NEXUS OF GREEN TECHNOLOGY AND GREEN ENERGY IN CLEAN WATER PRODUCTION AT ZERO CARBON EMISSION: AN EXPERIMENTAL STUDY

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ABSTRACT: *This paper reports an experimental finding that was conducted with green technology and green energy for optimize clean water production instream water at zero carbon emission ($CO_2eq = 0$). Required experimental run was estimated by using central composed design (CCD) model. Experimental data were analysed by statistical tools for achieving research objective. The experimental rig was developed with renewable granular biomass filter (RBF) and was operated at various feed pressure and flow rate. The finding revealed that the optimum pressure head 2.1 meter was required to produce required clean water quality (TSS≤ 0.8 mgL^{-1}) at 91.0% TSS separate efficiency. It was also found that the optimum clean water production rate was 1.0 m^3(hr-m^2)$^{-1}$] at TSS density in the product water 0.8 mgL^{-1}. The entire water filtration process was conducted with green energy, in that aspect, clean water production was at zero carbon emission. These findings could be a reference to the water industry, engineering professionals and policy implementing agencies involved in reducing carbon emission for mitigating climate change. This study concludes that green technological nexus with green energy for producing clean water is a potential route to reducing carbon emission for mitigating climate change, and thus, economic and environmental sustainability could be achieved.*

Keywords: Green Technology, Green Energy (SDG7), Clean Water (SDG6) , Zero Carbon Emission, Climate Change, Production performance, Environmental Sustainability (SDG13)

1.0 BACKGROUND OF THE STUDY

Global economic and environmental sustainability is associated with carbon emission and climate change. The current scenario is carbon emission depends on the rate of using fossil fuel in producing electricity and heat for operating economic activities [1, 2]. Carbon emission due to fossil fuel powered economy has been identified as the potential problem for climate change and downtrend of the global economy. **In this regard, an obvious question raises, what is the way to mitigating carbon emission?** This study is designed to answer this question.

As stated by IPCC, IEA and UNEP, the one of the potential carbon emission sources is the burning of fossil fuel, which positively associated with climate change [3–5]. Fact is that water and energy are the most essential utilities to perform economic activities, and at the same time, the potential carbon emission sources.

The statistical data on producing electricity, and water and supply demonstrated that the combined carbon emission from these sectors is about 2,634 Mt of CO_2eq for generating revenue per $1.0 million [6, 7]. It was also reported that carbon footprint of wastewater treatment ranged between 0.51 and 1.14 kgCO_2[(m)3 H_20]$^{-1}$ [8 9]. The researchers highlighted that carbon emission potential in clean water production ranges from 0.18 to 0.79 kgCO_2eq [m^3 H_20]$^{-1}$ [10, 11]. However, the carbon emission from energy industries is the highest, which is about 25 percent of total global carbon emission [12]. In this aspect, energy and water industry has been damaging environment and seriously jeopardizing the achievement of the sustainable development goals (SDG).

In this regard, the UN water (2020), UNEP (2023) and IPCC (2023) suggested to implement green technology for mitigating climate change [13, 14]. The report published by all these organizations demonstrates that green technology for energy and water production contribute could reduce carbon emission significantly toward climate change [15, 16].

On the background stated, this review article aims to gather information on various options of green technologies, which have been used in harvesting green energy for producing clean water at zero carbon emission to reduce global warming and to mitigating climate change..

1.2 Research Objective

This research is designed to answer the question stated in section 1.0. Broad objective of this research is to determine the optimum condition of clean water production by green technology and RBF at zero carbon emission ($CO_2eq=0$). Achieving the research goal, broad objective is divided into three parts:

1.2.1 To determine clean water production optimization rate [m^3(hr-m^2)$^{-1}$] with respect to TSS separation efficiency.

1.2.2 To optimizing feed water pressure with respect to TSS separation efficiency.

1.2.3 To Investigate for green energy consumption rate kW(m3)$^{-1}$ in producing clean water from in stream water sources at zero carbon emission ($CO_2eq=0$).

2.0 LITERATURE REVIEW

The low-pressure driven media filtering system (MFS) has been widely used by water industry for producing clean water. MFS has been installed at the primary level in the water filtration process to cater feed water for secondary and tertiary water treatment [17, 18]. A few indicators have been used for measuring the performance of MFS; the indicators are productivity in clean water production, efficiency in separating impurities from feed water, energy consumption rate [kWh(m^3-m^2)$^{-1}$] [19]. Reducing pollutants from feed water is also a measure of MFS's performance. The major pollutants reduced by MFS are chemical oxygen demand, Biological oxygen demand, natural organic materials and water-born bacteria [20, 21]. However, the fossil fuel energy consumption rate in clean water production is positively associated with carbon emission and climate change.

2.1 Green Technology for Green Energy Production at Zero Carbon Emission

A few definitions on green technology are available in the literature, but the most popular definitions are link with zero car bon emission [$CO_2eq = 0$]. Green technology is an umbrella term that describes the use of technology and science to create products and services, which are environmentally friendly and associated with zero carbon emission. The green technology also relates with the cleaner production process that improves operational performance, increase energy efficiency, and reduce waste. The green technology contributes to replace carbon emission potential fossil fuel by renewable energy for producing electricity and heat at zero emission [22]–[25].

A few reports claimed, green technology aims to developing green economy for mitigating climate change for achieving environmental sustainability [26], [27]. It was also reported that green technology primarily aims to decreases dependence on fossil fuels for generating electricity toward reducing carbon emission [CO_2eq] and air pollution [22, 28]. Khan *et al.* [29] and Su and Gao [29] also reported that green technology contributes to increase energy efficiency, which contribute to reduce energy consumptions and carbon emission rate per unit of product, which associated with the growth of green economy [26], [30]. Renewable energy is perhaps the most prominent aspect of green technology, which includes solar, wind, hydroelectric power, wind turbine and green hydrogen, which associated with net zero emissions and contribute to slow down climate change [31], [32].

2.2 Green Technology for Clean Water Production at Zero Carbon Emission

Water production is one of largest industry of the world which mostly have been operated by fusilli fuel energy. In this regard, Sohag *et al*. [32] and Lin and Zhou [33], reported that the primary benefit of using green technology for electricity and water production is to reduce the dependency on carbon potential fossil fuel. Shahidul *et al*. [33] has reported that a potential benefits of using green technology in energy industry is to producing electricity at higher efficiency, resulting in lower carbon emission rate per kWh [CO_2eq$(kWh)^{-1}$]. A similar report has been published by Alper and Oguz [34] and Sharif *et al.* [35], the published reports stated that green technology implementation in water and energy industry could significantly contribute to reduce carbon emission

The impact of green technology driven economy was studied by Mohsin et al. [2022] and claimed that a 1.0% increase in clean energy use contributes to increase green economic growth by 3.0% [34]. Bhattacharya et al. (2016) has reported a similar finding [35]. In this regards, a few researches have revealed that green technology driven circular economy for producing green energy is a means for replacing fossil fuel, which can potentially contributes to reduce carbon emission [36], [37].

The nexus of green technology and clean energy benefits society as it facilities to operate economic system at zero emission [38], [39]. In this regard, Others found a positive relationship among the adoption of green energy consumption, economic growth and environmental sustainability [39], [40]. A similar reports have been published elsewhere [41], [42]. The findings reported in this section concludes that green technology is one of the routes, which can contribute to achieve zero carbon emission for economy.

2.3 Effect of Feed Pressure on TSS Separation Efficiency

TSS separation performance from effluent by the media filter and membrane is associated with feed pressure. Hishamuddin, A H.,*et. al*. reported that TSS separation efficiency by a media filter is increased with feed water pressure up to a certain limit, when optimum separation limit achieved, the TSS separation efficiency tend to reduce [43]. It was report further that at higher feed pressure, the sand bed is expanded and porosity increase (gap between two sand gain increases), which contribute release TSS into the product water. A similar report has published by Shahidul, M. I. *et. al*., [44]. The higher feed pressure is also associated with higher energy consumption [45].

2.4 Effect of Feed Water Flow Rate on TSS Separation Efficiency

TSS separation performance from effluent by the media filter is associated with feed water flow rate. Shahidul *et al*. reported that TSS separation efficiency by a media filter is increased with flow rate up to a certain limit. With increasing the feed flow rate, when optimum separation limit achieved, the TSS separation efficiency tend to reduce [46]. It was also report that at higher feed pressure, the sand bed is expanded and porosity increase (gap between two sand gain increases), which contribute release TSS into the product water [20]. The higher feed pressure is also associated with higher energy consumption by the filtration media [47].

3.0 MATERIALS AND METHODS

3.1 Research Methodology and Experimental Setup

This experimental research aims to investigate the green energy consumption rate by RBF for producing clean water. The feed water for RBF was taken from water dam. The total suspended solid (TSS) in dam water was 10.0 mg$(L)^{-1}$. The experimental setup is presented in Figure 1.0 in the form of schematic diagram.

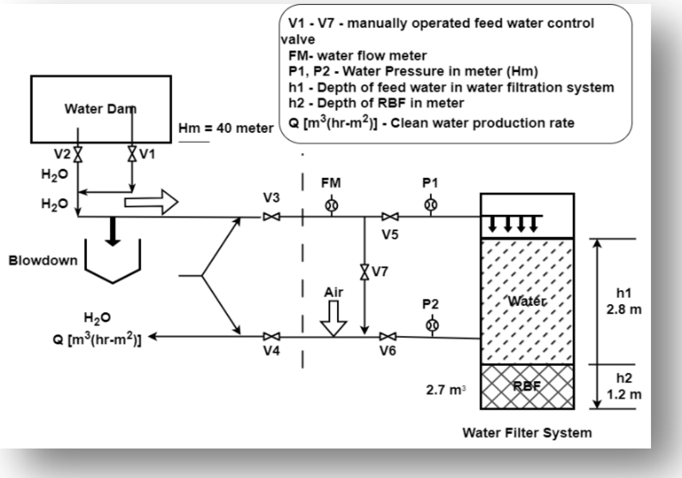

Figure 3.1: Schematic diagram of Experimental Set-up

The experimental rig is shown in Figure 1.0. The experimental run (N) was estimated by using CCD model [48]. Feed water flow rate was control by using valve V1, V2, V3, V5 and flow meter FM. The RBF fixed bed depth (h1) was 1.2 meter with porosity 0.4 [20]. Maximum feed water depth was 2.8 meter, it means range of h2 was 0.-2.8 meter. The cross-section area of the RBF was 2.25 m^2 and volume of RFB is 2.7 m^3.

Energy (Ep) and feed water Q [$m^3(hr)^{-1}$] source used for operating the experimental rig is DAM developed at elevation (Hm) of 40.0 meter. The potential energy Ep of dam water was used to supply feed water to the rig. Ep was calculated from equation (3.1).

$$Ep = \rho HQg\eta \qquad \text{Eq. (3.1)}$$

Here, ρ is water density. η is energy utilization efficiency. Data collection rate (during the experiment for every run) was one per hour. The scheduled for experiment was from 8:00 am to 16:00 pm. The total time spent for conducting the experiment was 72.0 hours. Experimental data were analysed by statistical techniques.

3.2 Theoretical Framework

This section contains the required theories and mathamatical models for data analysis.

3.2.1 Modet for Estimating Energy Consumtion Rate by RBF in CleanWater Production

Total energy consumoption by RBF in producing clean water can be estimated from equation (3.2):

$$E_{opt} = \frac{Q_{opt} x g x H_{0pt}}{3.6x10^6\eta} \qquad \text{Eq.(3.2)}$$

Here, E_{opt} is optimum energy consumtion rate [kW(m^3)$^{-1}$] 'g' is graviltity forec [9.2kg (ses)$^{-1}$] . Hm is the pressure head (meter) to supply water to RBF system. 'η' is energy utilization efficiency in RBF for clean water production. Q is product water production rate [m^3(hr-m^2)$^{-1}$].

3.2.2 Estimating Number of Experiments Require Conduct

The CCD model is used to estimate the required experiments (N). The CCD model is presented by equation (3.3) where n is the number of research variables [48] .

$$N(\text{no of experiment}) = 2^n + 2n + 1 \qquad \text{Eq. (3.3)}$$

3.2.3 Measuring Average Clean Water Production Rate

Average clean water production rate through RBF can be estimaetd from equation (3.4). The average pressure head loss can be estimated from equation (3.5).

$$\bar{A}(Q) = \frac{\sum_1^N Qi}{N} \qquad \text{Eq. (3.4)}$$

Here, 'Q' is the average [m^3(hr-m^2)$^{-1}$] clean water prudction rate from RBF. N is the total number of experiments conducted for collecting data to determining the research goal. Average pressure head (Hm) require to operate RBF system can be estimaetd from equation (3.5).

$$\bar{A}(Hm) = \frac{\sum_1^N Hi}{N} \qquad \text{Eq. (3.5)}$$

Here, Hm is pressure require to operate RBF system.

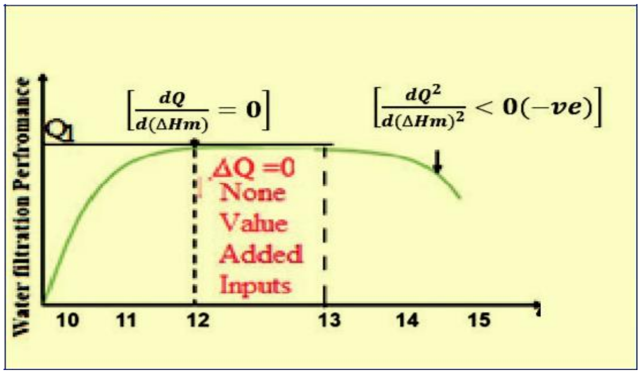

Figure 3.2: Optimization in Process

3.2.4 Optimization Model in Clean Water Production

The simplest concept of optimization is to determine required dependant and independent variables which would contribute to operate the system at zero waste and achieve maximum productivity. A typical model in water production optimization with respect to pressure head (Hm) is presented in Figure 3.2.

Equation 3.6 indicates that at H_{12} is the optimum level of output (Q_{opt}) and can marks as condition one (1) for satisfying optimum output. Figure 3,2 also demonstrates that outputs (Q) of RBF at higher pressure (>Hm_{13} meter) tend to reduce and its value is negative. This condition is presented by equation. (3.7).

$$\left[\frac{dQ^2}{dH^2} < 0(-ve)\right] \qquad \text{Eq. (3.7)}$$

Equation (3.7) is marked as second condition of optimality[49].

3.2.5 Resident Time of Feed Water

Hydraulic Residence Time (HRT) in filter media is associated with product water quality. HRT can be estimated from equation 3.8 [50].

$$HRT = \frac{Vn}{Q} \qquad \text{Eq. (3.8)}$$

Here, V is volume of filter media. 'n' is porosity of filter media used for water filtration. Q 1s flow rate per hour per square meter of media [m^3(hr-m^2)$^{-1}$].

3.2.6. TSS Seperation Efficiency

TSS separation efficiency is defined as the effect of feed pressure in separating TSS from feed water in conjunction with filter media. TSS seperation Efficiency (η) can estimate from the equation (3.9)

$$\eta = \frac{\text{TSS in product water}\left(\frac{mg}{L}\right)}{\text{TSS in feed water}\left(\frac{mg}{L}\right)} \qquad \text{Eq.(3.9)}$$

Required TSS in product water (clean water) is minimum 0.8 mg(L)$^{-1}$ [51].

4.0 EXPERIMENT AND DATA ANALYSIS

The broad objective of this research is to determine the optimum energy consumption rate to produce clean water at zero carbon emission. The experiment was conducted in three phases, which are discussed in section 4.1,4.2 and 4.3.

4.1 Clean Water Production Optimization with Respect to TSS Separation Efficiency

Experiment has conducted based on the methodology stated in section 3.1, and equation (3.3). The estimated experiment is 9.0 as research variable is 2.0. The experimental data are listed in Table 4.1.

Table 4.1: Experimental Data on Product Water and TSS Separation Efficiency

Experimental Run	Average Product Water Outputs from RBF [m^3(hr$^{)-1}$] $\sum_1^8 Qi$	Average TSS separation efficiency $\sum_1^8 \eta i$
1	0.5	0.3
2	0.7	0.6
3	0.8	0.75
4	0.9	0.85
5	1	0.91
6	1.1	0.915
7	1.2	0.85
8	1.3	0.8
9	1.4	0.75

The experimental data is plotted in Figure 4.1. Here, 'X' axis presents the independent variable (product water output rate [$Q=m^3(hr-m^2)$]. 'Y' presents the TSS separation efficiency (dependent variable, η).

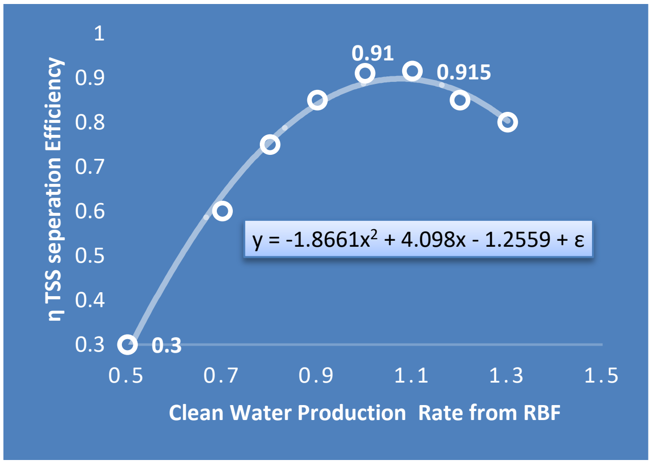

Figure 4.1: Optimum TSS Separation Performance

Figure 4.1 demonstrates the TSS separation efficiency (η) as the effect of water flow rate [$m^3(hr-m^2)$]. The TSS separation trend looks a polynomial curve, which is presented by the equation.

$$\eta = 4.098Q - 1.866Q^2 - 0.12559 + \varepsilon \qquad \text{Eq. (4.1)}$$

Here, 'η' is TSS separation efficiency. 'Q' is water production rate [$m^3(hr-m^2)$]. 'ε' is error term. From equation 4.1, optimum value of Q and 'η' at required TSS density in product will be determined.

Table 4.1 indicates that the value of 'η' at water output rate 1.0 [$m^3(hr-m^2)$] and 1.1 [$m^3(hr-m^2)$] is 91.0% and 91.5%, which is almost equal. On that ground, optimality test could be performed at product water output rate 1.0 [$m^3(hr-m^2)$] and 1.1 [$m^3(hr-m^2)$]. In accordance with optimality model state in section 3.2.4, the first test of optimality was conducted with equation (3.6).

$$\frac{d\eta}{dQ} = \frac{d}{dQ}(4.098Q - 1.866Q2 - 0.12559 + \varepsilon)$$

$$\frac{d\eta}{dQ} = (4.098 - 4.088Q) \qquad \text{Eq.(4.2)}$$

In accordance with the theory of optimization described at 3.2.4, equation 3.6, the value of equation (4.2) can be estimated.

At Q = 1.0, $\frac{d\eta}{dQ} \approx 0$, **At Q = 1.1** $\frac{d\eta}{dQ} \approx 0$

Thus test one for optimality is satisfied. The second test of optimality is conducted by second derivative of equation (4.2). The value of second test at 1.1-meter pressure head is:

$$\frac{d\eta^2}{dQ^2} = \frac{d\eta}{dQ^2}(4.098 - 4.088Q) = -4.4 \qquad \text{Eq.(4.3)}$$

Equation (4.3) shows, the value of second derivative [$\frac{d\eta^2}{dQ^2}$] of a equation (4.2) is negative. Thus, in accordance with equation (3.7), the second test for optimality is satisfied.

Findings

Based on the optimality test results, it can be concluded that for getting required TSS density in water [$TSS \leq 0.8mg(L^{-1})$] the optimum operating condition is;

Q_{opt} = 1.0 flow rate [$m^3(hr-m^2)^{-1}$].
ηopt = 91.0%.

4.1(a) Determining the HRT for Evaluating Filtration Performance

HRT (Hydraulic Residence Time) is an indicator for determining the performance of a water filtration System. Equation 3.8 is estimated to determine the HRT of the filtration system [50], [52].

$$\text{HRT} = \frac{Vn}{Q}$$

Here, V is the volume of RBF used for water filter. 'n' is porosity which is 0.4 for this experiment [50]. Q is optimum product water production rate 1.0 flow rate [$m^3(hr-m^2)^{-1}$](section 4.1). The volume of the sand is $2.7m^3$ {Figure 1.0.). Equation (3.8) is estimated to get HRT for this experiment.

$$\text{HRT} = \frac{2.7x0.4}{1.0} = 1.08$$

The estimated HRT 1.08 hour at TSS separation efficiency 91.0% at TSS density in product water 0.8 $mg(L)^{-1}$

Findings

The data analysis revealed that the optimum product water flow rate (Q_{opt}) is 1.0 [$m^3(hr-m^2)^{-1}$] at HRT 1.08 hours with TSS separation efficiency 91.0% and TSS density in product water is 0.8 $mg(L)^{-1}$. HRT of this process is 1.08 hour indicate that to get the required clean water quality ($TSS \leq 0.8mg\ L^{-1}$], the rig must be operated about one hour.

4.2 Experiment for Optimizing Feed Water Pressure with respect to TSS separation Efficiency

Experiment was conducted based on the methodology stated in section 3.1. In this experiment, the variable is 2.0. Equation 3.2 is estimated to determine the number of experiments run, which is 9.0. In conducting experiment, the height of water (Hm) inside the experimental rig was controlled from 0.7 to 2.7 meters. The required energy (Ep) to maintain the water flow [Q ($m^3(hr-m^2)^{-1}$] inside rig was estimated from equation (3.1.) The experimental data are listed in Table 4.2.

Table 4.2: Experimental Data on Pressure Head and TSS separation Efficiency

Experimental Run	Average Feed Pressure (Hm) $\sum_{1}^{8} Hi$	Average TSS separation efficiency (%) $\sum_{1}^{8} \eta i$
1	0.7	0.4
2	1.0	0.5
3	1.3	0.7
4	1.8	0.8
5	2.1	0.91
6	2.4	0.92
7	2.5	0.89
8	2.6	0.86
9	2.7	0.89

The experimental data is plotted in Figure 4.2. Here, 'X' axis presents the independent variable (pressure head, Hm). 'Y' presents the TSS separation efficiency (dependent variable, η).

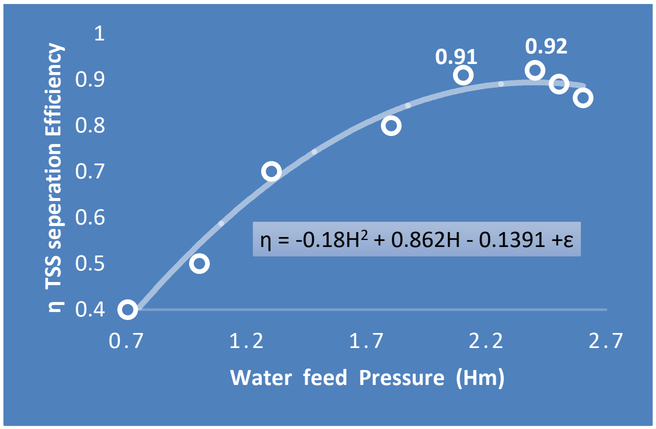

Figure 4.2: Optimum TSS Separation Performance

Figure 4.2 demonstrates the trends of TSS separation efficiency (η) as the effect of feed pressure (Hm). The trend of TSS separation efficiency looks like a polynomial curve, which is presented by the equation (4.4).

$$\boldsymbol{\eta = 0.862H- 0.18H^2-0.1291+\varepsilon} \qquad \textbf{Eq. (4.4)}$$

Here, 'η' is TSS separation efficiency. 'H' is feed pressure head in meter(m). 'ε' is error term. From equation (4.4), the optimum value of H and 'η' at required TSS density in product will be determined**.**

Table 4.2 indicates that the value of 'η' at feed pressure 2.1 meter and 2.4 meter is 0.91% and 0.92%, which is almost equal. On that ground, optimality test could be performed at feed pressure 2.1 meter and 2.4 meter. In accordance with optimality model state in section 3.2.4, the first test of optimality can be conducted with equation (4.4).

$$\frac{d\eta}{dH} = \frac{d}{dH}(0.862H--0.18H^2-0.1291+\varepsilon)$$

$$\frac{d\eta}{dH} = \mathbf{0.862\text{-}0.36H).} \qquad \textbf{Eq.(4.5)}$$

In accordance with the theory of optimization described at 3.2.4 equation (3.6), the value of equation (4.5) can be estimated at H=2.1 and 2.4 meter.

$$\frac{d\eta}{dH}(2.1\text{ m}) = \frac{d\eta}{dH}(2.4\, m) \approx 0.$$

Thus test one for optimality is satisfied. The second test of optimality is conducted by second derivative of equation (4.5). The value of second test at 2.4-meter pressure head is:

$$\frac{d\eta^2}{dH^2} = \frac{d\eta}{dH^2}\mathbf{(0.862--0.36H) = - 0.84m} \qquad \textbf{Eq. (4.6)}$$

Equation (4.6) shows, the value of second derivative $[\frac{d\eta^2}{dQ^2}]$ of a equation (4.5) is negative. Thus, in accordance with equation (3.7), the second test for optimality is satisfied.

Findings

Based on the optimality test results, it can be concluded that for getting required TSS density in water [TSS ≤ 0.8mg(L^{-1})] the optimum operating condition is,

$\mathbf{H_{opt}}$ **= 2.1meter pressure head.**

ηopt = 91.0%, at at TSS 0.8 mg(L^{-1})

Experimental Findings

The data analysis revealed that the optimum pressure to produce required water quality (TSS≤0.8 mgL^{-1}) is (H_{opt}) is 2.1 meter at optimum clean water production 1.0 [m^3(hr-m^2)$^{-1}$. Optimum TSS separation efficiency to produce required clean water was 91.0% and TSS density in product water was 0.8 mg$(L)^{-1}$.

4.3 Green Energy Consumption Optimization in Producing Clean Water

This section is developed to determine the optimum energy consumption rate [kW(m^3)] in producing clean water at zero carbon emission (CO_2eq=0). Schematic diagram of the experimental setup of this study is presented Figure 3.1. The procedure of conducting experiment is described in section 3.1.1. In this experiment, RBF and green energy has used for conducting experiment. The Optimum energy consumption rate can be estimated from equation (4.7).

$$\mathbf{E_{opt}} = \frac{\boldsymbol{Q_{opt}xgxH_{0pt}}}{\boldsymbol{3.6x10^6\eta}} \qquad \textbf{Eq.(4.7)}$$

Here, E_{opt} is total energy consumption in kW. 'g' is graviltity forec [9.2 kg (ses)$^{-1}$]. H_{0pt} is 2.1 meter as presented in Figure 4.2. 'η' is 0.6 , the energy utilization efficiency in RBF for clean water production. Qopt is 1.0 [m^3(hr-m^2)$^{-1}$] as presented in Figure 4.1. The estimated value is shown in equation (4.8).

$$\mathbf{E_{opt}} = \frac{\boldsymbol{1x2.1x9.2}}{\boldsymbol{3.6x10^6x0.6}} = \mathbf{0.089\ kw(m^3)^{-1}} \qquad \textbf{Eq.(4.8)}$$

Equation (4.8) shows that the estimated value of optimum energy consumption rate is 0.089 kw$(m^3)^{-1}$. This findings was validated by conducting further experiment. Experimental procedure stated in section 3.1 and equation (3.3) was used for conducting experiment. Estimated experimental runs (N) was 15.0. The experimental data is recorded in Table 4.3.

Table 4.3: Experimental Data

N	(H_{opt}) m	Q_{Opt} m^3[hr- m^2]$^{-1}$	kW$(m^3)^{-1}$	TSS in product water mgL^{-1}
1	2.1	1	0.0089	0.7
2	2.2	1.1	0.0103	0.9
3	2.1	1	0.0089	0.8
4	2.2	1.1	0.0103	0.8
5	2.1	1	0.0089	0.7
6	2.1	1	0.0089	0.9
7	2.1	1	0.0089	0.8
8	2.2	1.1	0.0103	0.8
9	2.1	1.1	0.0098	0.7
10	2.1	1.1	0.0098	0.9
11	2	1	0.0085	0.8
12	2.1	1.1	0.0098	0.8
13	2	1	0.0085	0.7
14	2.1	1	0.0089	0.9
15	2.2	1.1	0.0103	0.8
Average Energy consumption rate kW$(m^3)^{-1}$			0.00943	0.8

Experimental Findings

Table 4.3 demonstrates that optimum energy consumption rate [E_{opt}] which is 0.00943 kW$(m^3)^{-1}$. This energy has been by RBF rig to producing required quality [TSS ≤0.8 mg(L^{-1}] clean water. The experimental and estimated value is nearly same (within the variation is 3.0%). This finding demonstrated that research findings are validated successfully.

Table 4.4(a): **Scenario Analysis of Research Findings**

Research Objectives	Findings and Analysis
Optimum clean water production rate $[m^3(hr\text{-}m^2)^{-1}]$ of RBF	**Finding:** This experiment unlocks the fact that the performance of RBF in clean water production is optimum at 1.0 $[m^3(hr\text{-}m^2)^{-1}]$ with TSS separation efficiency 91.0% and TSS density in product water about 0.8 $mg(L)^{-1}$. **Commend:** The published experimental reports demonstrates that performance of slow sand filter in clean water production rate is about 0.4 $m^3(hr\text{-}m^2)^{-1}$[50], [52]; while the current research outcomes stated that RFB performed to produce clean water at 1.0 $[m^3(hr\text{-}m^2)^{-1}]$ which is about 60% higher. Thus, this study contributes to develop a guide to achieve SDG6.
Optimum pressure head (Hm) in clean water production at zero carbon emission $[CO_2eq]$	**Findings:** This study reveals the fact that the performance of RBF in clean water production is optimum at 2.1 Meter (3.8 psi) pressure head at TSS separation efficiency 91.0% and TSS density in product water about 0.8 $mg(L)^{-1}$. **Commends;** The low-pressure head is a measure of low carbon emission. Achieving required water quality at 3.0 psi is significantly lower compared to the others experimental findings [53], [54]. Thus, this study contributes to develop a guide to achieve SDG 6 and SDG7
Optimum Energy Consumption in clean water production at zero carbon emission $[CO_2eq]$	**Findings:** This study unlocks that the optimum energy consumption rate is 0.0094 $kW(m^3)^{-1}$ with TSS separation efficiency 91.0% and TSS density in product water about 0.8 $mg(L)^{-1}$. **Commends:** While, published reports on this issue stated that the energy consumption rate is 0.081 $kW(m^3)^{-1}$ at feed water flow rate 0.4 $m^3(hr\text{-}m^2)^{-1}$ [21], [53]. while the current research outcomes stated that energy consumption rate 0.0094 $kW(m^3)^{-1}$which is about 21.5% lower. This finding is confirmed that green technology powered filtration system is efficient. Thus, this study contributes to develop a guide to achieve SDG7 and SDG13.

Table 4.4b: Scenario Analysis of Research Findings

Research Objectives	Findings and Analysis
Effect of porosity on HRT and RBF's performance.	Findings: Estimated optimum HRT is 1.08 hours at f RBF's porosity 0.4 and clean water production1.0 $m^3(hr\text{-}m^2)^{-1}$ [section 4.1(a)]. Commends: A few research reports stated that the effective HRT ranges is 8 to 12 hours at feed water flow rate 0.4 $m^3(hr\text{-}m^2)^{-}$ at porosity 0.4 [50], [52]. With this background of research findings, it could be concluded that the performance of RBF and green technological nexus in clean water production is signifiable higher.
Effect of Green Energy on Carbon Emission.	RBF and green technological nexus have produced optimum amount of clean water at zero fossil fuel energy, which signifies no greenhouse gas was emitted during clean water production by RBF. Conclusion is RBF and green technological nexus is environmentally friendly and would be contributed to slow down climate change.

5.0 Experimental Findings and Scenario Analysis

Experimental findings reported in section 4.0 of this paper demonstrates the performance of RBF in produce required clean water at optimum green energy consumption. The summary of research findings and its impact on carbon emission and climate change are listed in Table 4.4a and Table 4.4b

5.1 Implication of Research findings and Conclusion

The research outcomes reported in this paper have several implications in the water and energy industries, engineering professions, and agencies involved in policy making for using green technology in economic activities. Findings published in this paper would be a guideline for design, build and operate production process at zero carbon emission. This study concludes that further research shall be conducted with green technology for producing electricity, heat and clean water at zero carbon emission for mitigating climate change.

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