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THE ENERGY EFFICIENT METHOD TO PRODUCE POTABLE WATER USING THE ROTARY CYLINDER SOLAR STILL

Naseer T. Alwan [1, 2], S. E. Shcheklein[1]

[1] Ural Federal University named after the first President of Russia B. N. Yeltsin 19 Mira St., Yekaterinburg 620002, Russia
[2] Kirkuk Technical College, Northern Technical University, 36001 Kirkuk, Iraq
tel.: +79122713619, e-mail: nassir.towfeek79@gmail.come

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In dry climate regions, the conversion of contaminated water into drinking water using solar distillation technology is one of the most widely used methods. The traditional solar distiller (CSS) is a tank with salty sea or contaminated fresh water placed in an airtight transparent chamber, where water is heated and evaporated due to the solar radiation penetrating inside. By evaporating, the water condenses on the inside of the transparent lid that covers the tank. The purified condensate, draining through the lid enters the prefabricated canal and then enters the catchment pot located at the bottom of the distiller. Despite the simplicity of the design, the performance of such distillers is extremely small.

This study provides experimental results for two types of solar distillers, the traditional solar distillation of CSS and a modified solar distillation system integrated with a rotating cylinder powered by a microdrive powered by a photovoltaic panel- MSS.

Preliminary studies have shown that the less thick the water layer, the faster it heats and evaporates. The new design includes a hollow cylinder rotating in the solar distiller's chamber, which, through capillary forces, captures water from the tank in the form of a film less than 1 mm thick.

The thin film of water evaporates in a matter of seconds. Thus, the area and the rate of evaporation increase radically.

The results of the experimental study showed that even in the Conditions of the Ural Climate Zone, the production of fresh water in a system with a rotating hollow cylinder on a summer day increased from 0.87 liters/m2 to 2.22 l/m2, i.e. by 155% compared to the traditional solar still distiller- CSS. Despite some complication and cost of MSS construction, the cost of producing 1 liter of fresh water for CSS and MSS is 0.059 and 0.054 dollars, respectively.

Keywords: drinking water, solar energy, distillation, efficiency, photovoltaics, rotating hollow cylinder, specific cost.

ЭНЕРГО-ЭФФЕКТИВНЫЙ МЕТОД ПРОИЗВОДСТВА ПИТЬЕВОЙ ВОДЫ С ИСПОЛЬЗОВАНИЕМ РОТОРНО-ЦИЛИНДРИЧЕСКОГО СОЛНЕЧНОГО ДИСТИЛЛЯТОРА

Насир Т. Алван [1, 2], С. Е. Щеклеин[1]

[1] Уральский федеральный университет имени первого Президента России Б. Н. Ельцина
ул. Мира, 19, Екатеринбург 620002, Россия
[2] Киркукский технический колледж, Северный технический университет, 36001, Киркук, Ирак,
tel.: +79122713619, e-mail: nassir.towfeek79@gmail.come

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В регионах с засушливым климатом процесс преобразования загрязненной воды в питьевую воду с использованием технологии солнечной дистилляции является одним из наиболее широко применяемых методов.

Солнечный дистиллятор традиционного типа (CSS) представляет собой резервуар с соленой морской или загрязненной пресной водой, помещенный в герметичную прозрачную камеру, в которой происходит нагрев и испарение воды за счет проникающего внутрь солнечного излучения. Испаряясь, вода конденсируется на внутренней поверхности прозрачной крышки, которая накрывает резервуар. Очищенный конденсат, стекая по крышке, поступает в сборный канал и далее поступает в водосборный бак, расположенный в нижней части дистиллятора. Несмотря на простоту конструкции производительность подобных дистилляторов крайне мала.

В настоящем исследовании приведены экспериментальные результаты для двух типов солнечных дистилляторов, традиционной солнечной дистилляции CSS и модифицированной системы солнечной дистилляции интегрированной с вращающимся цилиндром, приводимым в действие микродвигателем, питаемым от фотоэлектрической панели- MSS. Предварительные исследования показали, что чем меньше толщина слоя воды, тем быстрее она нагревается и испаряется. Новая конструкция включает в себя вращающийся в камере солнечного дистиллятора полый цилиндр, который за счет действия капиллярных сил захватывает воду из резервуара в виде пленки толщиной менее 1 мм. Тонкая пленка воды испаряется за считанные секунды. Таким образом, радикально увеличивается площадь и скорость испарения.

Результаты экспериментального исследования показали, что даже в условиях Уральской климатической зоны производство пресной воды в системе с вращающимся полым цилиндром в летний день, увеличилось с 0,87 л/м^2 до 2,22 л/м^2, т.е. на 155% по сравнению с традиционным солнечным неподвижным дистиллятором- CSS. Несмотря на некоторое усложнение и удорожание конструкции MSS стоимость производства 1 литра пресной воды для CSS и MSS составляет 0,059 и 0,054 доллара соответственно.

Ключевые слова: питьевая вода, солнечная энергия, дистилляция, эффективность, фотоэлектричество, вращающийся полый цилиндр, удельная стоимость.

Naseer Tawfeeq Alwan
Насир Тавфик Алван

Information about the author: PhD Candidate at Ural Federal University, Department of Nuclear Power Plants and Renewable Energy Sources, Russia.

Place of work: Ural Federal University named after the First President of Russia B.N. Yeltsin, Department of Nuclear Power Plants and Renewable Energy Sources

Position: Researcher

Education: Kazan National Research Technical University. A. N. Tupolev - KAI in the specialty "Heat and Power Engineering" (2014).

Awards and scientific awards: Certificate of Honor from the Ministry of Education and Science of the Republic of Tatarstan for great academic success and high creative achievements, (2014).

Research interests: Renewable energy sources, Solar desalination, heat and mass transfer.

Publications: more than 10, including 5 in refereed journals.

Сведения об авторе: аспирант уральского федерального университета, кафедра атомных станций и возобновляемых источников энергии.

Место работы: ФГАОУ ВПО «Уральский федеральный университет имени первого Президента России Б.Н. Ельцина», кафедра «Атомные станции и возобновляемые источники энергии»

Должность: Инженер-исследователь

Образование: Казанский национальный исследовательский технический университет им. А. Н. Туполева – КАИ по специальности «теплоэнергетика и теплотехника» (2014 г.).

Награды и научные премии: Почетная грамота министерства образования и науки республики Татарстан за большие успехи в учебе и высокие творческие достижения, (2014).

Область научных интересов: Возобновляемые источники энергии, Солнечное опреснение воды, тепломассоперенос.

Публикации: более 10, в том числе 5 в реферируемых журналах.

Sergey E. Shcheklein
Щеклеин Сергей Евгеньевич

Author information: Doctor of technical science, professor, Urals Federal University, head of Atomic Stations and Renewable Energy Sources Department.

Education: Urals Polytechnic Institute (1972).

Research interests: nuclear power units thermodynamics; questions of nuclear energy and thermophysics of the two-phase flows; NPP equipment lifetime enduring and reliability increasing; solar, wind and bioenergetics.

A scientific director of several realized innovation projects, including "The energoefficient house for the village", "Special systems of individual consumer solar energy supply", "The solar systems for the guarding alarm" etc.

A member of the editorial board of "Institute of Higher Education News. Nuclear Power", International Scientific Journal for Alternative Energy and Ecology magazine, Odessa National Polytechnic University article collection, International Scientific Journal "Heliotechnics". A Honoured power engineering specialist of Russian Federation, a member of International Energy Academy. Hirsch Index INDEX -13.

Publications: more than 450 scientific works, including 5 monographs, 80 inventions.

Сведения об авторе: доктор технических наук, профессор, заведующий кафедрой «Атомные станции и возобновляемые источники энергии» Уральского федерального университета имени первого Президента России Б.Н. Ельцина.

Образование: Уральский политехнический институт (УГТУ-УПИ) (1972 г.).

Область научных интересов: термодинамика ядерных энергетических установок, проблемы атомной энергетики и теплофизики двухфазных потоков, продление ресурса и повышение надежности оборудования АЭС, солнечная энергетика, ветровая энергетика, биоэнергетика.

Научный руководитель ряда реализованных инновационных проектов в т.ч. «Энергоэффективный дом для села», «Системы солнечного энергоснабжения автономных потребителей специального назначения», «Солнечные системы охранной сигнализации» и др.

Член редколлегий журналов «Известия вузов. Ядерная энергетика», международного научного журнала «Альтернативная энергетика и экология», Труды Одесского национального политехнического университета, международного научного журнала «Гелиотехника». Заслуженный энергетик России, действительный член Международной энергетической академии. Индекс Хирша РИНЦ -13.

Публикации: более 450 научных трудов, в том числе 5 монографий, 80 изобретений.

Introduction

Water scarcity is one of the world's main problems worsening over time, due to fluctuations in weather conditions all over the world. In civilized areas freshwater is available, but there is real suffering to get freshwater in rural and remote areas, Pollution rates of drinking water increased due to industrial development [1,2]. According to what has been reported, it is found that providing drinking water in certain areas can achieve net economic benefit and reductions in insurance and health care costs that increase the cost of installing the freshwater plant. This is genuine and an effective part of the major strategy, infrastructure investments in water treatment to supply fresh water supply to the homes and save the life of the poor populace in the rural, urban zone or militarism segments on limits of the country (the boundary of the country) [3]. Over a million populaces lack found by the World Health Association that admission to the cleanest drinking water. Furthermore, most of these populaces are living in rustic regions where it is difficult to construct a freshwater solutions system [4]. To provide fresh water, needs an energy source in order to convert saltwater or untreated water into fresh water. Most large plants around the world use fossil fuels (such as coal, oil, and natural gas) [5], but it is not sustainable, not available in all parts of the globe and, moreover, has side effects on the environment in comparison with renewable energy sources such as solar energy. There are many methods have been used to produce freshwater by using renewable energy sources, such as solar water distillation technology [6–8].

The current study aims to produce potable water experimentally with less energy consumption by integrating single slope solar still with rotating hollow cylinder (MSS) in order to increases evaporation surface area within solar still

list of symbols	
Units	
W / m^2	Watt Per Square Metre
m^2	Square Metre
ml/m^2	Milliliter per Square Meter
Nomenclatures	
CSS	Conventional solar still
MSS	Modified solar still
SD	Secure Digital Card
DC	Direct current
C	The total cost of the fabrication solar still
F	Fixed costs
V	variable costs

1. The modified model description

Several methods have been used to enhance productivity of a conventional solar stills [9], but most of these methods need expensive components and additional space. Therefore, the current study aims to produce potable water experimentally with less energy consumption especially in rural areas by integrating single slope solar still with rotating hollow cylinder. The productivity of conventional solar still has been investigated after modification using rotating hollow cylinder at a perfect rotational speed in order to increase the evaporation surface area within conventional solar still, a lightweight open-end rotating cylinder (corrosion-resistant galvanized iron) used. The cylinder fixed on iron shaft, which supported at its ends by two bearings. A small 12 Volt, DC motor which is used to move the car window. This motor can be supplied with electricity from any renewable energy source such as solar panels 30 Watts to supply DC motor during the daytime and connected to a storage battery to operate during sunset. The basic principle of this new method is to expose a large amount of water to sunlight than that usually exposed in conventional stills.

2. Fabrication of solar still

A schematic diagram show in figures 1 and 2 for the two models of solar stills, the first model is a conventional solar still (CSS) and the second model is a modified solar still with a rotating hollow cylinder (MSS). The dimensions of both stills are 100 * 50 * 61.8 * 26.6 cm (length, width, big side height and small side height respectively), which consisting of MDF wooden frame of dimensions 100 * 50 * 10 * 1.8 cm (length, width, height and thickness respectively). Plexiglass cover of 0.3cm thickness has been used with single slope of 35 degrees of dimensions 100 * 50 * 50 * 14.8 cm (length, width, big side height and small side height respectively) . The Plexiglas cover fixed on the wooden frame by an aluminum channel to collect the condensate water droplets on the cover, and then pass to the plastic water tank at the bottom of solar still. A water basin made of galvanized iron plate with thickness of 0.08 cm and dimensions of 94 * 46 * 10 cm (length, width, height respectively) placed on the base solar still with dimensions 100 * 50 * 0.18 cm (length, width and thickness respectively). The basin has been coated with black colour to absorb maximum amount of solar radiation energy, the inner surface of still covered by Aluminum foil with a thickness of 0.03 cm. A silicone glue has been used to instill all parts and prevent air leakage. Galvanized iron sheet 100 * 100 * 0.06 cm (length, width, and thickness respectively) has been used to fabricate the hollow cylinder and coated with black colour to absorb a maximum amount of solar energy and installed on a low carbon steel shaft of 0.8 cm diameter and 95 cm length using 0.8 cm ball bearings on the two ends of the shaft. The hollow drum was rotated using a small DC motor of 12 V and 0.1 Ampere used to move car's windows. The motor has been supplied by electricity from a small 30 Watts solar panel during the daytime, which connected to a storage battery to operate during sunset times.

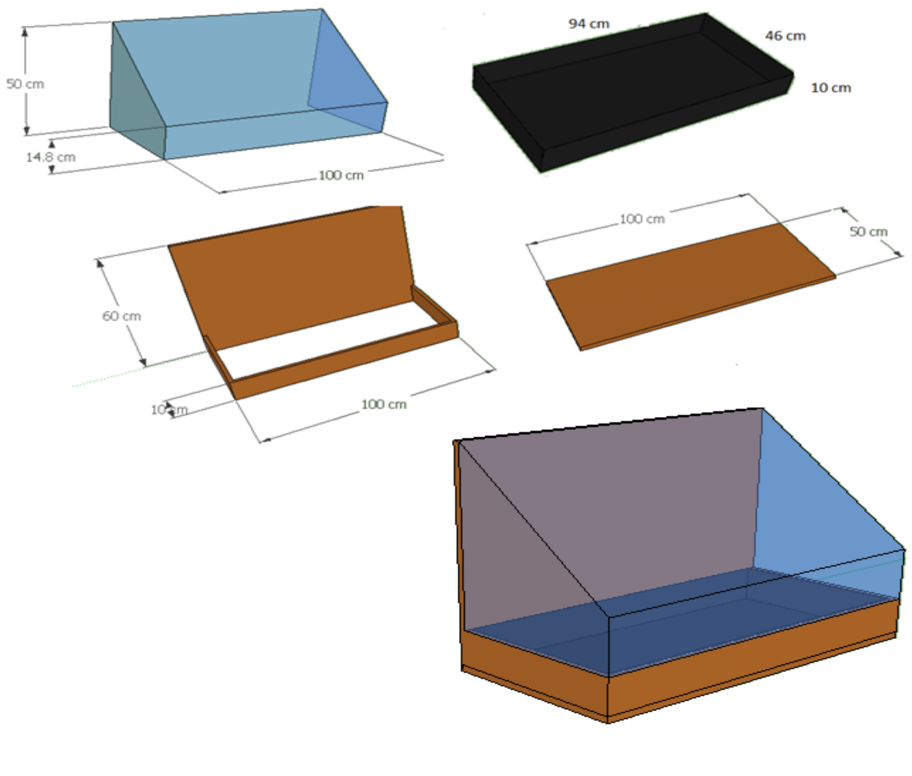

Fig. 1. A schematic diagram of conventional solar still CSS
Рис. 1. Принципиальная схема обычного солнечного дистиллятора CSS

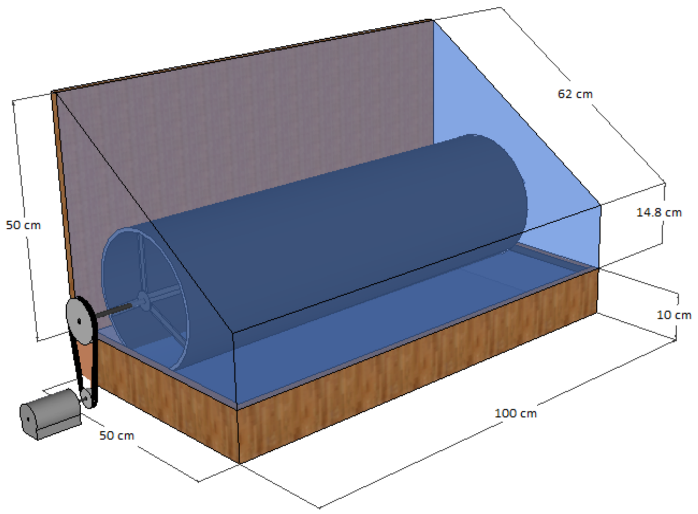

Fig. 2. A schematic diagram of modified solar still MSS
Рис. 2. Принципиальная схема модифицированного солнечного дистиллятора MSS

Different devices have been used to measure the different parameters as shown in table *1*. SD data logger 4 channel has been used with K-type 0.3 mm thermocouples, which calibrated between 0 and 100 °C, to measure the temperatures at different places of system such as Plexiglass cover, vapoure within solar still, basin water and basin liner. Anemometer device has been used to measure the ambient wind speed and solar power meter device used to measure solar radiation intensity in W/m^2. Humidity and temperature meter device have been used to measure the temperature and relative humidity for the ambient air.

Table. 1.

The various experimental measuring devices with their accuracy.

Таблица. 1.

Различные экспериментальные измерительные приборы с их точностью.

Measuring Device	Accuracy
SD data logger 4 channel (model 88598)	$\pm$ 0.3% rdg + 1°C
Digital laser infrared thermometer temperature (model TEGMART TE-TEM-LS-PRB).	$\pm$ 1.5%
Humidity and temperature meter (model GM1362)	Humidity 3% Temperature 0.5%
Solar power meter device (model TENMARS TM-207)	$\pm 10\ W/m^2$
Anemometer device (model ut363)	$\pm$5% rdg + 0.5°C

3. Procedures of test

The tests were carried out during June 2019 at the Ural Federal University of Yekaterinburg/Russia. The measurements conducted in two stages, in the first stage, primer testing on the experimental station was conducted to evaluate the performance and possibility of the amendment in the designs to reach the best case. Tests were conducted in different days and an uneven environmental condition with 10 tests and chosen 15.06.2019 as perfect day. Second stage included studying the hourly freshwater productivity for the two solar stills, tests begin at 08:00 am and continue to 20:00 pm (12 hours).

4. Results and discussion

weather data, which has been recorded, which included solar radiation intensity, relative humidity and ambient temperature. Figure 3 shows the experimental results for a perfect day on 15 Jun 2019. The effect of solar radiation started after 6:00 am and the maximum intensity of the solar radiation is approximately at 02:00 pm, in which the intensity of radiation $940\ W/m^2$. Early in the morning times, intensity of solar radiation and ambient temperature are relatively low, at the noontime, between 12:00 pm to 14:00 pm, the rate of solar radiation increases then falls again in the afternoon, the maximum ambient temperature occurs at around 12:00-

13:00 pm. The relationship was direct between solar radiation and ambient air temperature during a perfect day and inversely with relative humidity, increased solar radiation and ambient temperature led to decrease the relative humidity. The highest relative humidity values were recorded at the early hours and at sunset and lowest at sunrise, while the highest ambient air temperatures were recorded in the middle of the day at highest solar radiation and the lowest values were at sunset.

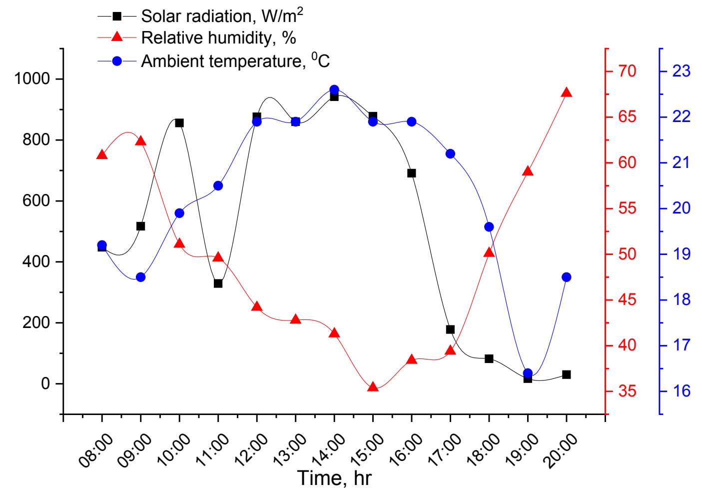

Fig. 3. Relation between the time per each hour and solar radiation intensity, relative humidity and ambient temperature
Рис. 3. Соотношение между временем в часе и интенсивностью солнечного излучения, относительной влажностью и температурой окружающей среды.

The condensation process within the solar still depends on the temperature difference between the basin water and solar still cover at a lower temperature (free convection) which is caused by buoyancy forces due to the differences in vapour density. When the basin water heated, the density changes in the boundary layer and led to the evaporation of some water molecules in the boundary layer of basin water. The generated vapour rises and replaces with a cooler vapour which will also heat up and rise. These phenomena continue to be called natural or free convection. The vapour reaches the cooler surface will lose part of its energy and condense. The condensation rate increases with the increasing temperature difference between the two surfaces. Therefore, in the current study, two factors have been investigated, first the basin water temperature, and the second is the inner Plexiglass cover temperature. In Figure 4, it was observed that the temperature difference between the basin water and a plexiglass cover is relatively few at the morning hours, because the thermal capacity of the water is greater than the plexiglass so, the plexiglass is heated firstly, and over time the temperature difference increases to reach the highest value 7.4 °C at 16:00 pm, then it starts to decrease until the end of the day.

In Figures 4 -5, it is observed that the temperature difference between the basin water and Plexiglass cover in the MSS model is less than that of the CSS model, to reach 7 °C at 16:00 pm in MSS model , due to that the basin water temperature within the MSS is lower than that of the TSS about 0 - 1.2 °C, because the solar radiation doesn't reach the water surface under the hollow cylinder, also because that the Plexiglass temperature in MSS model higher than that of the TSS about 0 - 0.3 °C, due to increase the evaporation rate of MSS.

But there is a new temperature difference that has been added to the distillation system, it between the outer cylinder surface and the Plexiglass cover, which was greater than the previous two temperature difference. In Figures 5, observed that the temperature difference between the outer cylinder surface and Plexiglass cover in the MSS reached the highest value 7.7 °C at 16:00 pm, due to that the hollow cylinder surface direct heated by solar radiation during daytime.

From figure 6 it can be illustrated that the MSS productivity is more than that of the CSS, there is two reasons for productivity enhancement, first one the thin water layer which formed over the cylinder surface that leads to high rate of evaporation compared with CSS, the rate of heat transfer between the cylinder surface and the thin film water layer adjacent to the cylinder surface higher, compared to the basin water and the basin liner of the conventional solar still, and thus the distillate is increased. The second reason is the increase in the surface area of evaporation section in MSS, which constantly renewed in comparison with the CSS[10], the surface area in MSS was $2.538\ m^2$, which equals to about five times the surface area in CSS $0.5\ m^2$ [11]. It can be seen also from figures 6, that the productivity of the MSS started early in comparison with CSS, to exceed the productivity of CSS several times until 10:30 am and reduced afternoon to reach 155 % at 20:00 pm, 870 and $2220\ ml/m^2$ from MSS and CSS, respectively.

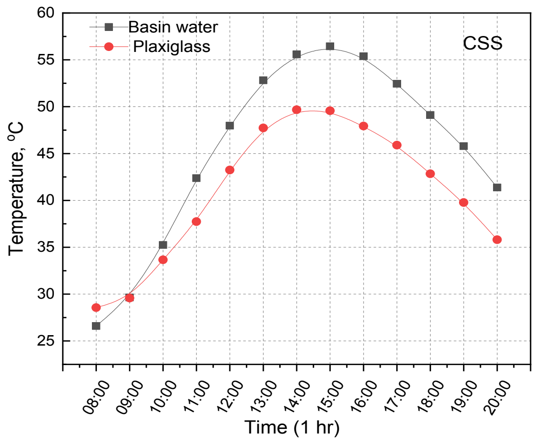

Fig . 4. Hourly temperatures of basin water and Plexiglass cover for CSS
Рис. 4. Почасовая температура воды и оргстекло для CSS

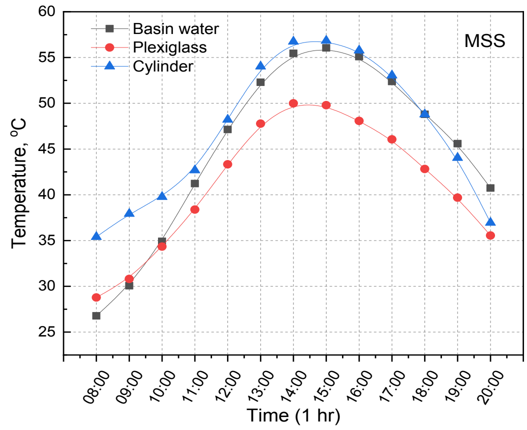

Fig .5. Hourly temperatures of basin water, Plexiglass cover and hollow cylinder outer surface for MSS
Рис. 5. Почасовая температура воды, оргстекло и внешней поверхности цилиндра для MSS

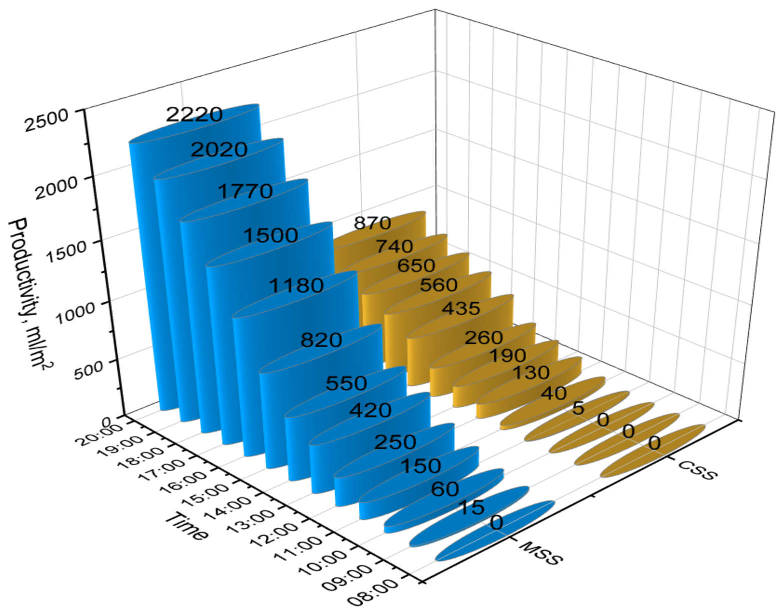

Fig .6. Hourly productivity for MSS and CSS
Рис .6. Почасовая производительность для MSS и CSS

5. Cost estimation

The production cost of one litre of potable water for a perfect day 15.06.2019 at the highest productivity improvement estimated as follows:

The total cost of the fabrication solar still C is equal to the fixed costs F plus the variable costs V [12]:

$$C = F + V \quad (1)$$

Where: $V = n \times 0.05 \times F$ (2)

Suppose the variable cost V is 0.05 F per year as a cost of periodic maintenance, n: Life expectancy for both solar stills are 10 years,

Then the total cost for CSS and ESS from table 2

$C = 62 + 10 \times 0.05 \times 62 = 93$ \$

$C = 145 + 10 \times 0.05 \times 145 = 217.5$ \$

The daily productivity from CSS per unit area 0.5 m^2 was 0.87 L/m^2, and for MSS 2.220 L/m^2, if assuming both solar stills operating 180 days in the year, therefore the total annual productivity during the work period 10 years for CSS is 1566 L/m^2, and for SSSSRHC is 3996 L/m^2. So, the cost of production of one litre of potable water from CSS is $93/1566 = 0.059$ \$ and from MSS is $217.5/3996 = 0.054$ \$.

Table 2.

Fabrication cost for MSS and CSS

Таблица 2.

Стоимость изготовления для MSS и CSS

Unit	Quality	Cost of CSS, $	Cost of MSS, $
MDF wooden board, 1.8 cm	2 m^2	14	14
Plexiglas cover 0.3 cm thickness	1.2 m^2	15	15
Galvanized iron sheet basin, 0.08 cm	1.5 m^2	11	11
Galvanized iron sheet drum, 0.06 cm	1 m^2	-	6
Drum accessories	-	-	5
DC- motor 12 V + regulator	1 piece	-	7
Photovoltaic system	1 piece	-	65
Spray paint heat-resistant	2 pieces	3	3
A mechanical float	1 piece	1	1
Heat-resistant silicone glue	2 pieces	3	3
Saltwater feeding system	-	15	15
Total cost	-	62	145

Conclusion

1. Increasing the ambient temperature or/ and solar radiation intensity with low relative humidity leads to an increase in the productivity of solar still, which means a direct relation between the solar radiation intensity or/ and the ambient temperature, with the amount of freshwater production,

2. Using the new hollow rotary cylinder solar still design, the productivity can be enhanced to reach about 155% depending on the environmental conditions and the improvements type.

Generally the cost of producing one liter of freshwater from a conventional solar still was 0.059 $, while an enhanced solar still was 0.054 $ [12]. In general, the cost of producing drinking water per cubic meter using renewables is higher than the cost of fossil fuels. But fossil fuels have side effects on the environment and are not available worldwide. Thus, the economic feasibility of renewable energy-based distillation systems becomes more justified.

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Транслитерация по BSI

Китай наращивает закупки углеводородов

Китай в прошлом году увеличил закупки сжиженного природного газа за рубежом на 12%, нефти и газа - на 7% и 5% соответственно.

По подсчетам издания Upstream, экспорт СПГ Китаем в 2020 году составил 67,6 млн тонн. При этом в декабре поставки СПГ из-за рубежа снизились в 4 раза, до 1,61 млн т по сравнению с 6,6 млн т в ноябре.

Как сообщило государственное статистическое управление Китая, в прошлом году страна импортировала 540 млн тонн нефти и 102 млн тонн газа. Если в декабре импорт нефти снизился на 15% по сравнению к декабрю предыдущего года, то газа, наоборот, подскочил на 18%.

Китай также незначительно увеличил собственную добычу нефти — на 1,6%, до 195 млн тонн, а объем переработки нефти на заводах страны — на 3%, до 670 млн тонн Добыча газа выросла за год на 10%, до 188 млрд кубометров, только в декабре подскочив на 14%.

На фоне падения цен на нефть Китай начал скупать подешевевшие энергоносители: нефть, газ, уголь и СПГ.

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