CHARACTERIZATION AND MODELING OF CONDENSATE RELEASED FROM AIR CONDITIONER

ALOR, O. E.[1]; AKULA, P.T.[2]; ANDA ILYASU[3]; & OBARAFO SAMUEL[1]
[1]Chemical Engineering Department,
Federal University of Technology Minna, Nigeria
[2]Department of Chemical and Biomedical Engineering,
West Virginia University, Morgantown, WV26506 USA
[3]Department of Library and Information Technology,
Federal University of Technology, Minna, Nigeria
E-mail: alor.emma@futminna.edu.ng, pta0001@mix.wvu.edu,
Ilyasu.anda@futminna.edu.ng, sammytudac@gmail.com
Phone No: +2347035752575

Abstract
The study assessed the variability in the physico-chemical, microbial and metallic constituents in condensate released from air conditioner. Four sampling points were randomly selected at the Federal University of Technology Minna, GidanKwano Campus, Niger State Nigeria. The collected samples of condensate were taken to the Federal Ministry of water Resources Regional Water Quality Laboratory Minna, for analysis after which a linear regression model was used to determine the discharge rate of condensate from air conditioner. The model was also applied to estimate the volume of water that could be collected from functional air conditioner in the study area. The laboratory analyzed results were compared with NSDWQ 2007/NESREA 2011 standards for water, the results from the laboratory analysis revealed that Lead and Carbonatewere not detected in the samples, while TDS, conductivity, dissolved oxygen and pH were detected to be 11.00±3.27 mg/l, 16.50±5.32µS/cm,7.16±0.04, and 7.16±0.04mg/l respectively in the samples which falls within the desired limit of standard. Results from the laboratory analysis revealed the amount of chromium, zinc, chloride, iron, sulphate and copper in the sample as 0.03 ±0.01mg/l, 0.12 ±0.15mg/l, 3.90 ±0.66mg/l, 0.03 ±0.02mg/l 4.25 ±1.71 mg/l and 0.14±0.09mg/l respectively, which does not exceed the maximum permissive limit of the NSDWQ 2007/NESREA 2011 standard for water.The concentration of sodium, potassium, calcium, magnesium and total hardness in the sample were 1.00 ±0.00mg/l, 2.50 ±0.58mg/l, 4.30 ±0.88mg/l, 3.91 ±2.32mg/l, and 8.21±3.19mg/l respectively, which does not exceed the maximum permissive limit levels of the NSDWQ 2007/NESREA 2011 standard for water, It was established that the physico-chemical, microbial and metallic constituents of condensate released from air conditioner does not exceed the acceptable, desired and permissive limit of NSDWQ 2007/NESREA 2011 standard for water. Based on these findings, the study recommends that the water,which may not be suitable for drinking, could be used for domestic and industrial purposes such as toilet flushing, outdoor watering, cloth washing, car washing and cooling tower and not to be consumed due to insecticides and other environmental control chemicals sprayed in places, which could be sucked into the water from the air filter units of an air conditioner. A condensate collection line and tanks should be included in the plumbing design of a building to avoid stains on walls, and control the growth of fungi and other bacteria in the environment.

Keywords: Condensates, air conditioner, physico-chemical, microbial and metallic constituents

Introduction
Air conditioning and refrigeration are used around the world for temperature variation and food preservation (Boulware, 2013). In an air conditioning system, the air is being cooled

at the cooling coil through dehumidification, causing water to be removed as condensate. Meanwhile, condensation is a process which result to change in state from a gas to a liquid, and it occurs when a vapor is cooled below its saturated temperature.

Condensate generated by air conditioner can be used, however proper and safe collection of the water is required, to control the breed of bacteria such as legionella. The water could be channeled into a collection tank, or collected into a vessel that has a narrow in-let tip (a can) to minimize exposure to atmospheric or biological contaminants from the environment (Boulware, 2013).

The moisture holding capacity of air is temperature dependent. Higher temperature air can hold more water vapor than colder air. The amount of water vapor being expressed as kilogram of water per kilogram of dry air is related to the dampness of the atmosphere known as humidity. Water vapor that exist in a gaseous mixture of air is termed relative humidity expressed as percentage of the water vapor that can be suspended at that temperature. As a result of the temperature difference between the cooling space of an air conditioner and that of the outer space, a reasonable amount of condensate could be estimated with respect to time, using a mathematical model.

Reclaimed air conditioning condensate is high-quality water with low mineral and chemical content and has many potential uses, but care must be taken with its use and distribution in a fashion that would cause aerosols (e.g. lawn sprinklers) should be avoided due to the possible exposure of persons to legionella bacteria. If the use of air conditioning condensate could expos persons to inhalation of bacteria, then proper collection and purification of the water should be done prior to use (Boulware, 2013).

Since this condensate could be collected, it can be classified, analyzed and used as a supplementary source of water rather than considering it a waste, which later turns out to cause stains and breed algae on the wall and floor of a building if not controlled (Boulware, 2013).

The global demand for water is increasingly becoming high, despite all possible techniques and strategies put in place by governing body of various nations to provide amenities that will make water available and accessible to humanity, drought and water shortage is still experienced in some nations (World Water Development Report, 2003).

Though the hydrosphere is estimated to contain about 1.36 billion m^3, only about 0.3 % of the water, existing as fresh water in rivers, streams springs and aquifers, is available for human use; the remaining 99.7% (salt water) is locked up in seas and oceans (Muhammad et al., 2007).

The condensate from air conditioner could be classified as a form of surface water termed to be an artificial source of water, it is also a dehumidified air gotten from an open space through an air conditioner per time, it is the collection of water vapor in the atmosphere or air through a condensation process (Boulware, 2013).

Characterization of condensate released from air conditioning system reveal to users how usable the water could be, meanwhile modeling an equation for the discharge rate will help an individual in estimating the volume of water that could be collected from an air condition per time. With the application of the modeled equation, air condition condensate collection duct or unit (Tanks) could be included in the plumbing design of a building with all the condensate from the building collected in a single tank, and may be used for irrigating indoor gardens, flowers, as well as being channeled to the toilet flushing system, or other domestic activities as well as industrial services such as using it in the cooling tower of a plant rather than watching it become breeding medium for algae on the wall and floor of a building resulting to stains if not controlled. The numbers of air condition in a building will determine the size of the tank to be used for the collection.

Amount of Water Required Per Day

Base on the consideration for use of condensate from air conditioning system, if a building is having a large numbers of air conditioner installed in it, and all the condensate been collected in a single condensate duct tank, the possible usage of the water could be for: toilet flushing, outdoor watering (garden), supplement for cooling tower, car washing, cloth washing and bath, (Gupter*et al.,* 2009).

The Table 1.1 below summarizes the volume of water that could be used for some activities.

Table 1.1: Volume of Water Required From Air Conditioning System

Activities	**Required Volume**
Toilet flushing	1.6 Gallons per flush (7.3 Litres)
Outdoor watering (garden)	4.4 Gallons per day (20 Litres)
Cloth washer	40 gallons per Load (181.8 Litres)
Car wash	8.8 Gallons per car (40 Litres)
Cooling Tower	Continuous channeling
Total Volume Required	17.6 Gallons (221.8 Litres)

Source: (Gupter*et al.,* 2009)

Materials and Methods

Description of the Study Area

The Federal University of Technology GidanKwano Campus (main campus) Minna, Niger State Nigeria, was selected as a case study for this research work, in which samples were collected at four different locations of the campus (Senate Building, School of Environmental Technology (SET), School of Engineering and Engineering Technology (SEET), and School of Entrepreneurship and Management Technology (SEMT).

The main campus at GidanKwano is located along Minna-Bida road about 20 km away from the Bosso Campus of the University, which is inside Minna town of Niger State (https://www.futminna.edu.ng/.../179-2017-2018-pre-admission-screening-exercise, 2018).

Minna City is both the administrative headquarters of Niger State and Chanchaga Local Government Area, she lies at latitude 90 37' North and longitude 60 33'East on a geological base of undifferentiated basement complex of mainly gnesis and migmatite (Students' Affairs Division FUTMinna Report, 2014).

Niger State of Nigeria lies between Latitudes 8^0 20'N and11^0 30'N and Longitudes 3^0 30'E and $7^0$20'E with twenty-five local government area councils, it is located in the North central part of Nigeria, sharing boundaries with Zamfara State in the North, Kebbi State and Republic of Benin in the Northwest, Kwara State in the Southwest, Kogi State in the South and Federal Capital Territory (FCT) and Kaduna State in the Southeast and Northeast, respectively (NMLH&S, 2001).

Sample Collection and Preparation
The water was collected within a period of two months (August – September) taking note of the weather temperature as related to the discharge rate, water was sampled from air conditioning system, adopting a flexible polyethylene tubing (rubber hose) to run from drain outlet securely into polyethylene (plastic) sampling keg (2 Liters) each, from four different locations of the Gidan Kwano campus (Senate Building, School of Environmental Technology (SET), School of Engineering and Engineering Technology (SEET) and School of Entrepreneurship and Management Technology (SEMT)), meanwhile the sampling keg was rinsed with the same sample before collection in compliance with the WHO, 2006 standard sample collection procedure, as gummed paper labels was used to prevent sample misidentification, samples were delivered to the Federal Ministry of Water Resources Regional Water Quality Laboratory Minna, Niger State, Nigeria, immediately after collection on the same day for analysis.

Determination of the physico-chemical, microbial and metallic parameters: All experimental /analysis was carried out at the Federal Ministry of Water Resources Regional Water Quality Laboratory Minna, Niger State, Nigeria, using standard procedures with compliance to the American Public Health Association (APHA, 2005) standard methods.

Results

Table 1.2 : Summary of Experimental (August – September) and Calculated Results Compared with NSDWQ and NESREA Standard

Parameters	Haier Thermocool	LG	Panasonic	SHARP	Average/ S.D	NSDWQ 2007/ NESREA 2011
pH	7.18	7.19	7.11	7.15	7.16±0.04	6.5-8.5
TDS (mg/L)	11	15	7	11	11.00±3.27	500
Conductivity (μS/cm)	16	23	10	17	16.50±5.32	1000
Temperature (°C)	26.2	26.3	26.3	26.2	26.25±0.06	Ambient
Dissolved Oxygen (mg/L)	7.18	7.19	7.11	7.17	7.16±0.04	>4.0
Chloride (mg/L)	4.0	4.6	3.0	4.0	3.90±0.66	250
Sodium (mg/L)	1.0	1.0	1.0	1.0	1.00±0.00	200
Potassium (mg/L)	3.0	2.0	2.0	3.0	2.50±0.58	50
Total Hardness(mg/L)	7.42	6.05	6.44	12.92	8.21±3.19	500
Calcium (mg/L)	4.0	3.61	4.0	5.6	4.30±0.88	180
Magnesium (mg/L)	3.42	2.44	2.44	7.32	3.91±2.32	40
Zinc (mg/L)	0.06	0.03	0.04	0.34	0.12±0.15	3.0
Iron (mg/L)	0.04	0.05	0.03	0.01	0.03±0.02	0.3
Copper (mg/L)	0.17	0.16	0.22	0.01	0.14±0.09	1.0

Chromium(mg/L)	0.04	0.03	0.04	0.02	0.03±0.01	0.05
Sulphate (mg/L)	4.0	6.0	5.0	2.0	4.25±1.71	100
Lead (mg/L)	0	0	0	0	0.00±0.00	0.01
BOD (mg/L)	0	0	0	0	0.00±0.00	6.0
COD (mg/L)	0	0	0	0	0.00±0.00	30
Carbonate (mg/L)	0	0	0	0	0.00±0.00	–

Figure 1.1 represents the plot of the concentration of various parameters against the average value of parameters in samples and standard value.

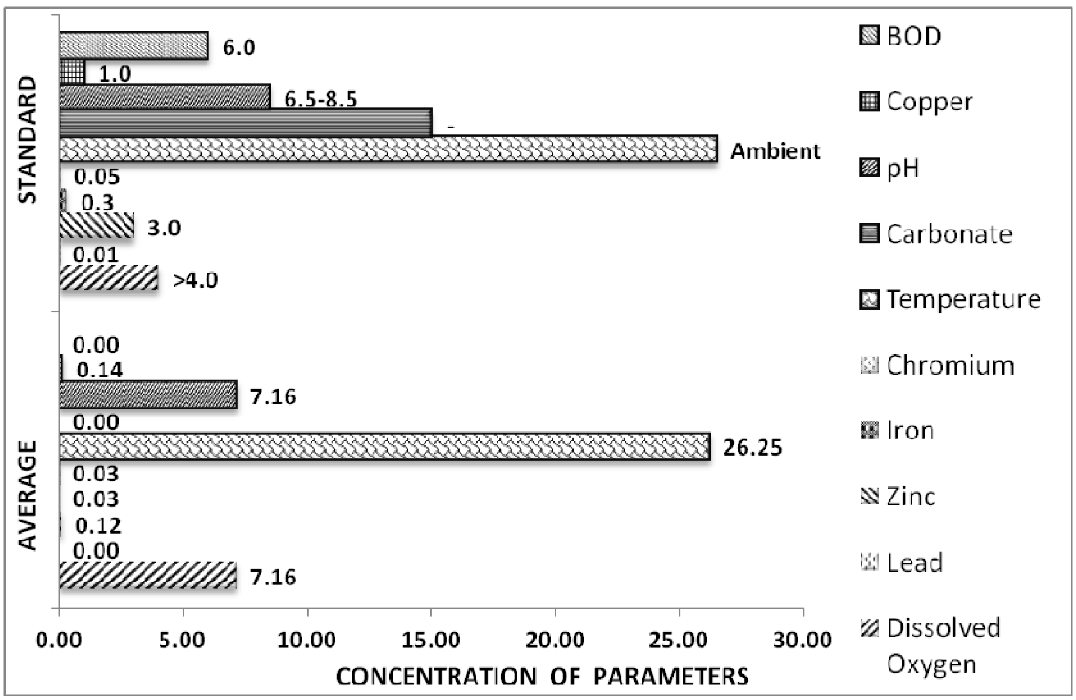

Figure 1.1: Average and Standard Concentration of Parameters

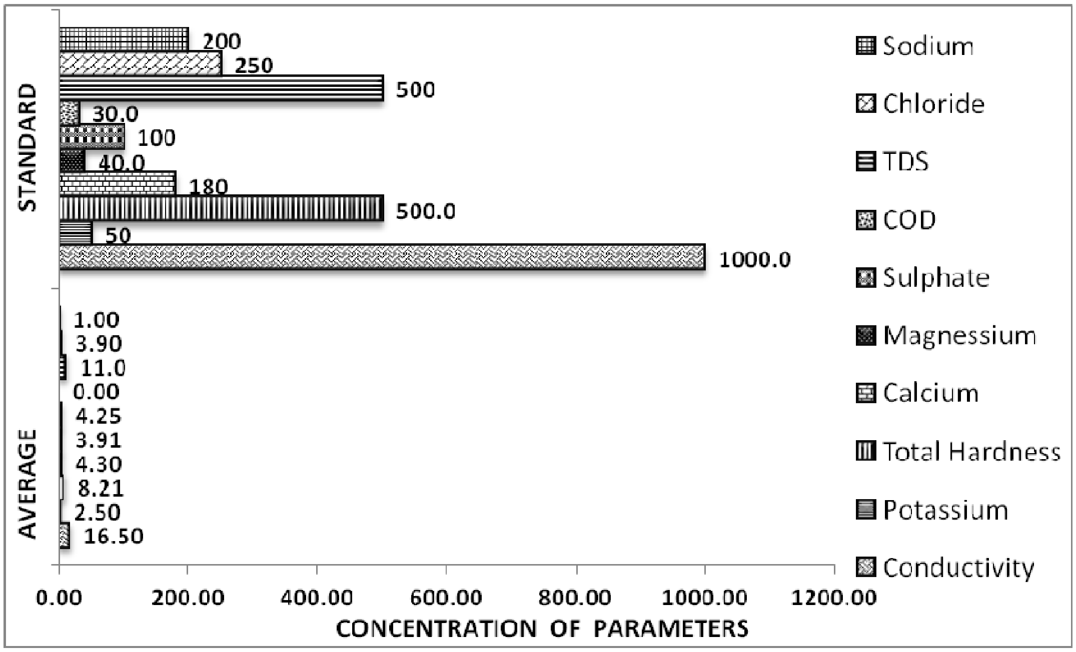

Figure 1.2: Average and Standard Concentration of Parameters

Discussion

From the results of the physico-chemical, microbial and metallic properties of air conditioner condensate in Table 1.2, It can be seen that there is no trace of Lead, BOD, COD and Carbonate with an average standard deviated value as 0.00±0.00, 0.00±0.00, 0.00±0.00, 0.00±0.00 respectively. The value of sodium seem to be identical for all products of air conditioner having a confidence limit of 1.00±0.00 and are between the desirable limit of the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007).

The pH value in Table 1.2 and Figure 1.1 implies that the samples from four different products of air conditioner (Haier Thermocool, LG, Panasonic and Sharp) has a proximity pH value of 7.18, 7.19, 7.11, 7.15 respectively and a confidence limit of 7.16±0.04. This is similar to the result for Hebron bottle water (7.16±0.24) reported by Nwodo *et al.,* (2011) in the assessment of water quality in Canaanland, Ota, Southwest Nigeria, which lies on the neutral range of a pH scale and falls between 6.5-8.5 range in the desirable limit of the NSDWQ, 2007 and the NESREA, 2011 for water. This can be said to be neutral.

The temperature value of sample shown in Table 1.2 has proximity values with a confidence limit of 26.25±0.06. This is similar to the result for well water (27.80±0.45) reported by Ezeribe *et al.,* (2012) in the assessment of physico-chemical properties in well water from Dass LGA, Bauchi State, Nigeria, which falls between the desirable limits (Ambient) of NSDWQ, 2007 and NESREA, 2011 for water.

The concentration of chromium has a confidence limit of 0.03±0.01, this is similar to the result for Gwange, Mashamari and Hausari (0.00, 0.0, and 0.00) reported by Mustafa *et al.,* (2013) in the assessment of physico-chemical and bacteriological parameters from wash borehole water in Maiduguri metropolis, Borno State, Nigeria, which lies between the permissive limits (less than 0.05 mg/L) of NSDWQ, 2007 and NESREA, 2011 for water.

The result in Table 1.2 and Figure 1.2 showed that concentration of zinc in the sample analyzed is very minute with a confidence limit of 0.12±0.15 compared to the maximum permissive limits (3.0 mg/L) of NSDWQ, 2007 and NESREA, 2011, for water.

The result in Table 1.2 and Figure 1.1 showed that concentration of copper in the sample analyzed is very minute with a confidence limit of 0.14±0.09, this is similar to the result for Gwange and Bulabullin-ngarannam (0.11 and 0.05) reported by (Mustafa *et al.,* 2013) in the assessment of physic-chemical and bacteriological parameters from wash borehole water in Maiduguri metropolis, Borno State, Nigeria, compared with the maximum permissive limits (1.0 mg/L) of NSDWQ, 2007 and NESREA, 2011, for water.

The result in Table 1.2 and Figure 1.1also showed that concentration of copper in the sample analyzed is very minute with a confidence limit of 0.03±0.02, this is similar to the result for tap water and chlorinated swimming pool (0.077 and 0.074) reported by (Nwodo*et al.,* 2011) in the assessment of water quality in canaanland, Ota, Southwest Nigeria, compared with the maximum permissive limits (0.3 mg/L) of NSDWQ, 2007 and NESREA, 2011, for water.

The concentration of TDS in Table 1.2 and Figure 1.2 describes the amount of dissolved solids in condensate samples from Haier Thermocool, LG, Panasonic and Sharp air conditioner with proximity TDS value of 11, 15, 7, and 11 mg/L respectively having a confidence limit of 11.00±3.27, this is similar to the result for Hebron bottle water and rain water (15.00 and 15.00) reported by (Nwodo*et al.,* 2011) in the assessment of water quality in canaanland, Ota, Southwest Nigeria, which falls between the desirable limits of NSDWQ, 2007 and NESREA, 2011, for water.

The conductivity value in Table 1.2 of the condensate samples from air conditioner with proximity value of 16, 23, 10, 17 μS/cm respectively has a confidence limit of 16.50±5.32, this is similar to the result for rain water (16.7±2.30) reported by (Nwodo*et al.,* 2011) in the assessment of water quality in canaanland, Ota, Southwest Nigeria, which falls between the desirable limits (less than 1000 μS/cm) of NSDWQ, 2007 and NESREA, 2011 for water.

Based on the values shown on Table 1.2 and Figure 1.2, the concentration of chloride in the sample is minimal having a confidence limit of 3.90±0.66, this is similar to the result for Asho and Nkwoka-obimo spring (3.9 and 3.99 mg/l) reported by (Okechukwu*et al.,* 2012) in the assessment of parameters in spring water in Nsukka, Nigeria, compared with the maximum permissive limit (250 mg/L) of NSDWQ, 2007 and NESREA, 2011 for water.

From Table 1.2 and Figure 1.2, potassium has a confidence limit of 2.50±0.58 which lies between the desirable limits (50mg/L for potassium) of NSDWQ, 2007 and NESREA, 2011 for water.

The total hardness is a sum of the concentration of calcium and magnesium in the sample, this is summarized in Table 1.2, the total hardness has a confidence limit of 8.21±3.19 which falls between the desirable limit (500 mg/L) of the NSDWQ, 2007 and NESREA, 2011 for water.

The result in Figure 1.2also showed that sulphate is minute in sample, having a confidence limit of 4.25±1.71 which fall in the permissive level of NSDWQ, 2007 and NESREA, 2011 for water relating this to a study carried out by Kori where he stated that the higher the values obtained the higher the capability of causing bad smells or odour (Kori *et al.,* 2006).

Results of the Modeled Equation for Condensate Discharge Rate

The Table 1.3 shown below depicts the recorded time and volume of sample used in developing the linear regression model through the application of Microsoft excel 2007 software package.

Table 1.3: Recorded Time and Volume of Discharged Condensate

Time (Min)	Measured Volume of Condensate (L)	Predicted Volume of Condensate (L)
0	0	0
10	0.15	0.1677
20	0.318	0.3187
30	0.483	0.4697
40	0.63	0.6207
50	0.769	0.7717
60	0.898	0.9227
70	1.027	1.0737
80	1.199	1.2247
90	1.372	1.3757
100	1.571	1.5267
110	1.742	1.6777
120	1.899	1.8287
130	2.036	1.9797
140	2.16	2.1307
150	2.275	2.2817
160	2.381	2.4327
170	2.492	2.5837

Modeled equation: $y = 0.0151x + 0.0167$(1.1)

Regression conformity check$R^2 = 0.9972$(1.2)

Where:

y – Volumetric discharge rate of condensatefrom air conditioner

$x =$ Discharge time derivative

R^2 Most be approximately = 1

Slope of the equation = 0.0151

Intercept of the linear equation = 0.0167

The Figure 1.3 illustrates correlation plots of predicted condensate volume against the measured condensate volume. It shows the agreement between the predicted and measured values.

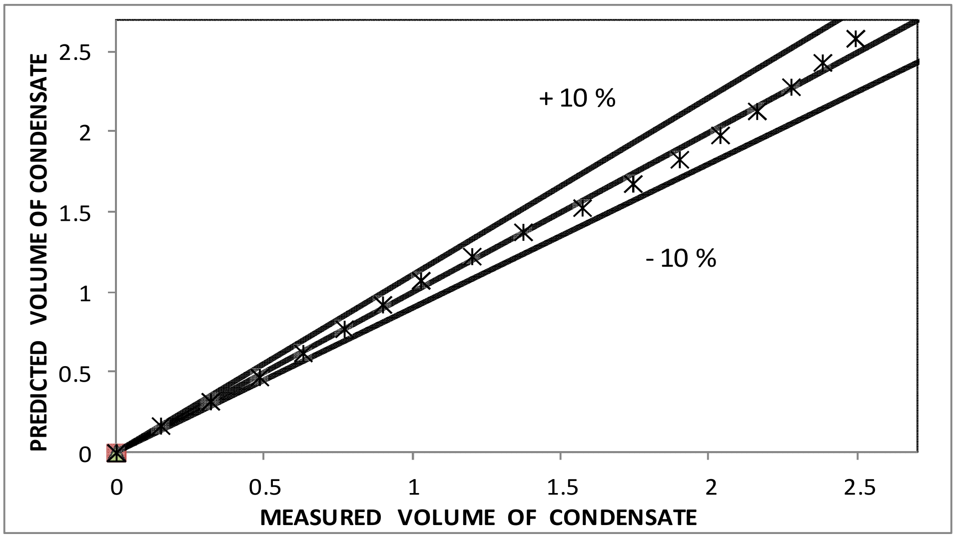

Figure 1.3: Correlation Plot of Predicted Against Measured Volume of Condensate

The modeled equation (equation 1.1) was used to estimate the amount of water that could be collected from air conditioners at various sampling location. The result in Table 1.4 was gotten as an estimate for volume of condensate from Haier Thermocool (2.2 and 1.6 Hp), LG (1.4 Hp), Panasonic (2.7 Hp) and SHARP (1.4 Hp) air conditioner. The assumptions made with regards to numbers of work days and work hours at the Federal University of Technology Minna, Gidan Kwano Campus will be explained next.

Assumptions

i. Work hour per day = 8 hours (8 am – 4 pm)
ii. Work days per week = 5
iii. Total number of Work days per year = 260 days
iv. The maximum day time temperature of Minna is about 35 ^{0}C in the months of March and April, while a minimum temperature of About 24^{0}C. The maximum day time temperature is about 35^{0}C is recorded in the months of December and January, the mean annual temperatures are between 32 ^{0}C to 33 ^{0}C, It should however be noted that the climatic conditions are subject to changes (Olasehinde *et al.,* 2014).

Required Tank Capacity $= \dot{v} \times D_n$ (1.3)

Where: $\dot{v}$ = Volumetric discharge rate per year (L / Yr)

$D_n =$ Number of work days per month

Let D_n = 260 Days / 12 months

As 260 Days $\equiv$ 1 year

NB : required tank capacity was rounded up to the nearest hundred.

Table 1.4: Volumetric Discharge Rate of Condensate from Air Conditioner

Location	Numbers of functional air conditioner	Litres per minute	Litres per hour	Litres per day	Litres per year	Required tank capacity/ month
Senate building	56	1.78	51.67	406.82	105,531.82	8,800 (L)
SET	49	1.56	45.21	355.97	92,340.34	7,700 (L)
Chem Engrg Department	19	0.60	17.53	138.03	35,805.44	3,000 (L)
SEMT	17	0.54	15.69	123.50	32,036.44	2,700 (L)
TOTAL	141	4.48	130.1	1,024.32	265,714.04	22,200 (L)

The result of the modeled equation shown in Table 1.4 revealed the amount of generated from an air conditioner to be 0.92 L/hr and 1,884.50 L/yr and require 200L storage capacity tank. While the amount of condensate that will be generated by functional air conditioner from the Senate building, SET, SEET (Chemical Engineering Department) and SEMT is estimated to be 105,531.82 L/yr, 92,340.34 L/yr, 35,805.44 L/yr and 32,036.44 L/yr respectively, and requires a condensate collection tanks with storage capacities of 8,800 litres for Senate building, 7,700 litres for SET, 3,000 litres for Chemical Engineering Department, and 2,700 litres for SEMT.

Conclusion

This study presented the level of physico-chemical, microbial, and metallic parameters such as, pH, TDS, conductivity, temperature, dissolved oxygen, chloride, sodium, potassium, total hardness, calcium, magnesium, zinc, iron, copper, chromium, sulphate, lead, BOD, COD and carbonated in the condensate discharged from air conditioning system at the Federal University of Technology Minna, Gidan Kwano campus, Niger State Nigeria.

The result shows that all the parameters analyzed does not exceed the permissive limit of NSDWQ, 2007 and NESREA, 2011 standards and a such the water could be used for domestic and industrial purposes such as toilet flushing, outdoor watering, cloth washing, car washing and cooling tower.

The modeled equation gave an approximate volume of water discharged per unit time from an air conditioner when compared with the experimental sampling time recorded at ambient temperature.

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