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Quantitative and qualitative characteristics of condensate water of home air-conditioning system in Iran

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ABSTRACT

The global atmosphere is a huge and renewable water resource which contains about 14,000 km^3 of water vapor. The aim of this study was to investigate the water produced by the air conditioners installed in Bandar-e-Abbas (BA) and its chemical and microbiological quality of this water. Moreover, it was also important to specify the best use of the water. In a nine-month period, 66 samples were taken in four clusters of BA, based on distance to shore and population and vehicle traffic. Quantity was measured by volumetric method; turbidity, alkalinity (ALK), total hardness, dissolved solids (TDS), and electrical conductivity (EC) were tested in laboratory; and counting of bacteria and fungi was done. SPSS 19.0 for Windows was used for data analysis. Mean of produced water was 21.3–47.6 L/d;, and mean for pH, turbidity, EC, TDS, ALK, and total hardness was 6.75–6.89, 2.33–2.55 NTU, 37.8–45.6 μS/cm, 28.8–33.3 mg/L, 34.3–38.2 mg/L as $CaCO_3$, and 18.2–21.6 mg/L as $CaCO_3$, respectively. *Legionella pneumophila* is present in 22% of samples and *Staphylococcus aureus*, *Micrococcus* sp., *Corynebacterium diphtheria*, *Bacillus* sp., and *Pseudomonas* were 21, 13, 18, 13, and 13%, respectively. Observed fungi in the tested samples were 23, 18, 16, 15, 14, and 14% for *Penicillium*, *Aspergillus*, *Cladosporium*, *Alternaria*, *Mucor*, and *Trichoderma*, respectively. The water quality is suitable to many municipal uses and due to the significant volume, the planning of utilizing this significant amount of free water would be economically justified.

Keywords: Condensate water; Air conditioner; Water extraction; Microbial quality; Chemical quality

1. Introduction

Every cubic meter of the atmosphere contains water vapor molecules. Water vapor density is at its highest rate in close to sources of earth. By volume, water vapor is 4% of the atmospheric gas mixture, and by mass, it is 3% of the air [1]. The global atmosphere is a huge and renewable water resource, which contains about 14,000 km^3 of water vapor [2]. There are many regions in the world that have high

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potential for condensate collection [3]. Generally, three major principles are used for extraction of water from atmosphere; including condensation method, absorption–regeneration method, and adsorption–desorption method [4]. Water production by condensation requires multiple energy conversion processes when cooling is applied, and a large volume of air to be cooled that results in significant energy losses. The main disadvantage of absorption–regeneration method is that it needs electric energy. Adsorption–desorption method is based on adsorption of water vapor from atmospheric air during the night using solid adsorbent and recovery of the extracted water by heating the adsorbent and condensing the water desorbed. The advantages of the adsorption–desorption method include the following: no electricity required, simpler structure, and cost-effectiveness [2]. The rapidly growing population will likely further compound water supply issues in many regions of the Middle East; in addition, industrial growth is also high; therefore, in most of these countries, the use of available water resources is greater than the rechargeable level. Alternative sources like desalination are thus used to meet the growing demand for water [5,6]. Many types of desalination methods need high level of energy and so involving these methods may be very expensive [7]. However low-cost clean water from the huge number of air-conditioning systems could be a useful solution to increase the total water supply.

Air-conditioning systems have been used in many parts of the world to provide thermal comfort and an acceptable indoor air quality [8].

In coastal areas of Iran, atmospheric humidity is high, so in summer humidity even reaches 100%. As mentioned earlier, such climates have good potential for growth of bacteria and fungi molds in the air. In southern Iran, especially in coastal cities such as Bandar-e-Abbas (BA), due to warm and humid climate in a long period of years, air conditioner is used as cooling systems. Air conditioners which are used in BA have two models: window and split. Window air conditioners often located in a tray behind a window and there is an outlet for discharging the condensed water in the end of tray. In split conditioners also, there is a pipe for condensation water discharge. The recent type is outfitted by an anti-bacterial carbon filter which infiltrates the return air.

The quality of atmospheric content water was the object of a few studies [9–12]. The chemical quality of atmospheric content water is determined by the dissolution of the surrounding gases and the small particles which arrive into the water [13]. Factors that may affect the environment are temperature, humidity, air movement, air change rate, ventilation, dust, and biological and gaseous pollutants. *Legionella pneumophila*, the causative agent of Legionnaires, is considered an important agent for respiratory disease, especially in humid places such as in cooling tower waters and air conditioners. Thus, measurement of this micro-organism can help to assess the risk of such diseases in the humid air [8]. Environments with high temperature and humidity are suitable condition for growth of molds and fungi; main agents for allergic reactions [14]. Spores of molds and bacteria are airborne, therefore it can be found in every environment and this normal flora is in most cases not harmful [15].

The aim of this study was to investigate the produced water of BA air conditioners and also the chemical and microbiological quality of this water. Moreover, it was also important to specify the best use of the water.

2. Materials and methods

The aim of present cross-sectional study was to find the best way to use the water produced by domestic air-conditioning system in the south of Iran, by evaluating the quantity, and microbial and chemical quality of condensate water. Total sample numbers in this study were 66.

Sampling area was BA city, center of Hormozgan province. Sampling plan was cluster-random; each cluster was one of BA regions. In this classification, BA was divided into four clusters, based on distance to shore and population density. Cluster 1 includes the coastal areas with high population density and vehicle traffic. Cluster 2 includes the coastal areas with low population density and vehicle traffic. Cluster 3 includes offshore areas with high population density and traffic vehicles, and finally, Cluster 4 includes offshore areas with low population density (Fig. 1).

Based on the area covered by each clusters, sample number for each region was determined; thus, 14, 16, 17 and 19 samples were taken from Clusters 1–4, respectively. In order to consider the seasonal conditions in the study, the samples were taken in a nine-month period, at intervals beginning from March to early December of 2011. Since in January–March quarter the BA weather is favorable (the average monthly temperature of 17.4–21.9˚C and the average relative humidity of 67–71.5%), the AC is not used during mentioned period.

In order to sampling for chemical parameter tests, polyethylene bottles with a capacity of 1.5 L which previously washed with distilled water were used. The bottles located on the desired locations and then transported to the laboratory in determined time

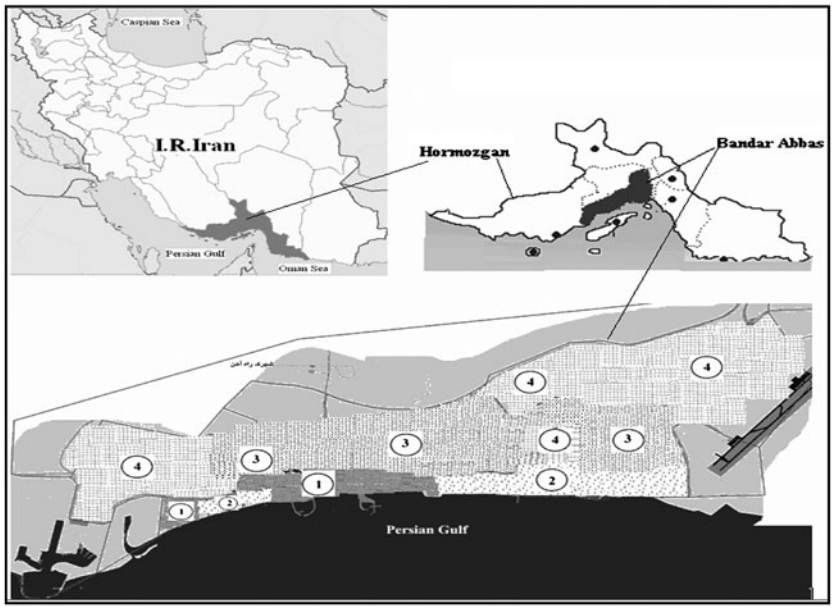

Fig. 1. Geographical location of BA and classification of BA on the four areas.

period. For biological tests, sterile glass bottles were used and sampling was done under sterile conditions (in the vicinity of the flame). Then, samples were transported to the laboratory in less than 4 h at temperature below 4˚C (in a cold box). Polyethylene bottles with a capacity of 20 L were used for quantity tests and collected water amounts were measured using a calibrated gage two times per day. After sampling, samples were sent to laboratory for tests which included: turbidity, alkalinity (ALK), total hardness, dissolved solids (TDS), and electrical conductivity (EC). Measurements for total hardness and ALK of water were done using titration methods and reagents made by Merck company, with expire date by the end of 2012, based on standard No. c 2340 of the standard reference method, were performed [16]. Measurement of pH using pH meter Elmetron Model CP-501 was conducted by using the method specified in the catalog system. EC and TDS samples using TDS meter model Aqualytic CD24 and turbidity using a turbidity meter Hach Model 2130B were measured. ALK measurements using titration methods and reagents made by Merck company, with expire date by end of 2014, based on standard No. B 2320 of the standard method, were performed [16].

In a biological test, after transferring the sample to the lab, we divided it into different vessels for bacterial culture and fungi counting. For bacteria culture, samples were moved in two 10 mL tubes and then were centrifuged for 10 min (200 rpm) to produce bacterial sediment. In this step, sediments divided in two parts; one of the sediments was inoculated in TSB (soya bean casein digest medium- tryptone soya broth) culture media by Pasteur pipette. Another part was inoculated in blood agar. After incubation (37˚C; 22–24h), a portion of the incubated culture was transferred to EMB media and it was incubated again for 22–24 h. After the incubation period has elapsed, a smear technique from blood agar was prepared by color Gram and were identified with a microscope.

For detection of intestinal bacteria, EMB culture media and four separate tests (IMVIC), indol, methyl red, Simmons citrae, and Voges Proskauer tests, were used. Results were expressed as colony-forming units (CFU)/m^3.

In order to count *Legionella*, the samples were concentrated using polyamide (Sartolon, Sartorius AG, Goettingen, Germany) membrane filter with 0.2 μm pore size. After that, polyamide filters were washed in sterile water. Samples were treated with acid (HCl–KCl solution, pH 2) and heated to remove other bacterial contamination and two plates of each sample were cultured on blood agar and selective media GVPC. Colonies grown from morphology and biochemical characteristics were identified and then bacterial growth was monitored and recorded in 3rd, 7th, and 10th days.

In order to count fungi, culture media and needed solutions were prepared and filled in 100 mL volume vessels and then sterilized. A solution composed of 0.1% oxytetracycline hydrochloride and water was

prepared and sterilized by membrane filter. About 10 mL of solution was added to100 mL of melted culture (about 45˚C). Specific volume of the sample in addition to the media of "yeast extract–dextrose–agar" with chloramphenicol was added into the plates. Plates were placed in an anaerobic incubator (25˚C) and were monitored for a period of 3–5 days. After this period, observations were made.

Data were analyzed using (mean, standard deviation, max, and min), student test and ANOVA ($p < 0.05$ for significant) with statistical package for the Social Sciences (SPSS) 19.0 for Windows.

3. Results

In general, three types of results were collected from experimental examinations: chemical and biological quality of condensate water; and quantity of water. Quality results shown in Tables 1 and 2 present the results of chemical examinations. Finally, results of biological tests are illustrated in Tables 3 and 4.

In average, for all clusters it was found that *L. pneumophila* is present in 22% of samples; percentage observed for *Staphylococcus aureus*, *Micrococcus* sp., *Corynebacterium diphtheria*, *Bacillus* sp., and *Pseudomonas* were 21, 13, 18, 13, and 13%, respectively. Similar results for fungi showed that 23% of samples were contaminated by *Penicillium* and 18% of samples by *Aspergillus*; other percentages were 16, 15, 14, and 14% for *Cladosporium*, *Alternaria*, *Mucor*, and *Trichoderma*, respectively.

Based on results, *L. pneumophila* is dominant counted bacteria in four zones. It can be because of ubiquity of this micro-organism, particularly in humid climate such as BA [17,18]. The result of this study is near to those of the last studies on this topic [19,20].

The dominating genera of fungi were found to be *Penicillium* and the highest fungi concentration was recorded to be 2,829 CFU/m^3 that was related to *Aspergillus*. One of the reasons for the abundance of fungal contamination is high humidity and acidic pH in the air at BA.

Table 1
Quantity of produced water by each home air conditioner in quarter periods (L/d)

Zone	Zone 1			Zone 2			Zone 3			Zone 4		
Sampling duration	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3	Season 1	Season 2	Season 3
Number	14.0	14.0	14.0	15.0	15.0	15.0	17.0	17.0	17.0	19.0	19.0	19.0
Mean	33.4	47.1	29.1	33.8	47.6	21.3	30.4	44.9	30.1	31.0	45.1	28.7
Std. dev.	3.7	4.3	3.0	3.8	5.0	2.5	3.3	5.1	2.2	3.6	4.2	3.0
Min	27.9	40.33	24.7	28.0	40.3	24.7	24.7	37.1	24.9	26.0	36.4	23.4
Max	37.9	52.7	33.8	39.7	55.3	32.5	35.1	52.7	34.5	37.1	51.4	33.8

Table 2
Chemical quantity of produced water in home air conditioners

Parameter	pH	Turbidity (NTU)	EC (μS/cm)	TDS (mg/L)	ALK (mg/L)	Total H (mg/L)	pH	Turbidity (NTU)	EC (μS/cm)	TDS (mg/L)	ALK (mg/L)	Total H (mg/L)
Zone	1						2					
Mean	6.81	2.46	45.0	34.0	38.2	21.6	6.75	2.33	45.6	33.3	36.8	18.6
Std. dev.	0.27	0.70	15.77	11.06	7.45	8.18	0.27	0.93	10.4	6.68	8.85	3.11
Max	6.3	1.2	59.5	46.4	51.2	34.3	7.1	4.0	60.0	42.7	52.3	22.7
Min	6.3	1.2	16.8	14.3	26.6	0.2	6.3	1.4	24.2	18.9	23.3	12.4
Zone	3						4					
Mean	6.89	2.55	41.8	28.8	36.1	18.2	6.84	2.39	37.8	30.8	34.3	19.1
Std. dev.	0.21	0.69	6.99	7.27	7.3	2.48	0.20	0.69	13.8	8.9	9.3	5.4
Max	7.3	3.7	55.4	41.2	68.0	29.6	7.1	3.8	63.0	49.2	48.0	29.8
Min	6.5	1.3	34.5	14.5	25.0	14.3	6.4	1.1	12.5	18.3	17.4	13.2

Table 3
Statistical parameters of colony counting of bacteria (CFU/m^3) in four zones

Zone	N	Parameter	*Corynebacterium diphtheria*	*Micrococcus* sp.	*Bacillus* sp.	*Pseudomonas*	*Staphylococcus aureus*	*Legionella pneumophila*
1	14	Min	108	3	14	88	184	11
		Max	2,571	2,705	2,760	2,723	2,116	5,520
		SD	918	837	812	944	619	1,672
		Mean	996	525	406	746	1,068	1,209
2	15	Min	2	3	8	44	38	11.0
		Max	2,220	2,445	4,155	1,440	1,707	4,565
		SD	666	779	1,085	554	512	1,463
		Mean	585	468	445	531	855	1,059.5
3	17	Min	2	2	2	11	45	8
		Max	1,282	1,630	1,875	910	2,031	2,394
		SD	972	1,697	974	865	637	1,277
		Mean	854	854	670	648	917	970
4	19	Min	9	2	30	7	9	5
		Max	4,463	2,292	3,061	870	3,009	3,009
		SD	1,261	691	892	295	945	917
		Mean	772	402	646	362	716	629

Table 4
Statistical parameters of colony counting of fungi (CFU/m^3) in four zones

Zone	N	Parameter	*Penicillium*	*Aspergillus*	*Cladosporium*	*Alternaria*	*Mucor*	*Trichoderma*
1	14	Min	77.0	120.0	3.5	71.0	3.0	1.0
		Max	2,540	920	1,986	1,600	1,298	2,297
		SD	723	260	615	450	377	702
		Mean	791.0	488.5	511.8	516.3	312.6	459.6
2	15	Min	10.0	20.0	1.0	59.0	4.0	3.0
		Max	1,720	1,159	1,684	1,269	670	975
		SD	609	318	536	414	235	295
		Mean	634.9	577.8	361.1	476.4	168.3	216.0
3	17	Min	2	2	2	11	45	8
		Max	1,282	1,630	1,875	910	2,031	2,394
		SD	972	622	753	327	461	616
		Mean	573.7	405.6	554.2	248.9	443.1	472.4
4	19	Min	2	3	7	8	26	6
		Max	1,410	2,829	894	1,001	1,167	1,448
		SD	364	706	240	269	352	436
		Mean	275.1	339.9	195.7	219.1	436.8	300.6

4. Discussion

Based on our results, pH of condensate water, which is slightly acidic (6.75–6.89), would be related to the presence of gases, and especially carbon dioxide in the air. Turbidity variations were 2.33–2.55 NTU; it would be because of suspended particles of dust presence in BA air and the second factor can also be related to the particle emissions from vehicles. In the areas close to the beach, the mean of EC and TDS of condensate water was higher than that of the areas away from the beach. This could be due to dissolution of salts from the sea which present in water droplets in the atmosphere above the sea. Based on total hardness and ALK of water results, this water classified into very soft category and because the water will cause corrosion, pH adjustment may be necessary for some industrial consumption [21–23].

Mean of bacterial colonies in window air conditioners was more than split types. It would be due to anti-bacterial filter in split air conditioners which reduce bacterial population in recycled air [24]. Statistical test confirmed significant difference between

average of colonies in two air conditioners types ($p < 0.05$). The mean of fungal colonies in two air conditioner types has significant difference too ($p < 0.05$).

Today, 2013 BA has about 700,000 populations with the average family size of five people. If we suppose one or two air conditioners installed in each household, then about 140,000–280,000 air conditioners are exist in BA. The average of extracted water per unit in the four regions is about 36 L/d. With these assumptions, it can be estimated that about 50,400–100,800 m^3 water can be extracted from BA air conditioners per day. Considering the water shortage problem in coastal cities of southern Iran, this water can be considered as a significant and important source for many types of urban and industrial consumptions, exclusion of drinking needs. According to the tests carried out, the water quality is suitable to many municipal uses such as landscaping, swimming pools, fountains in the parks, building construction, firefighting, car washes and so on. Due to the significant volume and good quality, the planning of utilizing this significant amount of free water would be economically justified. In order to ensure the microbial safety of the condensate water, the recommended amount of 5 g/m^3 of perchlorate powder has to be added to the water.

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