Exergetic Sustainability Evaluation of a Recirculating Aquaculture System

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Abstract — This paper presents exergetic sustainability evaluation of a Recirculating Aquaculture System (RAS). Some environmental and sustainability aspects of the RAS are investigated in terms of exergetic sustainability parameters. In this regard, the exergetic parameters, such as exergetic efficiency, waste exergy ratio, exergy recoverability ratio, exergy destruction ratio, environmental impact factor, and exergetic sustainability index are studied. The results show that increasing waste exergy ratio increases the exergetic efficiency and decreases exergetic sustainability index. However, the environmental impact of the RAS increases as the waste exergy ratio increases. Thus, it can be said that, the RAS requires much more improvement because of the higher environmental impact factor and lower exergetic sustainability index, resulting from the heat gained from the environment, the back water from the components in the system, the increasing quantity of the unused waste, and the high capacity of the pumps based on the fish production capacity of the system.

Keywords — Recirculating aquaculture system, Thermodynamics, Exergy, Environment, Sustainability

1 Introduction

During the past decade environmental and sustainability issues have become major problems to overcome since they have caused regional and global consequences. Some of these concerns arise from observable, chronic effects on, for instance, human health, while others stem from actual or perceived environmental risks such as possible accidental releases of hazardous materials [1].

In the past, an increase in the energy consumption of a country was considered a positive impact on the economic as well as social development of the country through energy intensity. The supply and utilization of low-priced and clean fuel are particularly significant for environmental sustainability as well as social, economic and institutional sustainability since energy plays a vital role in industrial and technological developments around the world [2-4]. Based on the energy consumption, it is well-known that micro-level system parameters sometimes have some considerable impact on the macro-level energy aspects, the environment, and sustainability. Of course, if one wants to approach these thermodynamically, there are two ways: energy analysis through the first-law of thermodynamics and exergy analysis through the second-law of thermodynamics [5]. Moreover, sustainability is also necessary to overcome current ecological, economic, and developmental problems [6]. For instance, in aquaculture industry, one of the primary goals of policy makers should be the promotion and improvement of Recirculating Aquaculture Systems. In this regard, it can be emphasized that, in terms of exergy-based sustainability, RAS becomes one of the main components to ensure the environmental sustainability in the fisheries sector. Therefore, the scientists, researchers, policy makers, and engineers, who work on useful solutions for the RAS, should aim at minimizing the energy consumption, maximizing the energy saving, and thus, developing the environmentally benign RAS. All such attempts are necessary to provide better efficiency, better usage of energy, and briefly, better environmental and energy sustainability of the RAS. Under these considerations, in this study, exergetic sustainability evaluation of the RAS is performed.

2 Analysis: Exergetic Sustainability Evaluation

2.1 Assumptions

In this study, the following assumptions are taken into consideration: i) steady-state steady flow system and components, ii) literature data [7] utilization for parameters development, and iii) negligible changes in kinetic and potential exergies.

2.2 Operating Principle of the RAS

Figure 1 illustrates the flow chart of main operating principle of the RAS.

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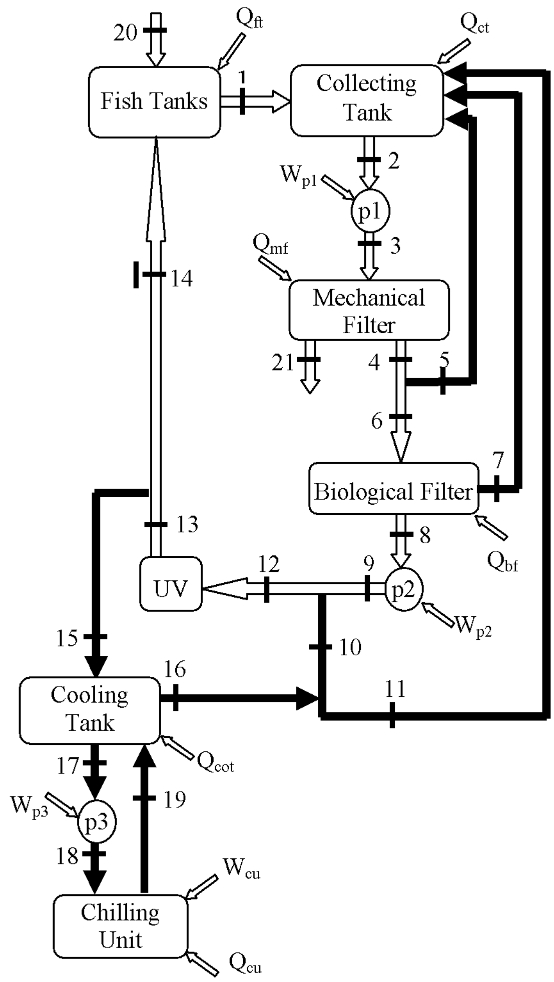

Fig. 1. A schematic of recirculating aquaculture system.

2.3 Parameters

The parameters in Eqs. (1-6) are considered for the exergetic sustainability evaluation of the RAS. All details including exergy analysis of the RAS and derivation of the parameters can be found in the literature [7, 8].

- *Exergetic efficiency* $\left(\eta_{ex}^{RAS}\right)$

$$\eta_{ex}^{RAS} = \dot{E}x_{r,out} / \dot{E}x_{in}^{RAS} = \dot{E}x_{14} / \left(\dot{E}x_2 + \dot{E}x_{p1,i}^{W} + \dot{E}x_{p2,i}^{W} + \dot{E}x_{p3,i}^{W} + \dot{E}x_{cu,i}^{W}\right) \quad (1)$$

where $\dot{E}x_2$ describes exergy out by mass from the collecting tank, $\dot{E}x_{p1,i}^{W}$, $\dot{E}x_{p2,i}^{W}$, $\dot{E}x_{p3,i}^{W}$ and $\dot{E}x_{cu,i}^{W}$; exergy input by work for pump1, pump2, pump3 and chilling unit, respectively.

- *Waste exergy ratio* $\left(r_{wex}^{RAS}\right)$

$$r_{wex}^{RAS} = \left(\sum \dot{E}x_{w}^{RAS} / \sum \dot{E}x_{in}^{RAS}\right) = \left(\dot{E}x_{cu}^{Q} + \sum \dot{E}x_{d}^{RAS}\right) / \left(\dot{E}x_2 + \dot{E}x_{p1,i}^{W} + \dot{E}x_{p2,i}^{W} + \dot{E}x_{p3,i}^{W} + \dot{E}x_{cu,i}^{W}\right) \quad (2)$$

where $\dot{E}x_{w}^{RAS}$ describes the quantity of waste exergy.

- *Exergy Recoverability Ratio* $\left(r_{exr}^{RAS}\right)$

$$r_{exr}^{RAS} = \sum \dot{E}x_{r}^{RAS} / \sum \dot{E}x_{in}^{RAS} = \left(\dot{E}x_5 + \dot{E}x_7 + \dot{E}x_{10}\right) / \left(\dot{E}x_2 + \dot{E}x_{p1,i}^{W} + \dot{E}x_{p2,i}^{W} + \dot{E}x_{p3,i}^{W} + \dot{E}x_{cu,i}^{W}\right) \quad (3)$$

where $\dot{E}x_{r}^{RAS}$ describes the quantity of exergy recovery potential for the system.

- *Exergy destruction ratio* $\left(r_{exd}^{RAS}\right)$

$$r_{exd}^{RAS} = \sum \dot{E}x_{d}^{RAS} / \left(\dot{E}x_2 + \dot{E}x_{p1,i}^{W} + \dot{E}x_{p2,i}^{W} + \dot{E}x_{p3,i}^{W} + \dot{E}x_{cu,i}^{W}\right) \quad (4)$$

- *Environmental impact factor* $\left(f_{envi}^{RAS}\right)$

$$f_{envi}^{RAS} = r_{wex}^{RAS} \times \left(\frac{1}{\eta_{ex}^{RAS}}\right) \quad (5)$$

- *Exergetic sustainability index* $\left(\Theta_{esi}^{RAS}\right)$

$$\Theta_{esi}^{RAS} = \frac{1}{f_{envi}^{RAS}} \quad (6)$$

3 Results and discussion

This paper presents the exergetic sustainability evaluation of a Recirculating Aquaculture System (RAS) by using the experimental data in the literature [7]. Figure 2 presents the variations of exergetic efficiency as a function of time (h) based on the characteristics of the RAS. The cold filtered water is one of the most important variables affecting the exergetic efficiency. As shown in Fig. 3, the exergetic efficiency is highly affected by the running period of chilling unit. In such a way that, when the chilling unit runs the temperature differences between the RAS and its surrounding increase and thus this causes the decrease of exergetic efficiency of the RAS. On the contrary, when the chilling unit stops the temperature differences between the RAS and its surrounding decrease and this increases the exergetic efficiency of the RAS. The results show that exergetic efficiency ranges from 0.219 to 0.352, respectively.

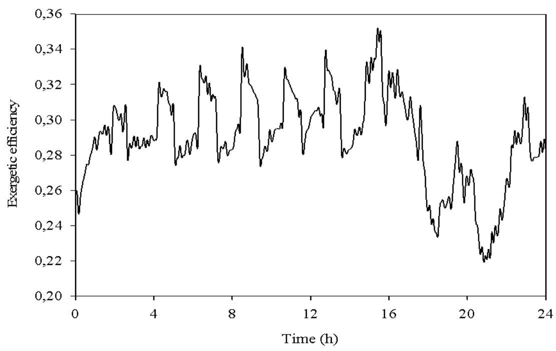

Fig. 2. Variation of exergetic efficiency with time.

Figure 3 presents the variations of exergy destruction ratio and waste exergy ratio as a function of exergetic efficiency based on the constant characteristics of the RAS. As shown in Fig. 3, when the exergy destruction ratio and waste exergy ratio increases, the exergetic efficiency decreases. In order to decrease the exergy destruction ratio and waste exergy ratio, it can be said that the required exergy output from the RAS should be maximized while the thermodynamic irreversibilities and the waste exergy outputs should be minimized during the RAS operation. If done, the contribution to exergetic sustainability of the RAS will be remarkable.

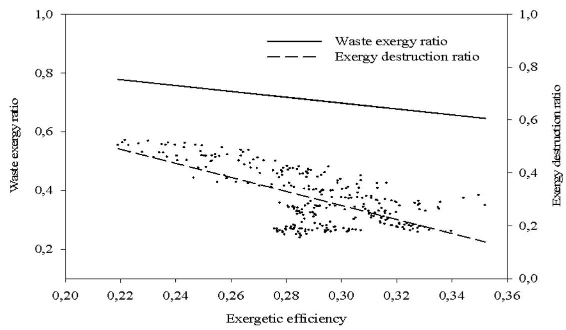

Fig. 3. Variations of waste exergy ratio and exergy destruction ratio with exergetic efficiency.

Figure 4 illustrates the variations of the waste exergy ratio, exergy destruction ratio, exergy recoverability ratio and exergetic sustainability index with time. It is seen that when the chilling unit runs the waste exergy ratio increases. However, when the chilling unit stops the waste exergy ratio decreases. As shown in Fig. 4, when the surrounding temperature decreases the exergy destruction ratio also decreases. When the surrounding temperature decreases exergetic sustainability index increases while the exergy recoverability ratio decreases. However, as the chilling unit stops the exergetic sustainability index and exergy recoverability ratio increase. On the contrary, the exergetic sustainability index and exergy recoverability ratio decrease when the chilling unit runs.

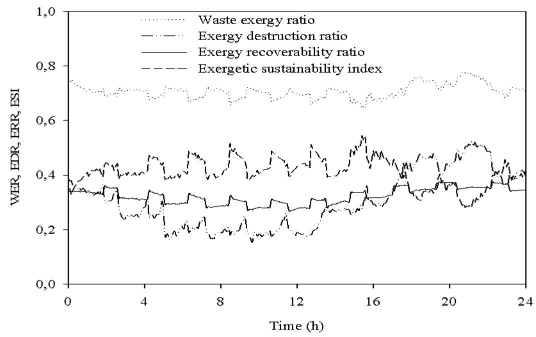

Fig. 4. Variations of waste exergy ratio, exergy destruction ratio, exergy recoverability ratio and exergetic sustainability index with time

Figure 5 indicates the variations of exergetic sustainability index and environmental impact factor as a function of waste exergy ratio. As shown in Fig. 5, while the waste exergy ratio increases the exergetic sustainability index decreases and environmental impact factor increases. It is estimated that waste exergy ratio ranges from 0.645 to 0.778 (its theoretical values range from 0 to 1), and environmental impact factor from 1.833 to 3.552 (its theoretical values range from 0 to +∞), exergetic sustainability index from 0.283 to 0.546 (its theoretical values range from 0 to 1). In terms of the second-law of thermodynamics, all outputs become meaningful for the RAS because they have potential to generate entropy in the environment.

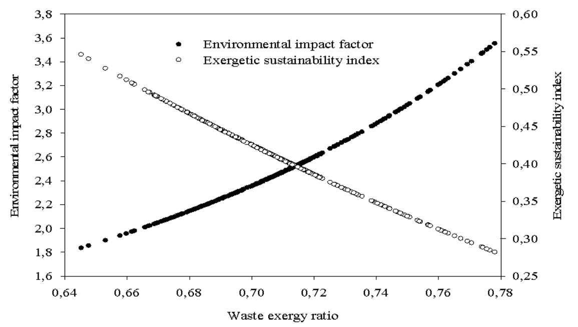

Fig. 5. Variations of exergetic sustainability index and environmental impact factor with waste exergy ratio.

Figure 6 indicates the variations of the exergetic efficiency, environmental impact factor and exergetic sustainability index ratio as a function of exergy recoverability. As understood from Fig. 6, the exergy recoverability ratio indicates the performance improvement potential of the RAS. As shown in Fig 6, when the exergy recoverability ratio increases the exergetic efficiency and exergetic sustainability index decrease while the environmental impact factor increases. Thus, if the RAS has a high value of waste exergy ratio, exergy destruction ratio and environmental impact factor then it is said that this RAS will not be an exergetic and environmental benign system. However, if the RAS has a low value of waste exergy ratio, exergy destruction ratio and environmental impact factor and has a high value of exergetic efficiency then it is said that this RAS is an exergetically and environmentally friendly system.

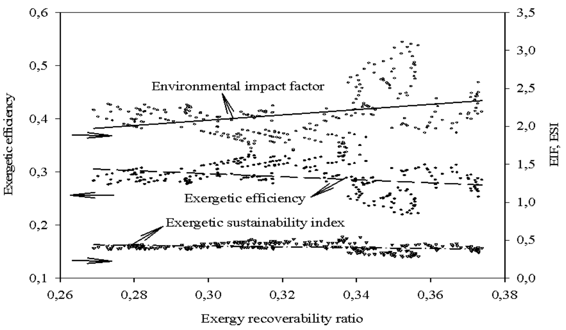

Fig. 6. Variations of exergetic efficiency, exergetic sustainability index and environmental impact factor with exergy recoverability ratio.

4 CONCLUSIONS

The exergetic sustainability evaluation of the RAS has been performed based on the actual data. In order to increase the exergetic sustainability index and to decrease the environmental impact factor, (i) heat gained from the environment should be minimized. (ii) exergetic efficiency should be maximized. (iii) the exergy recovery potential from the RAS should be optimized. (vi) exergy destruction during the RAS operation should be minimized. (v) the operating conditions of the components, particularly, of the pumps should be optimized and improved based on the fish production capacity of the system, and (vi) the back water from the components in the system should be minimized.

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