

Sustainable Use of Resources – Recycling of Sewage Treatment Plant Water in Concrete

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ABSTRACT

Concrete is the most widely used construction material in the world. Production of portland cement used in concrete produces over 2.5 billion tons of carbon dioxide and other greenhouse gases worldwide. In addition, concrete is one of the largest water consuming industries. Approximately 150 liters of water is required per cu. m. of concrete mixture, without considering other applications of water at the concrete industry. Water is a critical environmental issue and water supplies and water quality are becoming more limited worldwide. This paper presents an overview of the current state of knowledge about the use of reclaimed water, especially partially processed sewage treatment plant water in concrete. On the basis of identified knowledge, an initial laboratory investigation was conducted. A detailed research agenda has also been developed for additional knowledge on this topic in order to understand and to reduce the environmental impacts of the concrete industry.

INTRODUCTION

Because concrete is the most widely used material worldwide, concrete industries have the environmental and societal responsibility to contribute to sustainable development. The concrete industry is a significant contributor to air pollution and also a consumer of vast quantities of natural materials, including water. For each ton of cement produced, one ton of CO₂ and other greenhouse gases (which contribute to global warming), is released into the atmosphere. Worldwide, the cement industry produced about 1.4 billion tons CO₂ in 1995, which caused the emission of as much CO₂ gas as 300 million automobiles (almost 7% of the CO₂ production worldwide) [Malhotra 2000, Naik 2007].

There is a general appearance that concrete is not environmentally friendly or attuned with sustainable development, due to high volumes of material needed to produce the billions of tons of concrete worldwide each year, CO₂ emissions caused during the production of portland cement, high energy requirements, water consumption, and generation of construction and demolition waste [Meyer 2002, Meyer 2009]. Fortunately, the sustainable development concept was adopted by the American Society of Civil Engineers (ASCE) Code

of Ethics, in which it states that engineers should follow principles of sustainable development in the performance of their professional duties [ASCE, 2006]. This concept was implemented to the Code of Ethics of November 1996 and it states that the sustainable development should meet human needs while conserving and protecting the environment and natural resources necessary for the future.

The need of a sustainably developed and environmental friendly concrete industry is aggravated by population growth and scarcity of water. The world population doubled from 1959 to 1999, increasing from three billion to six billion. According to the United States Census Bureau, the world population is projected to reach nine billion by 2043; or, an increase of 50% relative to 1999 [USCB, 2009]. Thus, it is expected that the water demand will have an increasing trend; leading to water recycling and conservation [Sethuraman, 2006, USCB, 2009] as a necessity.

Shortage of water is perhaps the most critical environmental problem in several countries [Okun, 1994, EPA, 2004]. Freshwater accounts for only 2.5% of the Earth's water, and most of it is frozen in glaciers and ice caps. The remaining unfrozen freshwater is mainly found as groundwater, with only a small fraction present above ground or in the air [UNESCO, WMO, and IAEA, 2006]. Of the approximately 15,000 m³/s (340,000 mgd) of fresh water used in the U.S., only 29% is consumptively used and 71% is return to nature. This amounts to a total of about 10,600 m³/s (240,000 mgd), of which 14% originates from domestic and commercial water use [EPA, 2004]. The average amount available per person varies from less than 50 m³ per year in parts of the Middle East to over 100,000 m³ per year in humid and sparsely populated areas [UNESCO, WMO, and IAEA, 2006]. The concrete industry alone uses over one trillion gallons of water each year worldwide, not including wash water and curing water [Meyer, 2004]. In addition, the use of water for industrial purposes increases in proportion to a country's GDP (gross domestic product). From 10% in the low-income and medium-lower income countries, it increases to 59% in high-income countries [World Bank Group, 2000]. Therefore it is essential to conduct research of substitution of potable water by reclaimed water partially or totally to produce concrete, especially in the U.S.

There is a growing trend of considering water reuse as an essential component of water resources management and sustainable development, not only in dry and water deficient areas, but in water abundant regions as well. Some examples of successful water reuse projects are the use of reclaimed water in place of potable water for use in irrigation, environmental restoration, cleaning, toilet flushing, and industrial uses. It has been shown that the basis for the success of such projects are operational performance, institutional arrangements, conservative cost and sales estimates, and good project communication, avoiding institutional obstacles, inadequate valuation of economic benefits, or a lack of public information [EPA, 2004]. Actually, educational programs are imperative to convince the public and elected officials of the wisdom and safety of reusing reclaimed water [O'Connor et al., 2008]. Fortunately, water reuse is growing steadily not only in water-deficient areas (Mediterranean region, Middle East, and Latin America), but also in highly populated countries in temperate regions (Japan, Australia, Canada, North China, Belgium, England, and Germany).

An encouraging event in history happened during a workshop sponsored by the International Water Management Institute (IWMI, based in Colombo, Sri Lanka) and the International Development Research Centre (IDRC, based in Ottawa, Canada). The workshop was entitled "Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental

Realities" November 2002 in Hyderabad, India. At the workshop, the Hyderabad Declaration on Wastewater Use in Agriculture was adopted by several countries, including the U.S. [IWMI, 2002]. Further research on the use of reclaimed wastewater in concrete industry is needed and perhaps in the near future there will be a Declaration of Wastewater Use in Concrete.

The two objectives of this research are to: (1) show the current state of knowledge of the use of reclaimed wastewater (especially sewage treatment plant water) in the concrete industry; and, (2) present preliminary laboratory experiments, as well as the future research to be performed to investigate the performance of water from different stages of a sewage treatment plant in concrete production.

OVERVIEW OF CURRENT STATE OF KNOWLEDGE ABOUT THE USE OF RECLAIMED WATER (ESPECIALLY SEWAGE TREATMENT PLANT WATER) IN CONCRETE

Description of a typical sewage treatment system

A typical sewage treatment system consists of primary treatment, secondary treatment, and disinfection. In the first stage of treatment, raw wastewater pass through screens and grates, where sand, gravel, and larger objects are removed. In the second stage of treatment, microorganisms degrade the majority of organic material that remains in wastewater. Finally, the water goes through disinfection, where chemicals kill pathogens. Such chemicals are removed just before water is discharged in a water-body [MMSD, 2009].

Use of reclaimed water in concrete

Several researches around the world have studied the use of reclaimed water in concrete, with various levels of success. The re-use of recycled water from the recycling of unset/discarded concrete as mixing water for concrete is common practice in almost all ready-mixed concrete plants in Germany. The disposal of such wastewater is no longer being environmentally accepted. The recycled water consists primarily of the mixture of water, cement, and fines that remain after removal of the aggregate, but it also includes the wash water used for washing and cleaning the returning mixer trucks, concrete pumps, and other equipment, as well as the precipitation water collected on the production areas [Rickert and Grube, 2000, Rickert and Grube, 2003]. Overall, it was found that concretes made with recycled water are durable and exhibit the similar properties as concretes made with drinking water or fresh water [Chini and Mbwambo, 1996, Rickert and Grube, 2003].

The feasibility of using reclaimed wastewater in concrete mixtures has also been studied in Indonesia. The reclaimed wastewater is lower in quality than potable water. Researchers have shown that concrete with improved initial compressive strength could be made with reclaimed wastewater used partially or totally in lieu of the mixing water [Tay and Yip, 1987].

The use of potable and treated waters was also tested in Saudi Arabia, and setting time and compressive strength were evaluated for the concrete. Pore solutions extracted from the mortar specimens were analyzed for alkalinity and chloride content. Results showed that the treated water tested in this study qualifies to be used in making concrete [Saricimen, 2008].

The suitability of using treated wastewater for mixing concrete was evaluated in Kuwait. Concrete cube specimens were cast using tap water, preliminary treated wastewater, secondary treated wastewater, and tertiary treated wastewater obtained from the local wastewater treatment plant. It was found that the type of water used for mixing did not affect concrete slump and density. However, setting times were found to increase with deteriorating water quality. In addition, Concrete made with water from the primary and secondary treatment showed lower strengths for ages up to the age of one year and the possibility of steel corrosion increased too. Overall, tertiary treated wastewater was found to be suitable for mixing concrete without adverse effects [Al-Ghusain and Terro, 2003]. Cebeci and Saatci (1989) also reported that treated wastewater was not shown to have an adverse effect on concrete. On the other hand, raw sewage reduced the 3- and 28-day compressive strength by 9%. The results (setting time, and mortar and concrete strength tests) showed that biologically treated average domestic sewage is similar from distilled water when used as mixing water. Abrams (1924) examined the effect on concrete strength of waters carrying sanitary sewage and waters carrying industrial wastes. His study showed that only lime soak from tannery, refuse from paint factory, and acids waters were considered unsatisfactory. In Malaysia, researchers carried out two tests to determine the feasibility of using treated effluent for concrete mixing (Lee et al, 2001). Their results showed that treated effluent increases the compressive strength and setting time when compared with potable water and that treated effluent could be used as mixing water in concrete.

EPA has presented suggested guidelines for water reuse. Three configuration alternatives for water reuse systems are presented. One of the sources is the effluent generated by domestic wastewater treatment facilities (WWTfs). The configurations are: (a) Central Treatment Near Reuse site(s); (b) the reclamation of portion of wastewater flow; and, (3) reclamation of a portion of the effluent. Treated municipal wastewater represents a significant potential source of reclaimed water for beneficial reuse, for a myriad of purposes, including the concrete industry. As a result of the Federal Water Pollution Control Act Amendments of 1972, the Clean Water Act of 1977, and its subsequent amendments, centralized wastewater treatment has become commonplace in urban areas of the U.S. Within the U.S., the population generates an estimated about 1.8 million m³/s (41 trillion gpd) of potential reclaimed water [Solley et al., 1998]. Of course, reclaimed wastewater might need further treatment in order to guarantee the safety of the users, since raw sewage contains viruses and pathogenic bacteria. Important factors to be considered during this first stage of reuse planning are the: level of treatment (effluent quality), effluent quantity, industrial wastewater contribution to flow (level of inorganic material), system reliability, and the possible need of supplemental facilities (e.g., storage, pumping, and transmission).

Health Assessment of Water Reuse

There are certain aspects that should be taken into consideration for water reuse: (a) expected degree of human contact with the reclaimed water; (b) what concentration of microbiological and chemicals of concern are expected; (c) which treatment processes is necessary to achieve the required reclaimed water quality; and, (d) what are the sampling/monitoring protocols to assure water quality needed. In terms of diseases caused by waterborne organisms, the main transmission route is fecal-oral. A large variety of pathogenic microorganisms that may be present in raw domestic wastewater is derived principally from the feces of infected humans and primarily transmitted by consumption [EPA, 2004]. The main concern in terms of chemicals, are the adverse health effect due to long-term exposure to relatively low concentrations, usually released by industries. While all pollutants can become toxic at high enough levels, there are a number of compounds that are toxic even at relatively low levels

[EPA, 2003]. EPA has identified 126 analytes as “priority pollutants” of particular concern for aquatic systems [EPA, 2003], and extreme cases such as chemicals capable of mimicking hormones have been shown to disrupt the endocrine systems of aquatic animals [EPA, 2004]. The states of Arizona, California, Florida, Hawaii, Nevada, Texas, and Washington have their own regulations for water reuse in several industrial sectors [EPA, 2004]. For making concrete, the suggested wastewater treatment unit processes are secondary treatment and disinfection, BOD₅ (≤ 30mg/l), TSS (≤30mg/l), fecal coliforms (≤200 CFU/100ml), and Cl₂ residual (1mg/l Cl₂ residual (minimum). In addition, worker contact with reclaimed water should be minimized and a higher level of disinfection should be achieved (<14 CFU/ 100 ml fecal coliforms) when frequent work contact with reclaimed water is expected. However, coliforms are neither adequate indicator organisms for many bacterial pathogens nor for parasites and viruses.

Australia has also its own EPA guidelines [Cement Concrete and Aggregates Australia, 2007] for use of water and recycled water for the production of new concrete. The most common performance criteria for mixing water are in terms of relative strength and setting time, whereas prescriptive limits are usually given in terms of chloride, sulfates, and suspended solid contents. In many states in Australia, reclaimed water is classified for a range of usage. Class A is for open system with worker exposure potential, Class B is closed industrial system with no potential worker exposure, Class C (Closed industrial system with no potential worker exposure), and Class D (Agriculture –non-food crops). *Escherichia coli* (*E. coli*) is monitored as a pathogen indicator, which is a more appropriate sewage indicator. The EPA of Australia water recycling guidelines regulates *E. coli* per class: A (<10), B (<100), C (<1,000 and D (<10,000) (CFU/100ml).

METHODS AND MATERIALS

Characterization of sewage treatment plant water used in the laboratory experiments

Samples of wastewater were collected from the Milwaukee Metropolitan Sewerage District (MMSD) and analyzed. Characteristics of reclaimed wastewater are shown in Table 1.

Table 1. Characteristics of Reclaimed Wastewater from MMSD (provided by United Water)

	Total Suspended Solids TSS, mg/l	BOD ₅ mg/l	Ammonia NH ₄ -N, mg/l	Phosphorous P, mg/l	Fecal Coliform MPN/100 ml	pH
Influent primary at Influent Plant	231	257	11.5	3.85		
Primary effluent	86	183				
Aeration effluent	2400					
Secondary effluent					50000*	
Plant effluent (after disinfection)	6	5	0.2	0.3	40	

The value above is the average of the daily monitoring data for the year of 2006

* Average based on modeling

Preparing cement mortar cubes

A total of three batches were prepared with potable water and one with recycled water were prepared during October and November 2007. Cement mortars test specimens were cast in 50-mm (2-inch) cube molds to study the effect of sewage treatment plant water on mortar strength. Mortar cubes were prepared according to ASTM C109. The proportions of materials for the standard mortar mixture were one part of portland cement to 2.75 parts of graded standard sand by weight. The water-cement ratio was 0.485. Either potable water or water effluent from the secondary treatment was used in these laboratory experiments, without blending of these two types of water. A thin coating of mold release was applied to the interior surfaces of the molds and base plates, wiping excess. Mortar was mixed according to ASTM C305. A dry-paddle and a dry-bowl were placed in the mixing position of the mixer. Water was placed in the bowl, followed by the cement, and then mixer was started at low speed for 30 seconds. Sand was added slowly over another 30-second period, while continued mixing at slow speed. Mixer was stopped and changed to medium speed for an additional 30 seconds. Mixer was stopped and mortar was allowed to stand/rest for 1.5 minutes. Within the next 15 seconds, the bowl was quickly scraped down for additional mixing; then, it was covered with the lid for the remainder of the interval, and finished mixing for one minute at medium speed.

Flow of the mortar was then determined as follow: the flow-table top was wiped clean and dry, and the flow-mold was placed at the center. A layer of mortar (approximately 25 mm –1 inch thick) was placed in the mold and tamped 20 times. Then, the mold was filled with a second layer and tamped 20 times. Mortar was cut off to a plane surface, flush with the top of the mold, by drawing the straight edge of a trowel (held nearly perpendicular to the mold) with a sawing motion across the top of the mold. Carefully the flow-table top was wiped clean and dry, being especially careful to remove any water from around the edge of the flow mold. Table was dropped through 13 mm (½ inch) height 25 times in 15 seconds. Diameter was measured with a ruler along the four scribed lines on the table. The average of the sum of the four readings divided by the diameter of the mold (10 cm) was recorded as the flow. Following the flow test, all mortar was returned to the mixing bowl. Sides of the bowl were scraped down and remixed for 15 seconds at medium speed. Specimens were molded within two minutes and 30 seconds after completion of the original mixing of the mortar. A layer of the mortar (approximately 25 mm (one inch) was placed in all the cube compartments. Mortar was tamped in each cube compartment 32 times in about 10 seconds in four rounds, each round to be at right angles to each other and consisting of eight adjoining strokes over the surface of the specimen. Compartments were filled with the remaining mortar and tamped again as indicted above for the first layer. During tamping of the second layer, mortar forced out onto the tops of the molds were brought in after each round of tamping using gloved finger and the tamper.

The mortar in the tops of all the cubes extended slightly above the top of the mold. Mortar of each cube was troweled laterally and longitudinally. Mortar was cut off to a plane surface with the top of the mold by drawing the straight edge of the trowel, held perpendicular to the mold, with a sawing motion over the length of the mold. Molded specimens were placed in chamber with water for 24 hours. After 24 hours, specimens were removed from the molds and immersed in a saturated lime water curing tank. Specimens were tested for compressive strength starting at the age of 1 day to up to 91 days.

Determination of compressive strength

The compressive strength development was measured after 1, 7, 14, 28, 56, and 91 days of casting. The specimens were tested in triplicate using the Tinius Olsen Testing Machine. The specimen was removed from the curing tank. Surface was wiped. Straightness of the faces was observed. Specimen was placed below the center of the upper bearing block of the testing machine. Total maximum load was recorded and compressive strength of the specimen was calculated. Average of triplicate of all specimens is reported in Fig. 1.

RESULTS

Two main parameters were evaluated when comparing the mortar cubes made of potable water and sewage treatment plant water (post-secondary treatment): flow and compressive strength. The average flow for mortar cubes made of potable water and reclaimed water was 98.1% and 89.5%, respectively. Although there was reduced flowability/workability of the mortar with reclaimed water, negative impact of the use of reclaimed wastewater on the mortar cubes was not noticeable. Regarding the compressive strength, mortar cubes with sewage treatment plant water has shown improvement in strength during 3 to 28 days, according to Fig. 1. These results suggest that the organic content present in the sewage treatment plant water may be acting as a dispersing agent, improving the dispersion of particles of cement and reducing clumping.

Although more experiments are being considered to be performed to assure the laboratory results obtained, they are in agreement with similar research findings reported [Abrams 1924, Tay and Yip, 1987, Cebeci and Saatci, 1989, Chini and Mbwambo, 1996, Rickert and Grube, 2000, Lee et al, 2001, Rickert and Grube, 2003, Al-Ghusain and Terro, 2003, and Saricimen, 2008].

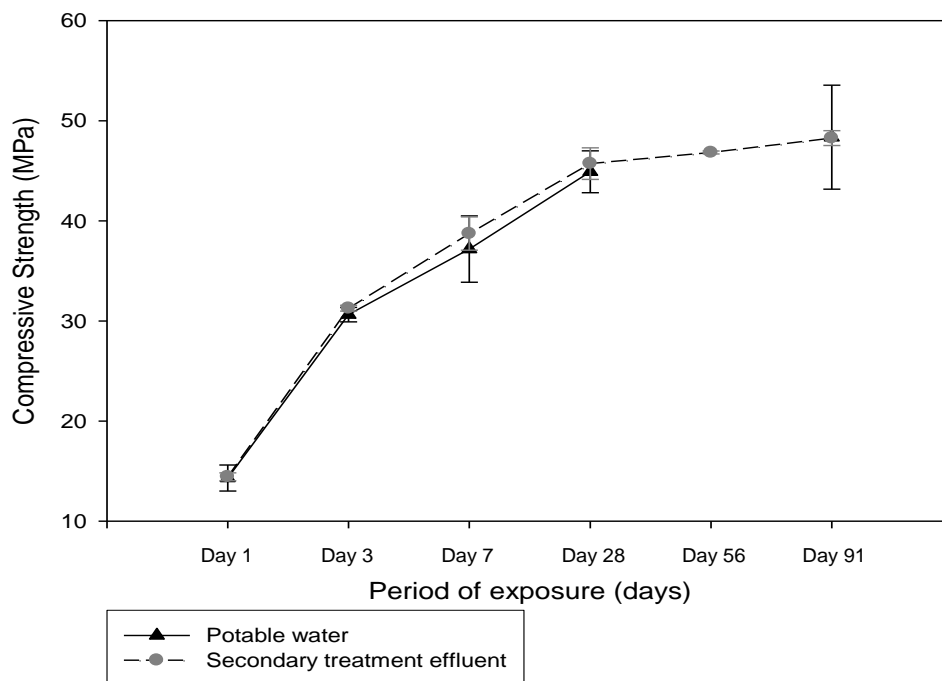


Fig. 1. Comparison of Compressive Strengths of Mortar Cubes Made with Potable Water and Wastewater.

Future work

Future work to be performed will include intensive laboratory experiments, preparing mortar cubes with sewage treatment plant water from different stages of the treatment process and different percentage in the formulation of mortar mixtures. The water samples to be tested will be: (a) influent of the primary treatment; (b) effluent of the primary treatment; (c) effluent of the aeration process; (d) effluent of the secondary treatment; and, (e) effluent after disinfection (Table 1). The plan is to test reclaimed water samples in different blending with potable water: 10%, 25%, 50%, 75%, and 100% sewage treatment plant water. By the end of these experiments, it is planned to develop classes for use of reclaimed water, according to different applications and human exposure.

CONCLUSIONS

These preliminary research findings suggested that significant differences do not exist between mortar cubes made of potable water versus sewage treatment plant water. Further research is needed because there is a strong need to manufacture concrete in a more sustainable manner. Some of the possible outcomes and contributions of this research are: to minimize the need for the use of potable water; eliminate the need to expand potable water supply for use in the concrete industry; minimize the need to construct more water treatment facilities due to population growth; save potable water for drinking purposes; make sewage treatment plants become more economically attractive by reusing water before its final treatment; and, other similar goals towards sustainable developments.

Other researchers around the world have been investigating the use of reclaimed water in concrete. However, not many have studied the use of sewage treatment plant effluent water in concrete. This research topic is also a challenge in terms of public health, when human contact with sewage treatment water is considered. Public education and close interaction with government agencies and police makers is a key when presenting the applicability of sewage treatment water in concrete, especially when human handling and exposure is a possibility.

ACKNOWLEDGMENTS

The authors thank Rudolph N. Kraus and Yoon-moon Chun. We also thank Sidharta Arora of the United Water for providing samples from different stages of the treatment process and technical information about the samples. We thank Aderiano da Silva for his insight about this issue of recycling water for concrete production.

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