

Use of Production and Brackish Water in Concrete Mixtures

Ramzi A. Taha*, Ali S. Al-Harthy, Khalifa S. Al-Jabri

Department of Civil and Architectural Engineering, Sultan Qaboos University, Oman

Abstract

The Sultanate of Oman lies in an arid region where fresh water sources are scarce. Economic and population growth spur the need for more housing, schools, roads, and many other civil works. In the construction of such projects, water is needed as a component in concrete mixing. Contractors in arid regions are sometimes faced with the problem of finding water of acceptable quality for their construction work. However, plenty of production water (oily and brackish water) is produced in the oil fields during oil production. In 2002, Petroleum Development Oman (PDO) produced an estimated 130,000 m³/day of crude oil with a corresponding 630,000 m³/day of production water, most of which are disposed off via deep well injection. This research project was initiated as a possible option for the use of production water as part of PDO's policy on sustainable development, materials efficiency, and waste reduction.

The main objective of this paper is to present the results obtained on the use of production (oily) and brackish water in concrete mixtures. Water samples were obtained from four PDO asset areas. Nine water samples, including a controlled potable (tap) water, were analyzed for pH, total dissolved solids (TDS), chloride, hardness, alkalinity, and sulfates. In addition, cement pastes and mortars and plain concrete mixtures were prepared using 100% substitution of potable water. Nine mixtures were prepared and cured for up to one and a half years. Mixtures were tested for initial setting times, compressive strength and flexural strength.

Research results indicate that there was a small decrease in the initial setting times for all cement paste mixtures prepared using production and brackish water in comparison with potable water. However, such values still exceeded the minimum 45 minutes initial setting requirement as set forth in ASTM C150. The use of PDO's production and brackish water did not cause any decrease in the compressive or flexural strength measurements of cement mortars or concrete mixtures in comparison with potable water. In general, there was no strength reversal with longer curing periods. However, for most concrete mixtures the strength tends to level off after three months of curing. Most production water mixtures resulted in higher strength measurements than those prepared using potable water. Further testing is necessary to investigate corrosion potential in reinforced concrete..

Keywords: *Brackish Water, Production Water, Polluted Water, Concrete, Mortar, Paste, Strength.*

1. Introduction

The Sultanate of Oman lies in an arid region where fresh water sources are scarce. Economic and population growth spur the need for more housing, schools, roads and many other civil works. In the construction of such projects, water is needed as a component in concrete mixtures. It is primarily needed for the hydration process of cementitious materials and for curing. Water is also needed for road construction projects, where it is used as mixing water for compaction and for dust control. Contractors in arid regions, and especially in remote areas of

the desert, are sometimes faced with the problem of finding water of acceptable quality for their construction work. However, plenty of water is produced in the oil fields during oil exploration. Water produced with oil forms the largest waste in the entire oil production business. An oil field is expected to produce more than ten times the amount of water as that of oil during its economic life [1]. In a recent year, about 630,000 m³/day of water is produced along with an oil production of 130,000 m³/day in Oman [2]. This wastewater is injected back underground for reservoir pressure maintenance and/or disposed off into shallow and deep reservoirs. It is essential to investigate the feasibility of using this water in construction.

* Corresponding author. Tel.: +96824141345

Fax: +96824413416 E-mail: rtaha@squ.edu.om

© 2010 International Association for Sharing Knowledge and Sustainability

DOI:10.5383/swes.01.02.001

Water quality has been a matter of concern in civil engineering construction [3], [4]. Most specifications require the use of potable water because its chemical composition is known and well regulated. In some situations where potable water is not readily available, many water types which are unacceptable for drinking may be satisfactorily used in concrete, road construction and other applications [5]. The performance requirements in British Standards [6] and AASHTO T26-79 [7] are the time of setting and the compressive strength. A note in the British Standard [6] requires that the compressive strength of concrete cubes made of untried water not to be less than 90% of cubes made with tap water. The note also states that water that results in a strength reduction of up to 20% can be acceptable, but the mixture proportions should be adjusted as appropriate. The physical and chemical requirements in the Standards refer to dissolved salts and solids in suspension. AASHTO T26-79 [7] prescribes test methods for the pH value in water as well as testing for chloride, sulfate, organic and inorganic contents.

The literature search indicated that various sources of non-fresh water including sea and alkali waters, mine and mineral waters, waters containing sewage and industrial wastes, wastewater produced from ready-mixed concrete plants, and solutions of common salt were previously tested for use in concrete mixtures [8]-[11]. It is difficult to draw a common conclusion regarding the use of these waters in concrete mixtures since impurities that exist in each water type are different. However, the general consensus is that there is a reduction in the ultimate strength of concrete when impure water is used. But with proper mix design (such as use of more cement and use of cementitious materials and admixtures) and by using some acceptable tolerance limits, it is possible to use impure water in concrete mixing and curing. Risk of steel corrosion in reinforced concrete is also a major concern.

2. Objective

The main objective of this paper is to present the results obtained on the use of brackish and production water in concrete mixtures. The following were specific tasks:

1. Perform chemical characterization of the water types used.
2. Determine initial setting times for various cement paste mixtures.
3. Determine compressive and flexural strengths of cement mortars and concrete mixtures

3. Materials

3.1. Coarse Aggregate

Crushed stone aggregate (10 and 20 mm maximum size) was purchased from a nearby crusher in Al-Khouth area, which is

from the same batch used in making normal concrete mixtures. Aggregate properties met specifications requirements used in Oman. Percent passing 2.36 mm sieve size was zero percent.

3.2. Sand

The fine sand was crushed gravel obtained from the same nearby crusher in Al-Khouth area. The gradation test conducted on the sand showed that it met specifications requirements. Percent passing 0.15 mm sieve size was nine percent.

3.3. Cement

The cement used in this project was ordinary Portland cement (OPC) purchased from Oman Cement Company. This cement is the most widely used one in the construction industry in Oman.

3.4. Mixing Water

Water samples were obtained from four major oil fields in Oman (Rima, Bahja, Nimr, and Marmul). These samples represent both groundwater (brackish) and production (oily) water. A total of nine water samples (including tap water) were collected in 2001 and analyzed for certain impurities that could affect concrete or slurry mixes. Measurements included: total alkalinity (as CaCO_3), sulfate content (as SO_4), chloride content (as NaCl), total dissolved solids and water hardness. Other parameters such as pH and conductivity were also measured. Table 1 presents the chemical analyses obtained on all samples. The analysis was conducted in the laboratories of the Ministry of Housing, Electricity, and Water in Oman. For the groundwater samples, the Marmul water is the closest in terms of its quality to tap water. However, the Bahja production water seems to have the highest salinity. Groundwater samples obtained from other sites were generally salty. There were differences in groundwater quality among the four Petroleum Development of Oman (PDO) sites. Similarly, the quality of production water was variable from one site to another. The results (Table 1) also show that the quality of groundwater and production water obtained from the same site was different. These results are expected since these water types come from different depths.

4. Mix Design

4.1. Cement Pastes

Cement paste samples were prepared using ordinary Portland cement and water. The quantities of cement and water used in each sample were 400 g and 133.5 ml, respectively. A water-to-cement ratio of 0.33 was used in all mixtures. For each mix a different water type was used, however, material quantities were fixed. Thus, a total of nine mixes were tested.

Table 1. Chemical analysis results of water samples

Water Type	Designation	Parameter Concentration					
		pH	TDS (mg/L)	Chloride (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)	Sulphate (mg/L)
Tap Water	TW	8.6	278	75	94	58	278
Bahja Groundwater	BG	6.7	8770	5100	670	55	7.5
Bahja Production Water	BP	7.4	66300	44500	13000	59	281
Rima Groundwater	RG	7.9	10960	5420	1730	134	826
Rima Production Water	RP	8.0	11540	5850	880	240	323
Marmul Groundwater	MG	8.0	1360	331	558	100	281
Marmul Production Water	MP	7.3	4900	2040	166	606	233
Nimr Groundwater	NG	7.6	7080	3080	1680	209	982
Nimr Production Water	NP	7.3	423	4000	490	399	330

4.2. Cement Mortar Cubes

Cement mortar cubes were prepared with all nine water types using water and standard sand at a water-to-cement (w/c) ratio of 0.4. The sand particles passed 850 microns and retained on 600 microns. Materials proportioning for each cement mortar cube were 185 g of ordinary Portland cement, 555 g of sand, and 74 g of water (Omani Standards, OS 26/1981). Nine different mixes were prepared using 70x70x70 mm cubes. Samples were compacted using a tamping rod. Cement mortars were placed in three equal layers and each layer was compacted using 25 blows per layer. Twenty-one samples were prepared for each mix. Three cubes each were tested for compressive strength after 7 days, 28 days, 3 months, 6 months, 9 months, 1 year, and 1 ½ year of curing. In total, 189 mortar cubes were prepared. All cubes were kept in the molds for 24 hours at room temperature. Then, they were removed from the molds and continuously cured in a water tank for an additional 27 days (exception are those specimens that were tested after 7 days). After 27 days, all samples were removed from the water tank and cured at room temperature. The unconfined compressive strength was determined using an automatic compression machine with a controlled loading rate of 4.86 kN/sec. Minimum compressive strength requirements for cement mortar cubes are 15 and 23 MPa after 3 and 7 days of curing, respectively (British Standards, B.S. 12:1958).

4.3. Concrete

Concrete mixtures were prepared using all nine water type. Batch quantities per 1 m³ of concrete were: water = 213 kg, cement = 420 kg, fine aggregate = 705 kg, 10 mm coarse aggregate = 335 kg, and 20 mm coarse aggregate = 780 kg. 100% potable water was replaced with non-fresh water. The target 28-days compressive strength was 30 MPa. Nine different mixes were prepared at a water-to-cement (w/c) ratio of 0.50 using 150x150x150 mm cubes. Eighteen samples were prepared for each mix and three each were tested for compressive strength after 28 days, 3 months, 6 months, 9 months, 1 year, and 1 ½ year of curing. Also, concrete prisms (100x100x500 mm) were prepared for flexural strength testing. Six prisms were prepared for each mix and three each were

tested after 28 days and 3 months. In total, 162 cubes and 54 prisms were cast. All cubes and prisms were kept in the molds for 24 hours at room temperature. Then, they were removed from the molds and continuously cured in a water tank for an additional 27 days. After 27 days, all samples were removed from the water tank and cured at room temperature. The unconfined compressive strength of the cubes was determined using an automatic compression machine with a controlled loading rate of 5.625 kN/sec. Prisms were tested at a loading rate of 0.2 kN/sec.

5. Test Results and Discussion Design

5.1. Cement Pastes

Fig. 1 shows the initial setting times determined for various cement paste mixes. The data indicate that there was a slight decrease in the initial setting times when tap water was replaced by non-fresh water. However, such values still exceeded the minimum forty-five minutes initial setting requirement (Vicat test) as set forth in cement specifications (ASTM C150).

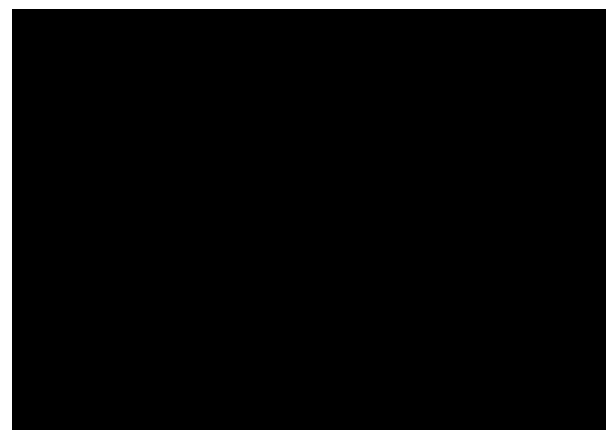


Fig. 1. Initial setting time results

5.2. Cement Mortar Cubes

Table 2 presents the unit weight values obtained for cement mortar samples prepared using all water types. Generally, there are no appreciable differences in unit weight among the various samples. Figs. 2 and 3 show the compressive strength results obtained on cement mortar cubes prepared using brackish and production water, respectively. Main observations that can be derived include:

(a) All water types met the 7-days compressive strength requirement of 23 MPa for cement mortars.

- (b) Samples prepared using the non-fresh water sources produced better compressive strength results than the control mixture (tap water only).
- (c) For all mixtures, compressive strength generally increased with longer curing periods (up to 18 months). There was no strength reversal with longer curing times.
- (d) It was more difficult to draw any conclusions regarding differences in strength measurements obtained using production and groundwater types.

Table 2. Chemical analysis results of water samples

Water Type	TW	BG	RG	MG	NG	BP	RP	MP	NP
Unit Weight (g/cm ³)	2.33	2.30	2.37	2.35	2.31	2.39	2.33	2.37	NA ^a

NA: Data Not Available

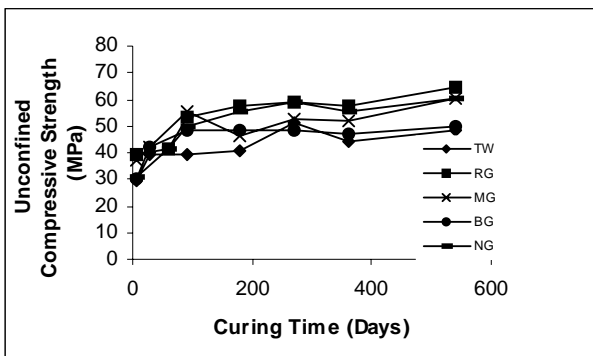


Fig. 2. Unconfined compressive strength of cement mortar cubes prepared using brackish water

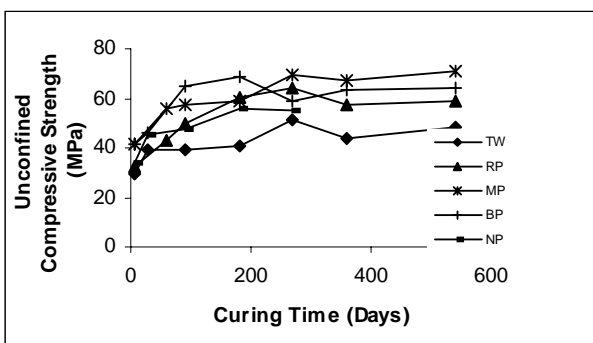


Fig. 3. Unconfined compressive strength of cement mortar cubes prepared using production water

5.3. Concrete

5.3.1. Fresh Concrete Properties

Tests conducted on fresh concrete include unit weight, slump, and Vebe test (a measure of workability). Results are presented in Table 3. Slump generally decreased when groundwater or production water was substituted for tap water. Exceptions are Marmul and Rima production waters where

there was an increase in slump. There was a slight increase in unit weight values when non-fresh water types were used. Time data produced from the Vebe tests for non-fresh waters were all higher than tap water. An abnormal behavior was obtained for concrete mixtures prepared using Bahja production water. Although the mixture was repeated twice, a zero slump was obtained in both mixes. Unit weight was also considerably higher than other mixtures.

Table 3. Fresh Concrete Properties

Water Type	Slump (mm)	Vebe Test (sec)	Unit Weight (kg/m ³)
TW	50	28	2,264
NG	40	42	2,295
NP	45	36.6	2,353
MG	25	31.5	2,256
MP	65	33.1	2,307
RG	40	35	2,373
RP	60	59.8	2,307
BP	0	NA ^a	3,390

^aNA: Data Not Available

5.3.2. Compressive Strength

The compressive strength results obtained on concrete mixtures prepared using groundwater and production water are depicted in Figs. 4 and 5, respectively. Main observations obtained from the compressive strength data are as follows:

- All mixtures met or exceeded the required 28-days design compressive strength of 30 MPa.
- All non-fresh water types produced equal or better 28-days compressive strength than the control mixture (tap water only). Exception is the concrete mix prepared using Rima groundwater.
- Compressive strength increased with longer curing periods for all mixtures.
- The highest compressive strength was obtained in the concrete mix prepared using Bahja production water (zero slump).

5.3.3. Flexural Strength

Table 4 presents the 28- and 90-days flexural strength data obtained on various concrete mixtures. Main observations obtained from the flexural strength data are as follows:

- All non-fresh water types produced equal or better 28-days flexural strength than the control mixture (tap water only).
- Flexural strength generally increased with longer curing periods. However, concrete mixtures prepared using Nimr groundwater, Marmul groundwater, and Marmul production water types experienced a slight decrease in flexural strength values.
- The highest 28-days flexural strength was obtained in the concrete mix prepared using Nimr groundwater.

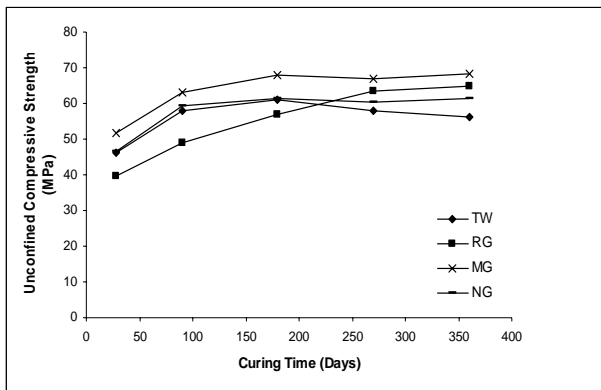


Fig. 4. Compressive strength of concrete cubes prepared using brackish water

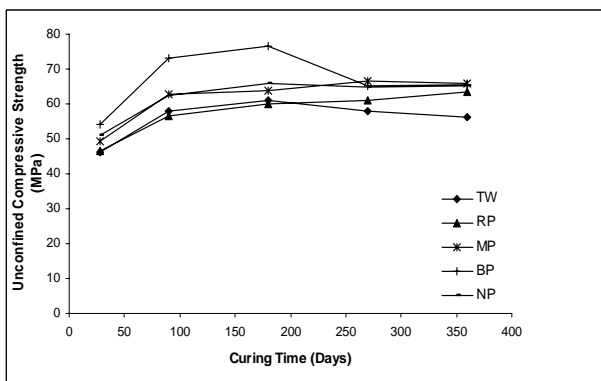


Fig. 5. Compressive strength of concrete cubes prepared using production water

6. Conclusions

This research project was initiated as a possible option for the use of brackish and production water as part of PDO's policy on sustainable development, materials efficiency, and waste reduction. In addition to potable water (control), eight water samples representing both brackish and production water were collected from the Rima, Marmul, Nimr, and Bahja areas in 2001. They were evaluated for use in cement pastes, cement mortars and concrete mixtures. Early results that brackish and production water types could find uses in cement mortars and concrete. However, further testing is necessary to investigate the durability (corrosion) of concrete when such water is used in the mix.

Acknowledgments

The authors would like to express their gratitude to Petroleum development Oman (PDO) for providing the financial support to the project under contract CR/ENG/CIVIL/00/06. Thanks are particularly due to Mr. Tan Ging Tuang, former Head, Corporate Environmental Affairs, for his continuous support and encouragement. Thanks to all our students and engineering technicians for their hard work.

References

- Stephenson M. Components of produced water: a compilation of results from several industry studies. *Journal of Petroleum Technology* 1992;44(5).
- Petroleum Development Oman. Summary of current status of produced water management 1998.
- Neville A. Water, Cinderella ingredient of concrete. *Concrete International* 2000;22(9):66-71.
- Neville A. Seawater in the mixture. *Concrete International* 2001;23(1):48-51.
- Kosmatka SH, Panarese WC. Mixing water for concrete: design and control of concrete mixtures. 6th Canadian Edition, Portland Cement Association 1995:32-35.
- British Standard BS 3148-1980. Method for test for water for making concrete. British Standard Institution 1980.
- AASHTO T 26-79. Standard method of test for quality of water to be used in concrete. AASHTO 1979.
- Abrams DA. Tests of impure waters for mixing concrete, *Proceedings of the American Concrete Institute* 1924;20:442-486.
- Cebei OZ, Saatci, AM. Domestic sewage as mixing water in concrete. *ACI Materials Journal* 1989;86(5):503-506.
- Chini AR, Muszyasti LC, Ellis PS. Recycling process water in ready-mixed concrete operations. Final Report submitted to the Florida Department of Transportation, University of Florida, Gainesville, Florida, February 1999.
- El-Nawawy OA, Ahmed S. Use of treated effluent in concrete mixing in an arid climate. *Cement and Concrete Composites* 1991; 13(2): 137-141.