4268)	29.5 (4281)
2T - 7 - Day	9/19/2014	7:35 PM	235	(52760)	4	29.0	(4199)	
3T - 7 - Day	9/19/2014	7:40 PM	245	(55015)	4	30.2	(4378)	
1T - 14 - Day	9/26/2014	9:10 PM	265	(59682)	4	32.7	(4749)	32.9 (4771)
2T - 14 - Day	9/26/2014	9:15 PM	263	(59108)	2	32.4	(4704)	
3T - 14 - Day	9/26/2014	9:20 PM	272	(61086)	4	33.5	(4861)	

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Table A-8. 21-Day and 28-Day testing results for $KMnO_4$-treated wastewater specimens

Specimen No.	Date	Time	Compressive force in KN (lbs.)		Failure type	Compressive strength in Mpa (psi)		Average strength (psi)
1T - 21 - Day	10/3/2014	7:00 PM	280	(62925)	4	34.5	(5007)	34.3 (4989)
2T - 21 - Day	10/3/2014	7:05 PM	265	(59484)	4	32.6	(4734)	
3T - 21 - Day	10/3/2014	7:10 PM	292	(65668)	4	36.0	(5226)	
1T - 28 - Day	10/3/2014	7:15 PM	275	(61877)	4	33.9	(4924)	34.4 (4992)
2T - 28 - Day	10/3/2014	7:20 PM	270	(60591)	4	33.2	(4822)	
3T - 28 - Day	10/3/2014	7:25 PM	292	(65733)	2	36.1	(5231)	

Table A-9. Test for normal distribution data

Sorted 28-Day strength original data (Mpa)	CDF	Expected data (Mpa)	Z-Value
33.22	0.04	32.83	-1.73
33.24	0.13	33.56	-1.15
33.72	0.21	33.98	-0.81
33.95	0.29	34.31	-0.55
34.87	0.38	34.59	-0.32
35.14	0.46	34.86	-0.10
35.22	0.54	35.12	0.10
35.24	0.63	35.39	0.32
35.63	0.71	35.68	0.55
36.07	0.79	36.00	0.81
36.65	0.88	36.43	1.15
36.93	0.96	37.15	1.73

For statistical comparison, it is always true that the statistics of both the control and test specimens are statistically significantly different if the confidence intervals do not overlap. However, the opposite is not always true. In other words, it is sometimes erroneous to determine the statistical significance of two statistics based only on confidence intervals that overlap. Although this is not the case in this project, the student t-Test analysis was performed to help determine if the mean values of the compressive strengths of test specimens for each curing time are statistically different from those of control specimens. The F-Test and t-Test results for the compressive strengths of specimens using 100% wastewater effluents, oxone-treated effluents and $KMnO_4$-treated effluents are reported in Table 9 to 11 respectively. Variables 1 and 2 in Table 9 through 11 represent the control data and the test data. The order of variable assignment is irrelevant for the t-Test. For the F-Test, the data with the higher variance has to be assigned to variable 1 because during the calculation of the F statistic, the variance of variable 1 is divided by the variance of variable 2. This also means that the closer the F-statistic value is to 1, the lesser the difference between the two variances. The variances for the strength results between the control and test specimens for all the curing days are not statistically different except for the 3 day and 21 day strength results of specimens using KMnO4-treated effluents and 100% wastewater effluents respectively. These two differences only indicate that the t-Test must be computed with an assumption that the two variances are not the same. The two-tail t-critical value was used for analysis in the t-Test in order to test whether the average compressive strengths of test specimens were significantly greater or less than those of control specimens. In order for the control and test strength results not to be statistically different, the t-stat value has to be less than the t-critical value. The t-Test results between the control and test specimens for all the curing days show that the means for the compressive strength results at 95% confidence level are not statistically different. Therefore the confidence interval and the t-Test analyses have both shown that the compressive strengths of the control specimens and those of test specimens are not statistically different.

Water and Energy Savings

The results from testing concrete specimens in this research show that wastewater effluents can be used to produce concrete with small differences in compressive strength. The wastewater effluents can be a very good source for mixing water in concrete production especially for applications that do not need steel reinforcements such as roadway pavements, parking lots, sidewalks and concrete masonry or slabs. Concrete companies can switch from using potable water to using wastewater effluents for such applications without compromising the strength of finished products. Municipalities can save large quantities of potable water if concrete companies start to use wastewater effluents as part of their mixing water for concrete production. Advanced treatment of wastewater to remove nutrients such as phosphorus and nitrogen require more energy and money to accomplish but these nutrients are not of concern in concrete production; and therefore advanced treatment to remove such chemicals may be unnecessary if effluents are to be used as mixing water.

Table 9. F-test and t-test results for specimens with untreated effluents

F-Test Two-sample for variances

Curing days	3		7		14		21		28	
Variable	1.00	2.000	1.00	2.000	1.000	2.000	1.00	2.000	1.00	2.00
Mean (MPa)	23.20	22.600	27.3 0	29.600	30.900	31.200	33.80	32.600	34.50	35.80
Variance	1.25	0.115	1.12	0.737	0.235	0.200	2.14	0.044	1.28	1.09
F	10.90		1.52		1.170		48.79		1.18	
F Critical one-tail	19.00		19.00		19.000		19.00		19.00	
t-Test: Two-sample assuming equal or unequal variances										
Curing Days	3.00		7.00		14.000		21.00		28.00	
Variable	1.00	2.000	1.00	2.000	1.000	2.000	1.00	2.000	1.00	2.00
Mean (MPa)	23.20	22.600	27.30	29.600	30.900	31.200	33.80	32.600	34.50	35.80
Variance	1.25	0.115	1.12	0.737	0.235	0.200	2.14	0.044	1.28	1.09
t Stat	0.79		-2.92		-0.800		1.37		-1.45	
t Critical two-tail	2.78		2.78		2.780		4.30		2.78	

Table 10. F-Test and t-Test results for specimens with oxone-treated effluents

F-Test Two-sample for variances

Curing days	3		7		14		21		28	
Variable	1.00	2.000	1.00	2.000	1.00	2.000	1.00	2.00	1.00	2.00
Mean (MPa)	23.20	23.700	27.30	28.300	30.90	31.200	33.80	33.40	34.50	34.5
Variance	1.25	0.480	1.12	0.845	1.55	0.200	2.14	1.26	2.15	1.28
F	2.61		1.33		7.75		1.70		1.68	
F Critical one-tail	19.00		19.00		19.00		19.00		19.00	
t-Test: Two-sample assuming equal or unequal variances										
Curing Days	3.00		7.00		14.00		21.00		28.00	
Variable	1.00	2.000	1.00	2.000	1.00	2.000	1.00	2.00	1.00	2.00
Mean (MPa)	23.20	23.700	27.30	28.300	30.90	31.200	33.80	33.40	34.50	
	34.50									
Variance	1.25	0.480	1.12	0.845	1.55	0.200	2.14	1.26	2.15	1.28
t Stat	-0.70		-1.19		0.56		0.31		0.63	
t Critical two-tail	2.78		2.78		2.78		2.78		2.78	

Table 11. F-test and t-test results for specimens with $KMnO_4$-treated effluents

F-Test Two-sample for variances

Curing Days	3		7		14		21		28	
Variable	1.00	2.000	1.00	2.000	1.000	2.000	1.00	2.00	1.00	2.00
Mean (MPa)	23.20	22.5000	27.30	29.500	30.900	31.200	33.80	33.80	34.50	34.50
Variance	1.25	0.011	1.12	0.389	0.312	0.200	2.89	2.14	2.16	1.28
F	117.50		2.88		1.560		1.35		1.68	
F Critical one-tail	19.00		19.00		19.000		19.00		19.00	
t-Test: Two-Sample assuming equal or unequal variances										
Curing Days	3.00		7.00		14.000		21.00		28.00	
Variable	1.00	2.000	1.00	2.000	1.000	2.000	1.00	2.00	1.00	2.00
Mean (MPa)	23.20	22.500	27.30	29.500	30.900	31.200	33.80	33.80	34.50	34.50
Variance	1.25	0.011	1.12	0.389	0.312	0.200	2.89	2.14	2.16	1.28
t Stat	0.96		-3.12		-4.000		0.48		-0.10	
t Critical two-tail	4.3		2.78		2.78		2.78		2.78	

A case study for the city of Greensboro in North Carolina, USA, showed that the city has been experiencing water shortages since the late 1990's. According to the COG (2013), the water system serves about 277,000 people with an average daily water demand of 127 million liters (33.7 million gallons) per day in 2013. Over the past few years, Greensboro has been buying water from the neighboring cities to account for the shortages while one of the city's Wastewater Treatment Plants discharges an average of 98 million liters (26 million gallons) of treated effluents per day. Greensboro has several concrete companies that consume substantial amounts of potable water from the city's water supply. For instance, Chandler Concrete, one of the concrete companies with four production plants, uses an average of 114, 000 liters (30,000 gallons) per day per plant of potable water for concrete production. Assuming a similar consumption for each company in Greensboro, the fresh water demand would be about 4.5 million liters (1.2 million gallons) per day for 10 companies especially in summer when construction activities are at peak. About 10 percent of the treated wastewater effluents discharged by the city on a daily basis is roughly sufficient to provide mixing water for concrete production in Greensboro. If one company in Greensboro can use even just 50% of effluents for their mixing water, the city of Greensboro can save enough water for about 600 people per day based on the current potable water average demand of 379 liters (100 gallons) per person per day and the population in Greensboro of about 277,000 people. Furthermore, if all these companies can start using a percentage of the wastewater effluent from the treatment plants for their concrete needs, the demand on fresh water may be reduced and perhaps the city of Greensboro may become self-sustaining in water resources.

Conclusions and Future Research

Concrete specimens using the untreated wastewater effluents, the effluents treated with oxone and the effluents treated with potassium permanganate were tested for compressive strength and compared to the control specimens that were made using potable water. The strength results of all test specimens were found to be similar to those of control specimens. Statistical analysis of the strength results showed that at 95% confidence interval, the compressive strengths of the control specimens and those of test specimens are not statistically different. Furthermore, most of the average compressive strengths for test specimens at different curing periods were slightly higher than those of control specimens and both the control and test specimens satisfied the required design strength at 28 days of curing.

The test specimens using untreated wastewater were also tested for bacteria mobility after 24 h of curing and it was found that the high concentration of bacteria in the effluents is not a health hazard in finished concrete products. The results in this research show that wastewater effluents can be used as an additional source of water for concrete production. Because most treatment plants discharge millions of gallons of treated wastewater effluents every day, the plants can be described as low-energy sources of unlimited concrete mixing water. The collection, treatment and distribution of portable water and wastewater consume huge amounts of energy every day across the nation and there is a need to change and improve our water usage strategies. The use of effluents as mixing water promotes wastewater recycling and helps get the most of the limited water supplies. This practice will save millions of gallons of potable water that is otherwise used for concrete production nationwide.

The results of the case study show that the city of Greensboro discharges about 98 million liters (26 million gallons) of tertiary treated wastewater effluents every day; and if the mixing water for just one concrete company is 50% wastewater effluent, the city would be saving about 227,000 liters (60,000 gallons) of portable water enough for 600 people per day based on an average demand of 379 liters (100 gallons) per person per day. The use of wastewater effluents for concrete production in Greensboro can help the city become self-sustaining in fresh water supply and save the energy used to import fresh water from the neighboring cities.

The full implementation of wastewater recycling at concrete production plants will require a new distribution system for the wastewater effluents. The recycled wastewater distribution system would make the supply of the effluents to the production plants convenient; and therefore, it is important for future research to investigate the possibility of bacteria regrowth and find ways to eliminate or control the bacteria levels in the distribution system. Although the new distribution system may be initially expensive to implement, the resulting benefits will far outweigh the initial investment cost and in the long run the idea would still be recommended for water and energy saving purposes. Although the chemicals that are not of concern in concrete mixing water such as nitrogen and phosphorus appeared not to have any effects on the strength of the specimens in this research, future research can investigate the interactions of these chemicals at high concentrations with concrete. Most of tertiary treatment of wastewater is aimed at reducing the concentration of such chemicals; and if they do not have any significant effects on concrete at high concentrations, then wastewater treatment plants participating in full recycling may save more energy by not targeting such chemicals for removal.

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Author's Contributions

Benard Chola: Considerable contributions to conception and design, data collection, interpretation, and led drafting of the writing for the article.

Stephanie Luster-Teasley: Considerable contributions to conception and design, assisted with analysis and interpretation of data, critical review of work for significant intellectual content, and final approval of submitted version.

Manoj Jha: Assisted with analysis and interpretation of data, critical review of research for significant intellectual content and clarity of the data, results, and discussion used for this article.

Miguel Picornell: Advisor for concrete experiments and methodology, helped provide guidance for data collection and interpretation, article drafting and review for critical and significant intellectual content.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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