WEENTECH Proceedings in Energy

ICEEE 2016

16th -18th August 2016
Heriot-Watt University, Edinburgh
United Kingdom

Volume 3: International Conference on Energy, Environment and Economics, September 2016

ISSN: 2059-2353
ISBN: 978-9932795-2-2
www.weentech.co.uk

Edited by:
Dr. Renu Singh, IARI, New Delhi, India
Dr. Anil Kumar, PSU, Thailand
Published by World Energy and Environment Technology Ltd.

Potential for Extracting Water from atmospherically Jordanian Air

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Abstract

This paper aims to provide solutions for water supply in regions suffering from shortage of fresh water, and contaminated water. It presents a method to extract pure water from atmospheric air. It depends on intensifying the water vapor from the air. The plant was designed to perform the optimum levels to produce high quality water with minimal electricity consumption. The harvesting water was inspected and analyzed based on ISO/IEC 17025 method to check the purity water. This study also investigates the potential of using a solar powered for atmospheric water generation (AWG) as a new option for fresh water production. A proposed solar AWG unit was assembled, analyzed and modeled using HOMER software. The results demonstrated that the water produced by the water extraction plant is pure, safe, economical, and acceptable tasting. It can be used as drinking water after treated by filter and disinfected by Ultra Violet Light (UV) technique. The feasibility analysis showed that there is a potential to adopt solar powered of AWG as strategic and alternative option for a small area; which is suffering from shortage of drinking water.

Keywords: Pure water, extract water, atmospheric, water inspection, filter, UV, AWG.

1. Introduction

The scarcity of drinking water is widely spread in many countries around world and particularly the regions of northern Africa, Middle East, and Central and Southern Asia. Currently Jordan is facing a serious water crisis due to limited and insufficient water resources. Since it has been classified as one of the top ten poorest countries worldwide in the availability of renewable water resources. The available sustainable water resources are significantly decrease to an annual 160 m^3/year share in recent years, compared to 3600 m^3/year in 1946. Therefore, Jordan faces a real problem in this issue, and it is seeking for possible solutions, in finding advanced technologies and wider cooperation [1]. There are different strategies to provide arid areas with fresh water which are mainly investigated by the following methods [1, 2]: transportation of water from other locations; desalination of saline water; and harvesting water from atmospheric air. The first method of transportation of water through these regions is usually costly, while the second method using desalination depends on the presence of saline water resources, which are usually rare in an arid regions. However the third method basically depends on atmospheric air which is a huge and renewable reservoir of water. At any certain time, there is approximately 3,100 cubic miles of water in the atmosphere, 98% of which is in the form of vapor, and 2% is as clouds. It is known that About 280 cubic miles of water evaporates or transpires daily into the atmosphere. In addition, one cubic mile of water contains over one trillion of water-gallons [3]. Hence, there are several advantages of the process of water-extraction from atmospheric air compared with the other techniques. First, as air is the source of water, it is renewable and clean. Secondly, the amount of water in atmospheric air is about 14000 km^3 compared to only about 1200 km^3 fresh water in the earth. Moreover, it is a technique based on natural resources, and the renewable energy sources like solar energy where the available area to collect solar radiation and volumes of air are by God gifted, which are preferable as a solution for the water-supply shortage in arid places [4]. And hence it can be used as a new and renewable water resource. Extraction of water from atmospheric air can be accomplished by two different methods. The first method is by cooling moist air to a temperature lower than the air dew point. The second one is by absorbing water vapor from moist air using a solid or liquid desiccant, with subsequent recovery of the extracted water by heating the desiccant and condensing the evaporated water [5].

The main purpose of this paper is to provide solutions for water supply in regions suffering from shortage of fresh water, and suffer from polluted or contaminated water. This manuscript describes the techniques of extraction of water form atmosphere in section one, while the section two discusses the related research from the body of literature. Section three illustrates the system component. Section four present a comprehensive description of water treatments using different filters. The experimental results were introduced in section five. The solar air water generation (AWG) simulation and feasibility analysis was discussed in section six. Finally, section seven summarizes the study findings through the conclusion.

2. Literature Review

A number of researchers have investigated the extraction of water from Atmosphere. Consequently many papers have been published in this area. The authors have extensively reviewed these researches and found that many interesting methods have been developed to harvest the water from different perspectives and modeling schemes. For example, Hall [6] proposed a cycle for producing water from atmospheric air by absorption technique using ethylene glycol as a liquid desiccant with subsequent recovery of the extracted water. Also, he studied the effects of temperature and humidity on the recovered water. The results were presented in the form of a composition psychometric chart. However, the paper does not provide any information about the mass of the recovered water [4]. Another relevant work was conducted by Sofrata, [7] constructed a non-conventional system to extract water from air based on an adsorption process, using a solid desiccant. Similarly, this paper examined the feasibility of the application of air conditioning systems for collecting water from moist air by cooling it to a temperature lower than the dew point. Alayli [8] used a typical S-shaped composite material for absorption of moisture from atmospheric air with subsequent regeneration using solar energy. On the other hand, Hamed [9-11] tested two methods to extract water from atmospheric air using solar energy. The first method based on cooling moist air to a temperature lower than the air dew point using a solar LiBr–H_2O absorption cooling system, while the second method based on the absorption of moisture from atmospheric air during the night using $CaCl_2$ solution as a liquid desiccant, with subsequent recovery of absorbed water during the day. The findings of this study revealed that the second method was recommended as a most suitable application of solar energy for water recovery from air. It is strongly recommended for climatic conditions with high temperatures and humidity such as in the coastal regions of the United Arab Emirates. Kabeel [12] investigated a possible technique for obtaining fresh water based on the process of cooling and dehumidification of air conditioning. The process was then analyzed and the operating parameters were optimized to maximize the condensate output. However, Awad et al [13] described the application of a simple vapor-compression refrigeration cycle for cooling moist air to a temperature lower than its dew point where moisture condensation takes place. In addition, a theoretical model for the selection of the optimum cooling temperature was developed. Gandhidasan and Abualhamyel [5, 14] investigated an analytical procedure for calculating the mass of absorbed water from atmospheric air using a liquid desiccant as a function of meteorological data and initial desiccant conditions.

As mentioned above, several investigators have studied to extract water from atmospheric. In general, there are two basically approaches, the first one basically depends on solar energy, and it is reported that the energy consumption is highly due to low conversion efficiency. Another approach for extraction water from atmospheric air by cooling moist air to a temperature lower than its dew point where moisture condensation takes place, is performed by absorption of water from the moist air into a solid or liquid desiccant with subsequent separation of water from the desiccant by heating and condensation of vapor [4, 11, 15]. The results showed that the second system is economic. This comparison was carried out when solar energy was used as the power supply to derive any of the two systems, with the use of LiBr absorption cycle for the cooling system and applying calcium chloride as the working desiccant for the absorption and regeneration system. Furthermore, it was found that the design and operation of the absorption and regeneration system is simpler than that of the cooling system. An analytical procedure for calculating the mass of water absorbed by the desiccant from the surrounding atmosphere as a function of meteorological parameters (temperature and humidity) and the desiccant initial condition (mass and concentration) was performed.

In this study, two considerations were taken when extracting water from atmosphere. Firstly; maximize the possible amount of water extraction using the different desiccants through the absorbent regeneration cycle at certain operating limits of surrounding conditions. Secondly, the heat required for the desiccant regeneration.

3. System Description: Atmospheric Water Generation System

Figure 1 shows a schematic diagram of the atmospheric water generating system, it consists of the following parts: fan, condenser unit, evaporator, and reservoir tank. Figure 2 displays the actual air water generating components. The air water harvesting units is worked according to these steps; (i) air is passed through an electrostatic filter, removing 93% of all air born particles; (ii) This clean humid airflow passes through a condensation unit receives (cooled coil) to reduce the air temperature, which leads to reduce capacity of air to carry water vapor, and then causing water vapor to condense; (iii) during the air water generating apparatus collects the water, it drops it into a collection tray and immediately passes through Ultraviolet (UV) light, where it stays in contact with UV rays for approximately 30 minutes. This kills over 90% of all germs and bacteria in the water; (iv) water harvesting is then pumped through a sediment screen, and then through two solid block activated carbon micron filters, removing over than 90% of any volatile organic chemicals that may be found in the water; (v) water is then filtered through AWS's proprietary ultra-filtration (UF) membrane, with a pore of 0.15 microns size o, to remove virtually all bacteria and common viruses; (vi) The water is then pumped into a reservoir tank; and finally (vii) The water is then recycled from the reservoir tank, every 30 minutes through the UV rays and back into the

reservoir tank. The rate of water extraction depends on the ambient temperature, relative humidity, the volume of air passing over the coil, and the machine's capacity to cool the coil.
Most of AWG machines work through electricity, that allow to integrate it with solar or wind energy, which becomes a totally green technology.

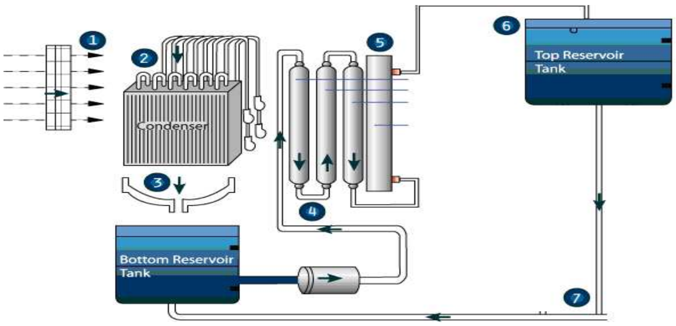

Fig.1 Schematic diagram of the air water generating system.

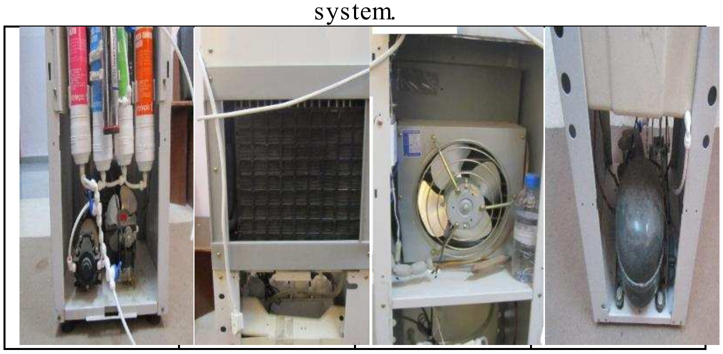

Fig. 2 Air water-generating components (electrostatic filter, UF Cartridge Filter, fan, condensation unit, and compressor).

4. Filter Function

Six types of filters were widely used in water treatment, which basically are: (i) Air-Filters, which it consist from two types of filter , (a) the first one electrostatic filter is the one into which air passes through before being condensed and converted into water. Our electrostatic filter effectively prevents micro particles and dust from entering the machine; while the second one (b) Carbon Filter functions as taste and odor remover. The second filter (ii) Ultra Violet Filter: the waters collected from the air, passes through a germicidal ultra violet system to ensure water is fully disinfected double-pass ultra violet, allows the water to pass through and to be treated using strong ultraviolet rays; the third filter. (iii) Sediment Filter, It removes any suspended particles remain in the water. (iv) Pre-Carbon Filter: It removes chlorine, bad taste, odor, sediment extant, and sediment. It mainly removes lead, copper, chloroform, chemical residuals, herbicides, pesticides, and other volatile organic compounds. (v) Ultra Filtration Cartridge: It is simply a bundle of permanently hydrophilic (water loving) capillary membrane filters. These filters have a highly porous, asymmetric structure in which the incoming water follows a path from the large pores on the outside wall to the small pores on the inside wall. Ultra Filter patented low-pressure membrane technology is unique for its high flow rates at minimal pressure requirements, and of its very tight pore size control (0.01 micron). This result is incomparable in the removal of organic contaminants, bacteria, and cysts; finally; (vi) Post-Carbon Block Filter: It removes extant odor and improves water taste.

5. Experimental Results

This air water-generating unit was tested under Jordan climate in Amman city, and it was operated frequently without any technical problem. During the test, both the relative humidity, the surrounding air temperatures were measured, and the amount of generated water was collected and weighted. Table 1 summarize the test results. Also, the inspection of sample water generation purity using filtration and UV technique.is depicted in appendix A.

Table 1 Summarize of experimental results.

	Test 1	**Test 2**
Test Time (Month)	March	April
Test Duration (h)	8 h	8 h
Average temperature (º C)	18	26
Average RH (%)	62	53
Water generation (liters)	9.5	8

6. Solar Air water Generation (AWG) Feasibility Analysis

6.1 Site Information

Amman city is largest city in Jordan by population lies at 31°56′59″N latitude and 35°55′58″E longitude. The solar radiation data for this area were obtained from the National Renewable Energy Laboratory (NREL) website. The annual average solar radiation for this region is 5.18 kWh/m^2/day. The site solar resource profile over a 1-year period is shown in Figure 3. The monthly average temperature and relative humidity were obtained from NASA surface meteorology and solar energy and displayed in table 2.

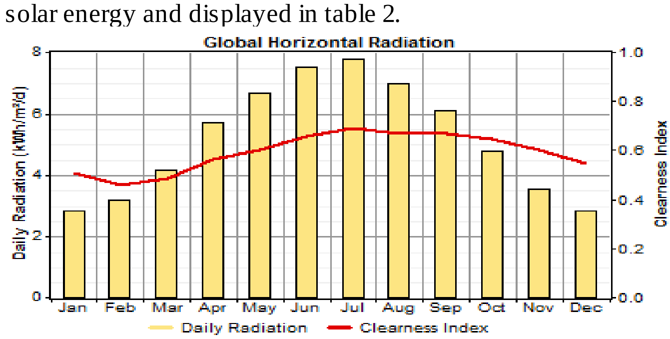

Fig. 3 Monthly average of the total solar radiation and clearance index.

Table 2 Monthly averaged temperature (°C) and relative humidity (RH %) in Amman city.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
T_{Avg}	10.6	11.3	14.1	18.8	22.1	24.2	26	26.3	25	21.7	17	12.3	19.2
T_{Min}	6.34	6.29	8.34	12.3	15.3	18.1	20.5	21.2	19.9	16.9	12.5	8.11	13.8
T_{Max}	15.1	16.2	19.6	24.9	28.6	30.4	31.8	31.9	30.5	26.6	21.7	16.8	24.5
RH	70	67	60	50	39	37	40	43	47	47	56	68	52

6.2 System Modeling and Result Analysis

AWG units was powered by using photovoltaic cell generator (PV), the supply system was analyzed by the hybrid optimization model for renewable energies (HOMER) commercial software was developed by National Renewable Energy Laboratory (NREL). The system modeling was based on the site information, and energy demand from the product data sheet. Below the following assumptions and limitations:

- **Assumptions**
  - The cost for the PV system was assumed: 1,500 USD /kW
  - The electricity tariff: 0.08 USD /kWh (middle tariff for domestic sector)
  - Operation hour is: 8 hours
  - The electricity price escalation: 4%
  - The inflation rate: 7%

- **Limitations**
  - There is enough available area for the PV system, but in practice it's not always available for the individual and residential projects
  - The excess electricity will not be sold to the grid (because the grid purchase just a limited quantity based on the total consumption and generation, and to avoid exceed this limited amount of energy the study assumed there is no sale back electricity).

Figures (4 & 5) and table 3 show the system configuration and simulation result. The analysis shows that the best PV size is 40 KW, this size will cover around 74% of the AWG unit load, and the gap will be filled from the national grid. The levelized cost of electricity (COE) is 0.06 USD/KWh. As shown in the table 3.

To calculate the levelized cost of water production (COW), the capital cost of the AWG unit (138,500 USD from email communication) add to the PV system cost, the new COE that depicted in table 4 was used to calculate COW, and the result presented in the table 5.

The analysis shows that the cost of water production from AWG is (0.07 USD /L). This cost is higher than normal water tariff and the actual operation cost. For example actual water cost from DISI project around (1.93 USD/m3) [16]. This mean the water cost from AWG around thirty six times more than the water cost from DISI project.

The feasibility analysis showed that it is not feasible to adopt AWG option as strategic and alternative option for the domestic water supply as DISI project due to water production cost, also the size limitation. But this option could be used as strategic and alternative option for a drinking water purposes. According to the 2009 Population and Family Health Survey, 31% of households in Jordan use bottled water as primary source of drinking water [17]. There are many bottled water product in the Jordanian market, and the cheapest option of bottled water is from local filtered water industry; which cost around (0.08 USD /L), this cost will increase by increasing water tariff, electricity, and fuel.

AWG offer a drinkable water with a competitive price to the bottled water price. And this technology will be more feasible if we take the Feed in Tariff for the excess electricity in consideration. Also if there is a reduction initial investment, and this could be by project scaling and localized this technology. Figure 6 shows COW versus initial investment reduction %.

The human health and environmental side effect should be taken in consideration; AWG offer a drinkable water without health and environmental side effect as bottled water and the filtered water industry, for example the widespread use of chemical treatment for water as chlorine has been proven to have hazardous side effects if taken excessively, the bottle re-use has a health concerns, and disposal or accumulation of non-biodegradable as bottle poses the environment.

Table 3 HOMER optimization results.

			PV (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	COE ($/kWh)	Ren. Frac.
			40	30	200	$ 41,500	1,115	0.060	0.74

Table 4 COE for integrated system (PV+AWG).

			PV (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	COE ($/kWh)	Ren. Frac.
			40	30	200	$ 179,900	1,113	0.208	0.74

Table 5 Cost of Water (COW) analyses.

Unit output (L/d)	Unit output (L/8hr)	Nominal power (KW)	Total power (KWh)	COE (USD /KWh)	TCOE (USD /kWh)	COW (USD /L)
1722	574	25	200	0.208	41.6	0.07

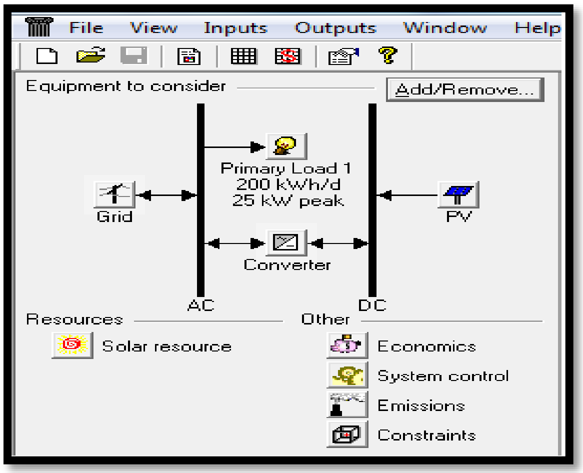

Fig. 4 HOMER system configuration.

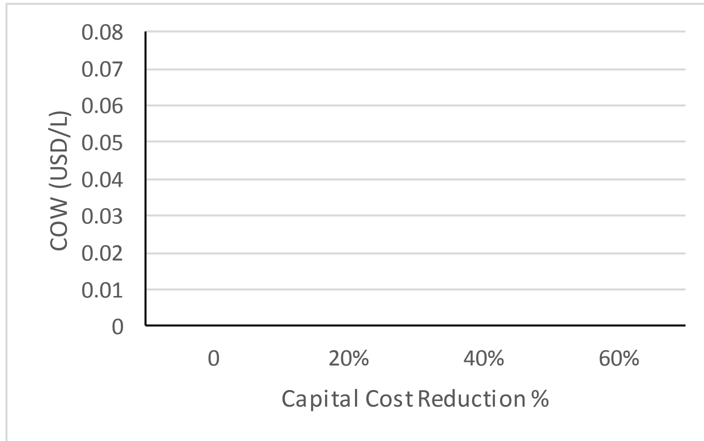

Fig. 6 Cost of water (COW) Vs. initial investment reduction %.

Fig. 5 40 KW Photovoltaic (PV) simulation result.

6. Conclusions

This study applies the approach of adapting air-water by intensifying the water vapor from the air to produce potable water in an economical and feasible way. The proposed solar powered system of AWG unit was analyzed and modeled using hybrid optimization model for renewable energies (HOMER) commercial software. The results of this study can be summarized as follows:

- It deems possible to get on the productivity of satisfactory atmosphere of the arid area, Jordan.
- The potential of large amounts of extracted water from air and low operating costs will make a radical change in solving the problem of drinking water-

supply shortage in Jordan, and open new perspectives for agriculture and the elimination of desertification in countries where is a water shortage.

- The analysis of the generated water from air shows that the generated water is drinkable.
- The study showed that the solar driven AWG technology is technically feasible and it can be worked and Jordanian weather conditions.
- The feasibility analysis show that it's not feasible to adopt AWG option as strategic and alternative option for domestic water supply as RDS project. But this option could be used as strategic and alternative option for a drinking water purposes.
- AWG can offer a drinkable water with a competitive price for the bottled water. And there is a high potential to reduce this price if we take the Feed in Tariff for the excess electricity in consideration, or if we go with a large project scale.
- The AWG technology is more environmental and health friendly than bottled water.
- AWG technology has an enormous advantage in case of an emergency where all water sources have to be interrupted.

All the above mentions show that there is a high potential for AWG technology as strategic option for dirking water in Jordan, and we should start immediately to investigate this technology more.

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Acknowledgement

The authors would like to express profound thanks and deepest gratitude to Royal Scientific Society Laboratories and Water Quality Sector / Water Authority of Jordan, and the Dead Sea water center for their fully technical support of this project which includes water inspection analysis.

Appendix A

Appendix A: Inspection of sample water generation purity using filtration and UV technique.

Component	Result	LRV	Unit	Method Used
A-BHC	<0.01	0.01	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
Lindane	<0.01	0.01	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
Heptachlor	<0.01	0.01	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
D-BHC	<0.02	0.02	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
Heptachlor epoxide	<0.01	0.01	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
P,P-DDE	0.02	0.01	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
Dieldrin	<0.01	0.01	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
P,P-DDD	<0.02	0.02	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
Endosulfan 2	0.03	0.01	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
P,P-DDT	<0.02	0.02	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
Endrin Aldehyde	0.02	0.01	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
Endrin Ketone	<0.01	0.01	ppb	Gas Chromatographic / ECD (Ref. CHO-OCP-R*003)
Electrical Conductivity	25.8	2	Us/cm	Laboratory Method (Ref. CHI-EC-R*004)
pH	7.00	N/A	unit	Electrometric Method (Ref. CHI-PH-R*003)
Calcium	3.21	0.3	mg/L	Ion Chromatographic Method
Magnesium	<0.3	0.3	mg/L	Ion Chromatographic Method
Sodium	1.15	0.3	mg/L	Ion Chromatographic Method
Potassium	0.39	0.3	mg/L	Ion Chromatographic Method
Chloride	<0.5	0.5	mg/L	Ion Chromatographic Method
Sulfate	0.48	0.3	mg/L	Ion Chromatographic Method
Carbonate	0	0	mg/L	Titrimetric Method
Bicarbonate	10.98	8.5	mg/L	Titrimetric Method
Nitrate	0.59	0.2	mg/L	Ion Chromatographic
Hardness	9	N/A	mg/L As CaCO3	Ion Chromatographic Method by Calculation
Ammonium	1	0.1	mg/l as NH4	Ammonia Selective Electrode
Turbidity	1.63	0.2	NTU	Nephelometric Method (Ref. CHI-TRB-R*003)
Iron	<0.1	0.1	mg/L	Atomic Absorption Spectrometric (Ref. CHI-MTAA-R*003)
Zinc	<0.06	0.06	mg/L	Atomic Absorption Spectrometric (Ref. CHI-MTAA-R*003)
Copper	<0.01	0.01	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer (Ref. CHI-MTICP- R*003)
Manganese	<0.01	0.01	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer (Ref. CHI-MTICP- R*003)
Lead	<0.01	0.01	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer (Ref. CHI-MTICP- R*003)
Chromium	<0.01	0.01	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer (Ref. CHI-MTICP- R*003)
Cadmium	<0.003	0.003	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer (Ref. CHI-MTICP- R*003)
Nickel	<0.01	0.01	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer (Ref. CHI-MTICP- R*003)
Arsenic	<0.005	0.005	mg/L	Hydride Generation / Atomic Absorption Spectrometric
Selenium	<0.005	0.005	mg/L	Hydride Generation / Atomic Absorption Spectrometric
Odor	2	N/A	TON	Threshold Odor Test
Total Organic Carbon	2.26	0.3	mg/L	Persulfate-Ultraviolet Oxidation (Ref. CHO-TOC-R*002)
Aluminium	0.02	0.01	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer
Barium	<0.01	0.01	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer
Silver	<0.01	0.01	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer
Antimony	<0.005	0.005	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer
Fluoride	<0.2	0.2	mg/L	Ion Chromatographic Method
Nitrite	<0.2	0.2	mg/L	Ion Chromatographic Method
Mollybdenum	<0.01	0.01	mg/L	Inductivety Coupled Plazma / Atomic Emission Spectroscopy Ultrasonic Nebulizer
Total Dissolved Solids	16.51	N/A	mg/L	Calculation by Factor to EC Ratio
Anionic Surfactants	<0.02	0.02	mg/L	Colorimetric Method
Total Coliforms	23	1.8	MPN/100mL	Multiple Tube Fermentation (Ref. MIC-TFC-R*003)
Escherichia coli	<1.8	1.8	MPN/100mL	Multiple Tube Fermentation (Ref. MIC-TFC-R*003)
Mercury	<0.15	0.15	ppm	Hydride Generation

The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

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Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.
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WEENTECH Proceedings in Energy- International Conference on Energy, Environment and Economics, September 2016
Edited by:
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Dr. Anil Kumar, PSU, Thailand
Publisher: World Energy and Environment Technology Ltd., Coventry, United Kingdom
Publication date: 12 September 2016
ISSN: 2059-2353
ISBN: 978-9932795-2-2
To purchase e-book online visit www.weentech.co.uk or email conference@weentech.co.uk