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Quantity and quality of condensate air conditioner water for potential use in drinking purpose

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ABSTRACT

The demand for freshwater is increasing day by day around the world. Hence alternative sources are being explored that can minimize the demand of traditional sources. Water from air conditioners (ACs) is a potential option. Therefore, the aim of this study is to examine the quality of condensate AC water to ascertain whether it is potable and to determine the amount of water that can be harvested from split-type ACs (3, 4, and 4.5 ton)/h. A general brand of AC was assessed in this study. A total of 270 AC water samples were collected from June to July 2017 covering a total floor area of 1,694.55 m^2. The findings showed that, without proper treatment, AC water is unsafe to drink. However, according to lab test results, it can be made drinkable if it is boiled and filtered. Finally, a model is also proposed for continuously converting AC water into pure drinkable water.

Keywords: Air conditioner water; Water quality; Treatment; Water demand; Potential use.

1. Introduction

Water, the universal solvent, is a critical, limited, and renewable resource [1,2]. However, the need to ensure the availability of sustainable, cost-effective, and reliable supplies of drinking water is becoming increasingly urgent for small communities in rural as well as city areas. If electricity is generated regularly, air conditioners could become an alternative source of water during periods of water crises, especially for displaced populations [3]. It was observed that the water extracted from air, by condensation, can support up to almost half of the needs of the case study infrastructure represented by a modern hotel [4].

According to the World Health Organization (WHO), the standard water amount is 150 L/capita/d for drinking and other domestic purposes [5]. In Bangladesh, most people use groundwater for drinking purposes. However, only 1.7% of the water on Earth is in the form of groundwater. Thus it is vital to find ways to minimize the use of groundwater. Moreover, while ~97% of the Earth's water is in the oceans and 2% is in ice caps and glaciers, these sources are unsuitable for humans because of their salinity and inaccessibility. Also, only about 0.001% of all the water on Earth is in the atmosphere at any one time [3,6].

In recent times, there has been substantial growth in the use of air conditioners (ACs) in both domestic and commercial buildings. Air-conditioning systems are most ordinarily used to create a comfortable interior environment, typically for humans. However, air conditioning is also used to cool/dehumidify rooms filled with heat-producing electronic devices such as computer servers and power amplifiers, and also in settings that display and store artwork.

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Air-conditioning systems have been used in many parts of the world for many years [7], and it has been suggested that air-conditioning condensate water could be employed in water-saving techniques, either at the individual household level or in larger-scale buildings. Furthermore, it has been argued that condensate water should not be considered as a waste product, however, it can be reused for cooling towers and irrigation purpose [8].

According to the WHO, water quality depends on physical, chemical, biological, and aesthetic properties [5]. However, the use of condensate water from ACs raises some specific concerns of significant hazard to public health [5]. The condensate water may contain heavy metals due to contact between water and cooling coils and other parts of AC [9]. Nevertheless, in Qatar, an experiment was conducted a decade ago that showed that over 6 million L/y of condensate water could potentially be captured from ACs in a building [10]. More recently, another experiment in Qatar was performed that established the feasibility of using condensate water as an alternative and untapped water source [11]. Also, some researchers have analyzed water collected from air conditioning system of a building and continuous treatment of such collected water [12,13].

The condensate water may be used for various purposes except drinking. The limited volume harvested could be used for cleaning the laboratories, washing scientific equipment, watering of potted plants in greenhouses, conducting some scientific experiments, and flushing toilets [3,14]. It may also be possible to use condensate water for water-cooled equipment, fountains, and other water features, aquariums, evaporative coolers, washing vehicles, water for laundry operations, and other industrial processes [15].

The need for water in Bangladesh is increasing day by day, driven by a growing population and a high rate of urbanization. The depletion of freshwater resources is also being exacerbated by the enhanced demand for irrigation, industrial, and municipal water. In Bangladesh, the present sources of freshwater will soon not be sufficient to sustain the current quality of life or the economy. Thus, it is critical to identify alternative sources of water that can play an important role in maintaining the water supply. It is generally agreed that the recycling and development of modern water technologies should be implemented for effective water resource management and that AC water harvesting may be one of the approaches that could significantly augment toward the demand for freshwater.

In this study, the water quality parameters of condensate AC water and the quantity of such water produced daily from various split-type air conditioner units under different operating conditions were investigated in order to determine whether it is possible to be used for drinking purposes.

2. Methodology

2.1. Sample collection

The site for this study was a garment factory owned by BHML (Beauty, Hasan, Manik, and Lili) industries Ltd., located in Gazipur, Bangladesh. The ACs in this factory is used mainly for maintaining the necessary equipment. This study covered a total floor area of 1,694.55 m^2. Water samples were collected from three types of split-type general AC (3, 4, and 4.5 ton) at three different times during the day and during the night (Table 1). All the samples were collected from June to July 2017. A total of 270 water samples were collected from the selected site. The parameters that were assessed were pH, color, turbidity, electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD_5), total iron, and *Escherichia coli*. A variety of methods and instruments was used to determine the physico-chemical parameters of the water samples which are shown in Table 2.

2.2. Observations on water quantity

The quantity of water produced by three types of air-conditioning unit (3, 4, and 4.5 ton) was measured by volume at three different operating temperatures (18°C, 20°C, and 22°C). The average quantities of water generated were calculated per unit time (1 h) for each of the three different types of AC. This calculation is simple that involves multiplying the total amount of water produced by the running hours of the AC(s) and the number of air-conditioning units.

2.3. Measurements of physical, chemical, and microbiological parameters

The quality of the condensate AC water was also investigated based on the key parameters (pH, color, turbidity, EC, DO, BOD_5, total iron, and *E. coli*) that are utilized in water quality monitoring programs. After samples of AC water were collected from three different types of air-conditioning units, these vital physical, chemical, and microbiological parameters of water were tested in laboratory. The American Public Health Association (APHA) methods were used for testing the selected samples of condensate AC water [16]. The tests were conducted two times: first, the tests were done before boiling and filtering the water samples and, then the tests were conducted after boiling and filtering. The results of these two tests were then compared with the standard values for drinking water as laid down in Environmental Conservation Rules (ECR) [17].

3. Result and discussion

3.1. Quantity of condensate water

Figs. 1 and 2 illustrate the average amount of water (day and nighttime) that was collected from the three different types of air-conditioning unit (3, 4, and 4.5 ton) at three different AC temperatures (18°C, 20°C, and 22°C). The quantity of water produced by each AC during the day and the

Table 1
Daily sample collection times

Sample no.	Day	Night
1	9:00 A.M.–10:00 A.M.	7:00 P.M.–8:00 P.M.
2	11:00 A.M.–12:00 P.M.	8:00 P.M.–9:00 P.M.
3	2:00 P.M.–3:00 P.M.	9:00 P.M.–10:00 P.M.

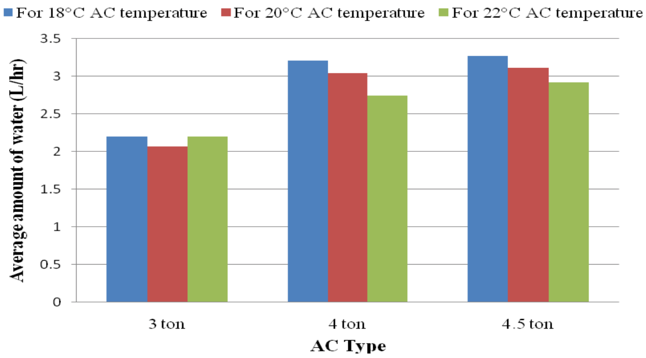

Fig. 1. Average quantity of condensate water collected during daytime at three different AC temperatures.

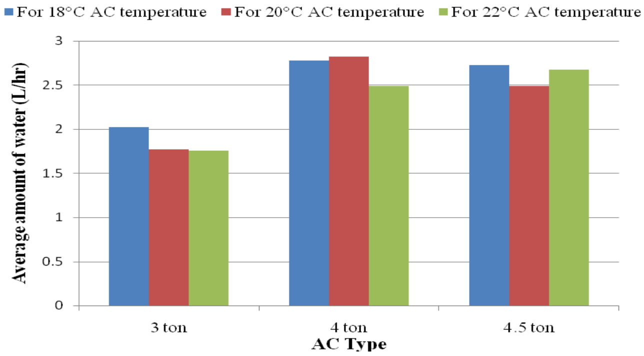

Fig. 2. Average quantity of condensate water collected during nighttime at three different AC temperatures.

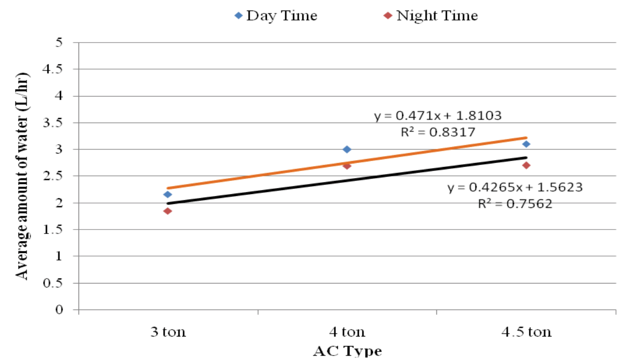

Fig. 3. Comparison of AC water generated in daytime and nighttime with trendline.

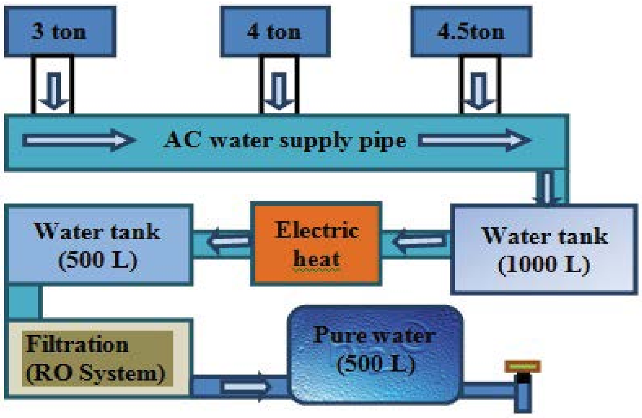

Fig. 4. Proposed system for AC water purification.

nighttime varied to a certain extent. The quantity of water generated during the daytime collections was 2.159, 2.997, and 3.101 L/h and at nighttime these amounts were 1.849, 2.695, and 2.702 L/h, respectively for 3, 4, and 4.5 ton of air-conditioning units.

Fig. 3 shows the variation in the generated AC water in both the day and the night time. It also shows the trend line for both cases. The quantities of water collected are considered to be significantly high. A high R^2 of 0.831 for daytime and 0.756 for nighttime was obtained from the linear regression, which shows that there is a close agreement between the fitted data and the volume of observed AC water. It is clear that there is a proportional increase in condensate water quantity and AC capacity in tons.

3.2. Physical, chemical, and microbiological quality of condensate water

Table 2 depicts the comparison of laboratory test results of AC water with Bangladesh standards for the quality of drinking water. It is clear from the results that without proper treatment of condensate AC water are unsuitable to drink as it contains high count of *E. coli* and high concentration of BOD, and as such do not comply with the Bangladesh standards. However, according to the results of laboratory testing, this water is suitable for drinking purposes if it is boiled and filtered beforehand.

4. Cost benefit analysis

As mentioned above, AC water may be able to play a vital role in minimizing the demand for freshwater. If it is possible to manage condensate water properly, it will be feasible to reduce some of the costs associated with meeting the demand for water, and generate some income as well. Based on the results of a questionnaire survey of industrial authority, it was ascertained that the average running time for the ACs at the factory site understudy during the daytime and nighttime was 9 and 5 h, respectively. It was also established that there were 15 ACs in the area under study, five for each of the AC types (3, 4, and 4.5 ton).

Based on this information and the data presented in the tables above, the total quantity of AC water that could be collected per day at the site was calculated and from that the total amount per year (Table 3). Then, the estimated cost involved in the setting up of the AC water purification system illustrated in Fig. 4 was determined (Table 4). Based on the values in Tables 3 and 4, an estimation of the potential revenue from the production of AC water was then made (Table 5). The results clearly show that not only there is a benefit of converting AC water into drinking water in terms of reducing the pressure on limited groundwater supplies; but there is also room to make a profit from setting up such systems.

Table 2
Comparison of laboratory test results with standard values

Parameter	Unit	Test method	Concentration before boiling and filtration	Concentration after boiling and filtration	Bangladesh standards [17]
pH	–	APHA Standard Method 4500-H^+ B	7.26	6.59	6.5–8.5
Color	Pt-Co	Spectrophotometer HACH (USA) DR 2800 (Pt. Co. Standard Method)	32	9	<15
Turbidity	NTU	APHA Standard Method 2130 B	1.57	1.37	<10
Electrical conductivity (EC)	µS/cm	APHA Standard Method 2510	75.5	52.7	<300
Dissolved oxygen (DO)	mg/L	APHA Standard Method 4500-O G	8.62	7.5	>6.0
Biological oxygen demand (BOD_5)	mg/L	APHA Standard Method 5210-D	9.3	0.15	<0.20
Total iron	mg/L	Spectrophotometer HACH (USA) DR 2800 Ferro Ver Method	0.025	0.01	0.3–1.0
E. coli	cfu/100 mL	Membrane Filtration	160	0	0

APHA: American Public Health Association [16].

Table 3
Total quantity of AC water collected at selected site

Type of AC (tons)	Average amount of water during daytime (L/h) *A*	Amount of water during daytime (L/9 h) ($A \times 9$) = *C*	Average amount of water during nighttime (L/h) *B*	Amount of water during nighttime (L/5 h) ($B \times 5$) = *D*	Amount of water during daytime and nighttime (*L*) ($C + D$)	Amount of water/d (L) 5($C + D$)
3	2.159	19.431	1.849	9.245	28.676	143.38
4	2.997	26.973	2.695	13.475	40.448	202.24
4.5	3.101	27.909	2.702	13.51	41.419	207.095
Total amount of collected water from selected site (L/d)						552.715
Total amount of water per year = (552.715 × 293) = 161,945.495 L						

Calculated based on 1 d off per week and 20 d holiday per year.

Table 4
Estimated cost of constructing a new system for AC water purification

Item	Quantity	Unit cost (Tk)	Total cost (Tk)
Plastic pipe	100 m	100	10,000
Water tank	1 (1,000 L)	10,000	10,000
Water tank	2 (500 L)	7,000	14,000
Electric water heater	1	15,000	10,000
Filter (RO system)	1	40,000	40,000
Setup cost		10,000	10,000
Bottle and labeling cost	163,000	5	815,000
Maintenance cost	15	3,000/AC/y	45,000
Labor cost	4	120,000/y	480,000
Electricity cost		24,000/y	24,000
Total cost per year			1,458,000

RO = reverse osmosis; 1US$ = 80 Tk; most of the prices were obtained from Rajuk Supermarket, Dhaka, Bangladesh.

Table 5
Potential revenue per year from AC water

Total quantity of AC water (L)	161,945.495
Total amount of drinkable water (L) *A*	160,000
Selling price/L (Tk) *B*	15
Total earn per year (Tk) ($A \times B$) = *C*	2,400,000
Total cost/y (Tk) *D*	1,458,000
Total revenue/y (Tk) (*C*–*D*)	942,000

The above figures are calculated based on a wastage factor of 1.2% and on the current (October, 2018) market price of 1 L bottle water in Bangladesh of 20 Tk.

5. Conclusions

The current study explored uses of a potential new water resource, that is, condensate AC water, which otherwise would be wasted and instead could be used for a range of different purposes such as drinking, washing, and gardening. It was estimated that the average amounts of water generated per hour by a 3, 4, and 4.5 ton of AC were 2.159, 2.997, and 3.101 L, respectively. During the daytime and that during the nighttime these amounts were 1.849, 2.695, and 2.702 L, respectively. It is clear that the condensate AC water is unsuitable to drink as it contains a high count of *E. coli* and high concentration of BOD. However, this water is suitable for drinking if it is boiled and filtered beforehand. It was also estimated that the installation of an AC water purification system could generate significant revenue per year. The overall findings are very promising and it is therefore essential that the potential application of this study is further explored by conducting more intensive sampling and analysis on a greater range of ACs. Also, as this study was performed during the summer months, testing also needs to be undertaken in different seasons in order to identify whether there is any variation in output under different conditions.

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Appendix

Table A1
Amount of AC water collected during daytime

Type of AC (ton)	Average outside temperature (°C)	AC temperature (°C)	Day-1 (L/h)	Day-2 (L/h)	Day-3 (L/h)	Day-4 (L/h)	Day-5 (L/h)	Average water (L/h)	Standard deviation (L/h)
		18	2.61	2.25	2.53	1.58	2.07	2.206	0.34
3		20	1.32	1.80	1.56	3.14	2.51	2.066	1.42
		22	1.49	2.69	1.79	2.37	2.69	2.206	0.59
		18	4.12	3.32	3.37	2.62	2.61	3.208	0.79
4	30.85	20	3.16	3.03	2.43	3.39	3.19	3.04	0.26
		22	1.33	2.72	2.79	3.09	3.78	2.742	1.59
		18	2.96	3.71	3.35	2.89	3.44	3.270	0.23
4.5		20	1.87	3.09	3.75	3.44	3.40	3.11	1.07
		22	0.86	2.63	3.44	3.55	4.13	2.922	3.23

Table A2
Amount of AC water collected during nighttime

Type of AC (ton)	Average outside temperature (°C)	AC temperature (°C)	Day-1 (L/h)	Day-2 (L/h)	Day-3 (L/h)	Day-4 (L/h)	Day-5 (L/h)	Average water (L/h)	Standard deviation (L/h)
		18	0.96	2.44	2.14	2.16	2.41	2.022	0.568
3		20	1.09	2.20	2.41	1.56	1.58	1.768	0.769
		22	0.97	1.81	1.32	2.49	2.19	1.756	0.740
		18	1.19	3.42	3.19	2.84	3.25	2.778	1.665
4	29.34	20	2.67	3.43	3.19	2.47	2.34	2.82	0.485
		22	2.20	2.28	2.42	2.49	3.05	2.488	0.223
		18	0.79	3.43	2.87	3.11	3.42	2.724	3.229
4.5		20	0.71	3.77	3.25	2.74	3.07	2.708	0.230
		22	1.40	2.60	3.34	2.87	3.16	2.674	1.070

Table A3
Average quantity of AC water collected during daytime and nighttime

Type of AC (ton)	AC temp. 18°C	AC temp. 20°C	AC temp. 22°C	Average amount of water generated during daytime (L/h)	AC temp. 18°C	AC temp. 20°C	AC temp. 22°C	Average amount of generated water during nighttime (L/h)
	Amount of water generated during daytime (L/h)				Amount of water generated during nighttime (L/h)			
3	2.206	2.066	2.206	2.159	2.022	1.768	1.756	1.849
4	3.208	3.040	2.742	2.997	2.778	2.820	2.488	2.695
4.5	3.27	3.11	2.922	3.101	2.724	2.708	2.674	2.702