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Dissolved Oxygen and Ammonia Mass Balance in a Recirculating Aquaculture System for Raising the Nile Tilapia

Ahmed M. Ragab[1,*], Abdel-Ghany M. El-Gindy[2,3], Osama Kaddour[1], Samir Ahmad Ali[4]

1. Engineering Science Department, Faculty of Fish Resources, Suez University, Suez, Egypt.
2. Agricultural Engineering Department, Faculty of Agriculture, Ain Shams University, Egypt.
3. Faculty of Desert Agriculture, King Salman International University, Ras Sudr, Egypt.
4. Agricultural and Bio-systems Engineering Department, Faculty of Agriculture, Benha University, Qalyubiyya, Egypt.

[*]Corresponding Author: ahmed.ragab@suezuni.edu.eg

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ABSTRACT

A dissolved oxygen and ammonia mass balance for recirculating aquaculture system for the Nile tilapia raising was developed on Python program to achieve two goals. The first goal was to predict the required hourly dissolved oxygen addition and the removal of ammonia from water to attain water quality with optimum range for the Nile tilapia. The second goal focused on designing the required oxygen generator and biofilter. The product of this work is a stand-alone graphical user interface (GUI) program. Users can use it easily in the design and operation of recirculating aquaculture systems. The rates of dissolved oxygen consumption through fish respiration, biological filtration, and the nitrification process were determined in model structure besides the addition of ammonia through fish. The effect of different growth periods and the average fish mass on dissolved oxygen consumption and ammonia addition were studied. Model validation was conducted. The expected and actual dissolved oxygen consumption by the model were in agreement. In reality, the dissolved oxygen consumption by fish respiration ranged from 1836.76 to 24350.48 mg O_2 h^{-1}; while in the model, it was from 1830.24 to 23615.26 mg O_2 h^{-1}. The expected and actual total dissolved oxygen consumption values ranged from 2706.14 to 38950.23 and from 2712.66 to 38697.19 mg O_2 h^{-1}, respectively. The expected average ammonia excretion was from 193.36 to 1699.41 mg h^{-1}; while theoretically, it was from 194.44 to 1345.50 mg O_2 h^{-1}. The individual fish weight ranged from 4.26 to 122.79 g in reality. Similarly, it was from 4.22 to 135.86 g during the same period in the results of the model upon validation.

INTRODUCTION

Recirculating aquaculture systems (RASs) are one of the most widely used land-based fish farming methods, with up to 99 percent of the system's water volume recirculated per day **(Rakocy, 2006)**. To treat the high amount of water in RAS, produce more cost-effective fish and improve the water quality which ensures disease control and high production, a system consisting of tanks, different types of filters, and pumps is required **(Bregnballe, 2015)**.

Temperature and dissolved oxygen are important and critical factors in the process of aquaculture **(Qiang *et al.*, 2019)**, which have significant influences on the growth and development of aquaculture organisms **(Zhang *et al.*, 2020)**. In RAS, controlling dissolved oxygen is critical; it can be obtained through aeration, either by providing pure oxygen or mixed air with high oxygen content. It is highly important to control dissolved oxygen by aeration in the high loading capacity of fish such as tilapia and catfish **(Lekang, 2013)**. In Egypt, with respect to species in aquaculture, the tilapia fish have been widely farmed, accounting for roughly 67 percent of the total cultured species in 2014 **(Shaalan et al. 2018)**.

An optimal DO level (5.0 mg L-1 or above) in aquaculture enables animal growth and development. A low DO level (below 3.0 mg L^{-1}) is related to reduced growth and significant mortality risk **(Rahman *et al.*, 2020)**. Consequently, it's critical to ensure that the DO content is always higher than the lowest value. Oxygen dissolves poorly in water. Salinity and temperature significantly affect dissolved oxygen saturation in water. At low temperature and salinity, the maximum saturation concentration occurs **(Lekang, 2013; Timmons *et al.*, 2018)**. The saturation value for growing warm water species is 8.26 mg L^{-1} at 25 °C **(Mongrids & Kusta, 2006)**. In most warm water systems, dissolved oxygen levels should be around 5-6 mg L^{-1} for optimal fish growth **(Timmons *et al.*, 2018)**.

Remarkably, fish need oxygen to thrive and survive **(Mallya, 2007)**. When converting ammonia to nitrite and nitrate, nitrifying bacteria in the biofilter require oxygen as well. For the oxygen consumption of these two species, the dissolved oxygen content must be regularly measured and managed. Water temperature, feed consumption, fish size, and fish activity affect oxygen consumption in the system. If the size of the fish grows and the temperature rises, the amount of oxygen consumed increases. Based on the amount of meal and the degree of temperature, the oxygen consumption of the fish increases since it metabolizes the feed. For every kilogram of feed consumed, fish consumes about 0.12 kilogram of oxygen. Another aspect boosting oxygen consumption is fish activity **(Thorarensen & Farrell, 2011)**. Low dissolved oxygen levels can cause fish stress, biofilter failure or severe fish losses. To guarantee satisfactory fish production, dissolved oxygen should be accurately monitored and expected. Predicting dissolved oxygen in RAS is one of the most important methods of determining fish productivity and is critical to the system's design and evaluation **(Ali, 2012a; Khater, 2012; Khater *et al.*, 2021)**.

Fish feed seems to be the only supply of nitrogen solids and carbon, both of which are major pollutant sources. The amount of solids produced in a RAS is expected to account for 30 to 60% of the applied fish feed by weight **(Chen *et al.*, 1994)**. Fish excretions and a small percentage of uneaten feed make up the majority of the solid waste. Its volatile (organic) fraction ranges from 50 to 92 percent, while the total solid concentration in the effluent is typically 1.5– 3% **(Mirzoyan *et al.*, 2008)**.

Sri-uam *et al.* (2016) considered ammonia concentrations exceeding the limit of 0.05 mg/L as fatal. The protein content of the fish feed ranges from 25% to 65% **(Lovell, 1988)**, equivalent to the organic nitrogen content of 4.1–10.7%. The fish only retain about 20–30% of the nitrogen from the supplied meal **(Sandu & Hallerman, 2013)**, while the remainder is discharged into the water. Thus, it is estimated that around 75% of the fish protein nitrogen is released into water, with a significant portion composed of total ammonia nitrogen (TAN) **(Ebeling *et al.*, 2006)**. The calculated amount of ammonia produced was 2.5 percent **(Alt, 2015)** of the feed fed to fish. Many fish species suffer from ammonia toxicity, even at low concentrations **(Timmons *et al.*, 2018)**. Aerobic nitrification is the most used TAN treatment in RASs **(Guerdat *et al.*, 2010)**, and hence, less toxic nitrate is accumulated in the system. Water exchange (20–40 percent system volume per day) is frequently used to keep nitrate concentrations high and non-toxic **(Hu *et al.*, 2012)**. This activity could lead to environmental pollution. Ammonia concentration began with high levels at the beginning of the experiment, but a decline was recorded by time **(Gichana *et al.*, 2019)**.

Wambua (2019) developed a Nile tilapia RAS model with a high capability to expect environmental requirements for different stocking densities. The R^2 values for ammonia, pH, dissolved oxygen, electrical conductivity and energy were 0.95, 0.89, 0.23, 0.87 and 0.85, respectively. **Tanveer, (2020)** developed a model for goldfish raising and reported R^2 values of 0.99 and 0.98 for ammonia and dissolved oxygen, respectively. **Khater *et al.*, (2021)** in a study to develop a predicting model for RAS for the Nile tilapia raising reported R^2 values of 0.991, 0.992, and 0.954 for the relationships between the expected and actual oxygen fish intake, biofiltration and whole RAS, respectively.

The main objective of this study was to develop a mathematical model on a python program to expect dissolved oxygen consumption and ammonia production at different growth periods and fish weight. The mathematical model was built using the important equations that simulate the oxygen consumption of the Nile tilapia, nitrifiction process and the nitrification bacteria in the biological filter. In addition, it used the ammonia production by Nile tilapia equation and the equations of the biological filter calculations. The mathematical model is helpful and necessary to choose and design oxygen generators and biological filters, the most important components of the RASs.

MATERIALS AND METHODS

2.1. Model development

2.1.1. Dissolved oxygen model

The dissolved oxygen model has a lot of interactive inputs to consider. Oxygen is consumed as a result of both fish oxygen intake and the nitrification process, while the oxygen generator supplies water with oxygen (Fig. 1).

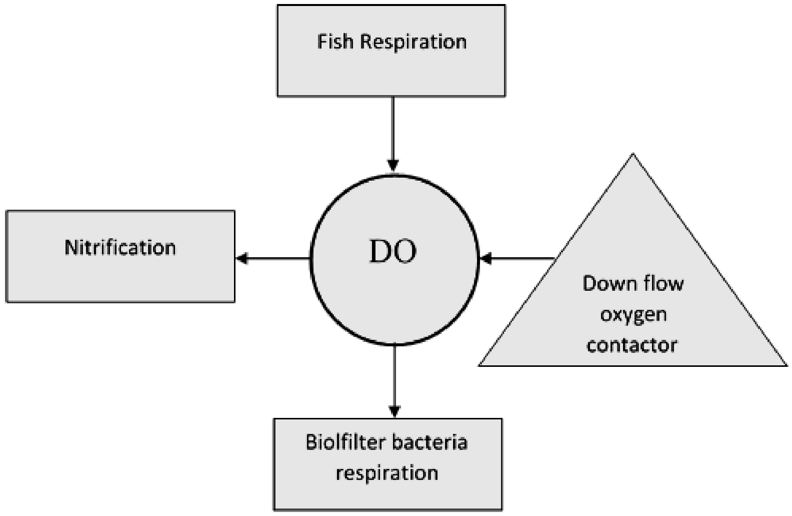

Fig. 1. Dissolved oxygen interactions in the model

The total necessary amount of oxygen supplementation is calculated as follows: (modified from the method of **Khater *et al.* (2021)** by substituting for the dissolved oxygen addition through pipe flow by zero because water inlet is submerged)

$$\mathbf{DOR_{FR} + DOR_{BFB} + DOR_N = DOR_{sup}} \quad \mathbf{(1)}$$

Where, DOR_{FR} is the rate of dissolved oxygen intake by fish; (mg O_2 h^{-1}), DOR_{BFB} is the rate at which dissolved oxygen is consumed by the bacteria in the biofilter (mg O_2 h^{-1}); DOR_N is the rate at which dissolved oxygen is consumed by nitrification (mg O_2 h^{-1}), and DOR_{sup} is the proper oxygen supplementation (oxygen generator) (mg O_2 h^{-1}).

By differentiating equation (1), the rate of change in the dissolved oxygen concentration can be calculated according to the study of **Ali (2012b)** using equation (2):

$$\mathbf{\frac{dDO}{dt} = DOR_{FR} + DOR_{BFB} + DOR_N} \quad \mathbf{(2)}$$

Where, dDO/dt is the rate of change in dissolved oxygen concentration during the time interval (mg O_2 h^{-1}), and dt is the rate of change in the time interval (h).

Ali (2012b) reported that, when calculating oxygen concentration for each component at each time step, the net oxygen change is added to or subtracted from the oxygen concentration at the previous time step. In each given time (t), the concentrations of DO can be determined as shown in equation (3) as follows:

$$\boldsymbol{DO_t = DO_{t-1} + \left(\frac{dDO}{dt} . dt\right)} \quad \mathbf{(3)}$$

Where, Do_t is the DO concentration (g) at time t and DO_{t-1} is the DO concentration (g) at time t−1.

On average fish weight and water temperature, the rate of dissolved oxygen intake by fish in the tank can be computed using the following equation of **Ali (1999)**:

$$\boldsymbol{DOR_{FR} = BM \times (2014.45 + 2.75W - 165.2T_W + 0.007\,W^2 + 3.93T_W^2 - 0.21WT_W)} \quad \mathbf{(4)}$$

Where, DOR_{FR} is the rate of dissolved oxygen intake by fish; (mg O_2 h^{-1}), BM is biomass (kg fish); W is the average of individual fish weight (g), and T_W is water temperature (˚C).

Total Ammonia Nitrogen (TAN) that is converted from NH_3 to NO_3 is used to determine oxygen consumption through the nitrification process. It can be calculated in equation (5) **(Lee *et al.*, 1991)**. Equations (6 and 7) are extracted from the study of **Khater *et al.* (2021)** and equation (8) following that of **Ali (2012b)**:

$$\boldsymbol{DOR_N = 4570 \times NC \times NR} \quad \textbf{(5)}$$

$$\boldsymbol{NC = 0.1(1.08)^{(T_W - 20)}} \quad \textbf{(6)}$$

$$\boldsymbol{NR = \frac{0.03 \times FA}{(24)}} \quad \textbf{(7)}$$

$$\boldsymbol{FA = FR\% \times W \times N} \quad \textbf{(8)}$$

Where, DOR_N is the rate at which dissolved oxygen is consumed by nitrification (mg O_2 h^{-1}); 4.57 is the stoichiometric coefficient **(Lawson, 2013)** for oxygen consumption in nitrification (g O_2 g $_{TAN}^{-1}$); NC is the nitrification coefficient; NR is Nitrification rate (gTAN h^{-1}); V_W is water volume; FA is feed amount (kg feed day^{-1}); FR% is feeding percentage (% of body fish day^{-1}); W is individual fish weight (g), and N is the number of fish.

In the biological filter, the dissolved oxygen consumption rate by nitrification bacteria can be calculated as follows **(Lawson, 2013)**:

$$\boldsymbol{DOR_{BFB} = \frac{2.3 \times BOD_5 \times (BM)[1 - E_{BOD}]}{24}} \quad \textbf{(9)}$$

Where, DOR_{BFB} is the rate at which dissolved oxygen is consumed by biological filter bacteria (mg O_2 h^{-1}); BOD_5 is the average unfiltered BOD_5 production rate (2160 mg O_2/kg fish .day); BM is total fish mass, (kg fish), and E_{BOD} is the filter BOD removal efficiency (%).

The rate of oxygen added through downflow oxygen contactor was concluded following the study of **Khater *et al.* (2021)**:

$$\boldsymbol{DOR_{DOC} = \frac{DOR_{sup} \times V_W \times 10^{-3}}{\mathrm{POAE}(\%) \times \mathrm{POTE} \times 0.7467}} \quad \textbf{(10)}$$

Where, DOR_{DOC} is oxygen contactor required power (hp); POAE (%) pure-oxygen absorption efficiencies (= 80-90% as **(Watten & Timmons, 1994)**); POTE is pure transfer efficiencies (kg O_2 kW^{-1} h^{-1}, = 4 as **(Watten & Timmons, 1994)**), and the factor of 0.7467 kW hp^{-1} is the horsepower to the watts conversion factor.

2.1.2. Fish growth model

Dissolved oxygen, water temperature, photoperiod, unionized ammonia, the density of fish stocking, feed availability, and feed quality all affect fish growth. The following model **(Yang Yi, 1998)** was used to determine the fish growth rate (g day^{-1}) for each fish, taking into account the most important environmental parameters, viz.dissolved oxygen, unionized ammonia and water temperature. The fish growth rate can be calculated following the procedures of **Yang Yi (1998)** as follows:

$$FGR = \{0.2919\tau k\delta\varphi hfW^{m}\} - kw^{n} \quad \textbf{(11)}$$

Where, FGR is the fish growth rate (g day^{-1}); τ is the temperature coefficient ($0 < \tau < 1$, dimensionless); κ is the photoperiod coefficient ($0 < \kappa < 1$, dimensionless); δ is the dissolved oxygen coefficient ($0 < \delta < 1$, dimensionless); φ is the NH_3 coefficient ($0<\varphi<1$, dimensionless); h is the feed intake factor (g^{1-m} day^{-1}); *f* is the relative feeding level ($0 < f < 1$, dimensionless) ;k is the coefficient of catabolism, and h, m, n are constants.

2.1.2.1. Temperature factor (τ)

When the temperature is within the recommended range, the rate of feed consumption reaches its maximum value. The rate of feed intake lowers when the temperature does not reach the recommended range. When the temperature falls into the limited range, feed consumption stops. The temperature factor (0:1) is defined as follows **(Bolte *et al.*, 1995)**.

$$\tau = EXP\left\{-4.6\left[\frac{T_{opti}-T}{T_{opti}-T_{min}}\right]^{4}\right\} \qquad if\ T < T_{opt} \quad \textbf{(12)}$$

$$\tau = EXP\left\{-4.6\left[\frac{T-T_{OPT}}{T_{max}-T_{opti}}\right]^{4}\right\} \qquad if\ T \geq T_{opt} \quad \textbf{(13)}$$

Where, T is the temperature factor; T_{min} is the minimum limit temperature for feed consumption by fish, ºC; T_{max} is the maximum limit temperature for feed consumption by fish, ºC, and T_{opti} is the ideal temperature for feed consumption by fish, ºC.

2.1.2.2. Photoperiod factor (k)

Many cultured fish species such as the Nile tilapia have a habit of feeding only during daytime hours. Photoperiod factor (κ), based on 12:12h of the light-dark cycle and used for daily feed intake adjusting, is written as follows:

$$k = photo\ period/2 \quad \textbf{(14)}$$

Where, photoperiod is the daytime between sunrise and sunset (h), which can be determined from sunrise to sunset **(Hsieh, 1986)**. The constant of 12 is the photoperiod in the 12:12h of the light-dark cycle.

2.1.2.3. Dissolved oxygen factor (δ)

There are three stages of the dissolved oxygen (DO) impact on fish growth. When DO is lower than the lowest limit level, DO_{min} fish feeding stops. When DO is higher than the critical level, DO_{crit}, (DO) does not affect feeding. When DO is in the range from DOmin to DOcrit, feeding is affected by DO **(Nath, 1996)**.

$$\delta = 1 \quad if\ DO > DO_{critical} \quad \textbf{(15)}$$

$$\delta = \frac{DO-DO_{min}}{DO_{critical}-DO_{min}} \quad if\ DO_{min} \leq DO \leq DO_{critical} \quad \textbf{(16)}$$

$$\delta = 0 \quad if\ DO < DO_{min} \quad \textbf{(17)}$$

The DO_{crit} and DO_{min} entered in the model were 3.0 and 0.3 mg L^{-1}, respectively **(Yang Yi, 1998)**.

2.1.2.4. Unionized Ammonian Factor (φ)

Unionized ammonia (NH_3) is highly toxic to fish **(Boyd, 2020)**. An equation similar to that for DO can be used to measure the effects of unionized ammonia **(Nath, 1996)**. When NH_3 exceeds NH_{3max}, the fish will stop feeding. There is no effect on feeding when NH_3 is less than the critical value, NH_{3crit}. When the concentration of NH_3 is higher than the critical value, $NH_{3crit,}$ and lower than a maximum value, NH_3max, then feed consumption will reduce while the concentration of NH_3 increases.

$$\boldsymbol{\varphi = 1 \quad if\ \mathrm{NH_3} < NH_{3crit}} \tag{18}$$

$$\boldsymbol{\varphi = \frac{NH_{3max} - NH_3}{NH_{3max} - NH_{3crit}} \quad if\ \ NH_{3crit} \leq NH_3 \leq NH_{3max}} \tag{19}$$

$$\boldsymbol{\varphi = 0.0 \quad if\ \mathrm{NH_3} > NH_{3crit}} \tag{20}$$

For the Nile tilapia **Abdalla (1989)** reported that, NH_{3max} = 1.40 mg L^{-1} and NH_{3crit} = 0.06 mg L^{-1}.

2.1.2.5. Relative feeding level (*f*)

The available feed amount and quality strongly affect fish growth. To calculate the relative feeding level's value (f) in the model, **Ali (2012a)** used the model at progressive values of (f), beginning from 0, step 0.01 up to 1.0. The data used in the model were used from the study of **Rakocy (1989)** and derived from semi-intensive tilapia culture, which is why it was used to estimate the value of the relative feeding level **(Ali, 2012a)**. This is a good match for what we're looking for. The calculated value of (f) was 0.37 which was entered in the model.

The model factors (h, n, and m) were entered as 0.80, 0.81 **(Nath *et al*., 1994),** and 0.67 **(Ursin, 1967)**. The equation is used to calculate the accumulated growth, beginning with 1 gram of individual fish and reaching a marketable weight of 250 grams **(Ali, 2012a)**.

$$\boldsymbol{W_n = W_{n-1} + DGR_n} \tag{21}$$

The feeding ratio could be calculated by **Ali's (1999)** equation:

$$\boldsymbol{FR = 17.02 \times e^{\left(\frac{(L_n W_n + 1.14)^2}{-19.52}\right)}} \tag{22}$$

$$\textbf{Amount of feeding } (\mathbf{kg}\ /\boldsymbol{day}) = \boldsymbol{FR \times W_n \times\ No.}\textbf{ of fish}/\mathbf{100000} \tag{23}$$

Where, DGR is the daily growth rate, g; W is the average fish weight, g; n is the number of days since the beginning, and FR is the feeding percentage, percent of fish weight.

2.1.2.5. Catabolism factor "k":

The optimal and limit temperatures differ depending on the species. It was suggested that for the tilapia, Tmin = 15 ºC, Tmax = 40 ºC, and Topti = 28 ºC **(Lawson, 2013)**. Water temperature has an impact on the catabolism term. The impact is referred to as follows **(Nath, 1996)**:

$$\boldsymbol{k = k_{min} exp[s(T - T_{min})]} \tag{24}$$

Where, K_{min} is the fasting catabolism coefficient at T_{min}, g^{1-n} hr^{-1}, and s is a constant. The κ_{min} was determined by validation and κ_{min} = 0.025 and s = 0.015 were proper for tilapia produced in the work of **Nath (1996)**. Furthermore, κ ranged from 0.0319 to 0.0468. **(Liu & Chang, 1992)**.

2.1.3. Ammonia model

The total NH_3-N_2 (TAN) is the most significant form of N_2 in aquaculture since it has higher toxicity **(Boyd, 2020)**. Unionized ammonia and the ammonium ion are two components of TAN that remain in a balance based on the water pH level and temperature **(Timmons *et al.*, 2018)**. The NH_3 becomes the dominating species when the pH rises, which is extremely harmful because NH_3 is more toxic than NH_4^+. However, at this stage, only the TAN can be measured rather than NH_4^+. Equation (25) **(Ali, 1999, 2012a)** can be used to calculate the mole fraction of ammonia generation.

$$\mathbf{AP = 16.38 - 0.49W + 0.0019W^2 + 1.23T - 0.0025WT} \tag{25}$$

Where, AP is ammonia production (mg kg_{fish}^{-1} hr^{-1}). In the model, the TAN production is a function of the individual fish weight and water temperature. To determine this value is crucial for two reasons. Firstly, the system's nitrate production capacity can be computed as a function of TAN. Secondly, the required biofilter size can be determined. The nitrification process includes the production of nitrate from TAN. The biofilter is assumed to convert all the TAN to No_3 in the model. A nitrate-nitrogen ratio of 4.34 grams per gram of TAN excretion was calculated **(Lawson, 2013)**. Once the type of biofilter is chosen, the size of the required biofilter can be easily estimated. Rotating biological contactors (RBC) are used in this model **(Khater, 2012)**.

Primarily, The required surface area will be determined based on ammonia excretion (mg TAN kg_{fish}^{-1} hr^{-1}) and the maximum rate of ammonia loading. The model was run using an NH_3 loading rate of 11.25 mg TAN m^{-2} $hour^{-1}$ **(Rijn & Rivera, 1990)**.

$$\mathbf{R.S.A.} = \frac{\mathbf{AP}}{\mathbf{A.L.R.}} \times \mathbf{BM} \tag{26}$$

Where, R.S.A. is required surface area (m^2), and A.L.R. is ammonia loading rate, (mg TAN m^{-2} h^{-1}). Secondly, the RBC's media volume can be determined after the determination of the RBC's media-specific surface area.

$$\mathbf{V_b} = \frac{\mathbf{R.S.A.}}{S_b} \tag{27}$$

Where, V_b is the appropriate biofilter media volume(m^3), and Sb is the specific surface area (m^2 m^{-3}).

2.2. Analysis procedures

For growing fish in a RAS, there is no single suggested design. A system typically includes fish culture tanks, pumps to provide sufficient water flow and mechanical and biological filters to ensure proper quality. The system was divided into small parts so that it would be easier to deal with them in the models, considering that the water was well mixed.

2.3. Methods

The data used for the validation and application in this paper were based on data from private RAS **(Ali, 2012a, 2012b, 2013; Ragab *et al.*, 2016)** and Benha University, Faculty of Agriculture, RAS Project **(Ali, 2012b; Khater, 2012; Khater *et al.*, 2021)**.

2.4. Programming language

Python 3.8.6. was used to construct the model. Matplolib (V. 3.0.3), Numpy (V. 1.16.2), Tkinter (V. 8.6), and Math (V. 1.2) packages had been installed and used. Anaconda application was used to make python use easier.

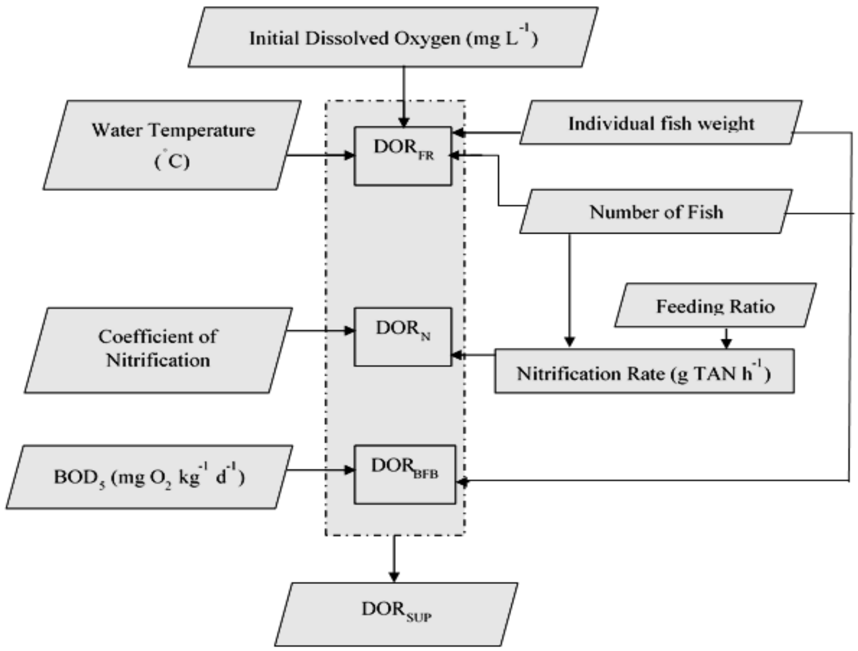

Fig. 2. Flowchart diagram of the dissolved oxygen predicted model

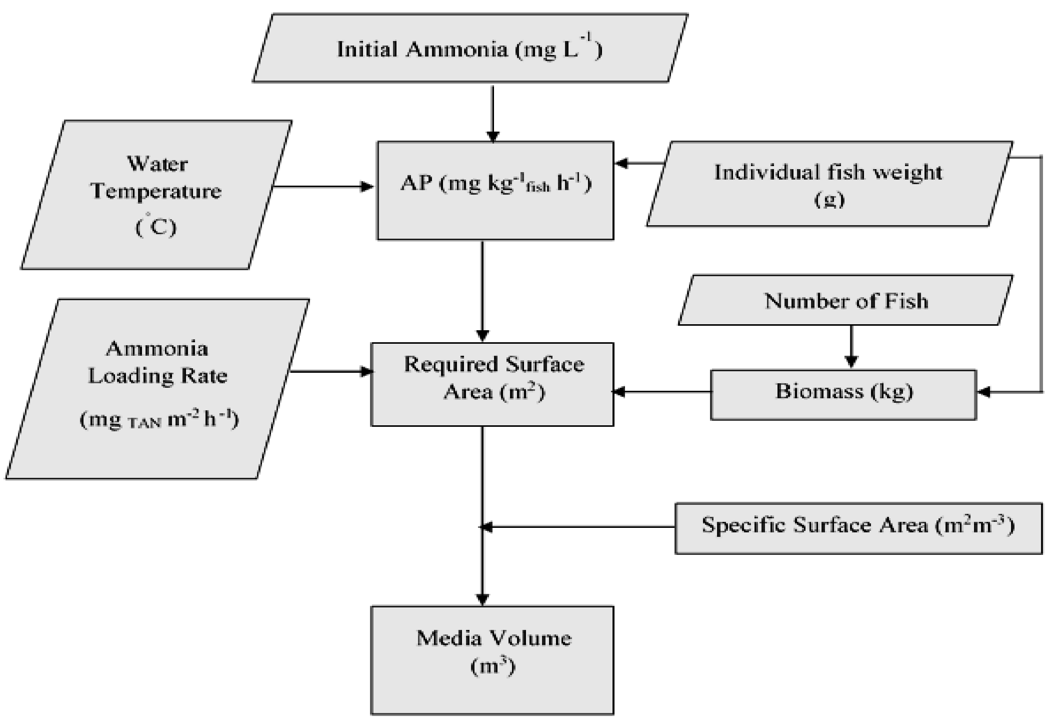

Fig. 3. Flowchart diagram of the ammonia predicted model

RESULTS

The produced stand-alone GUI program. The program is named RAS design and operation assistant. It is consisted of three parts. Energy balance inputs screen, mass balance inputs screen as shown in Fig. (4), and the result screen as shown in Fig. (5). The program supports figures aiding the user to design and operate RAS with another screen, presenting the maximum stocking density, oxygen supplementary, power of oxygen pump, flow rate, the volume of biofilter media and flow rate to remove TAN. Another feature of the RAS design and operation assistant is the ability to save data in an Excel

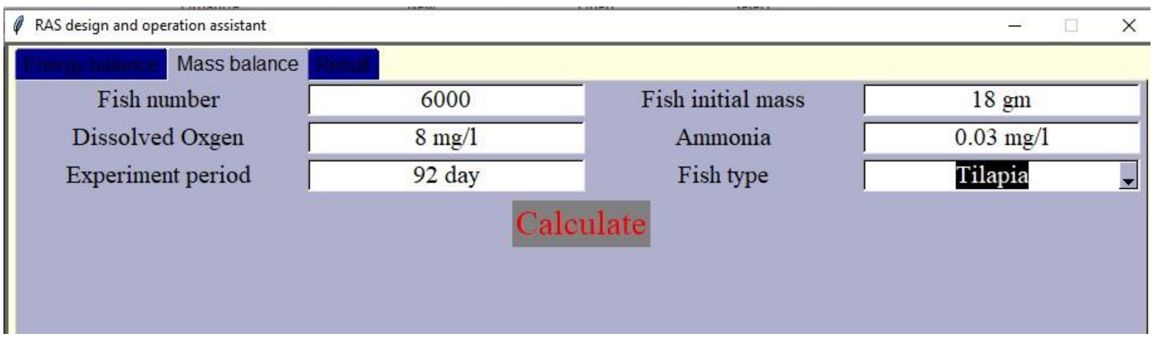

Fig. 4. Stand-alone GUI: mass balance results screen

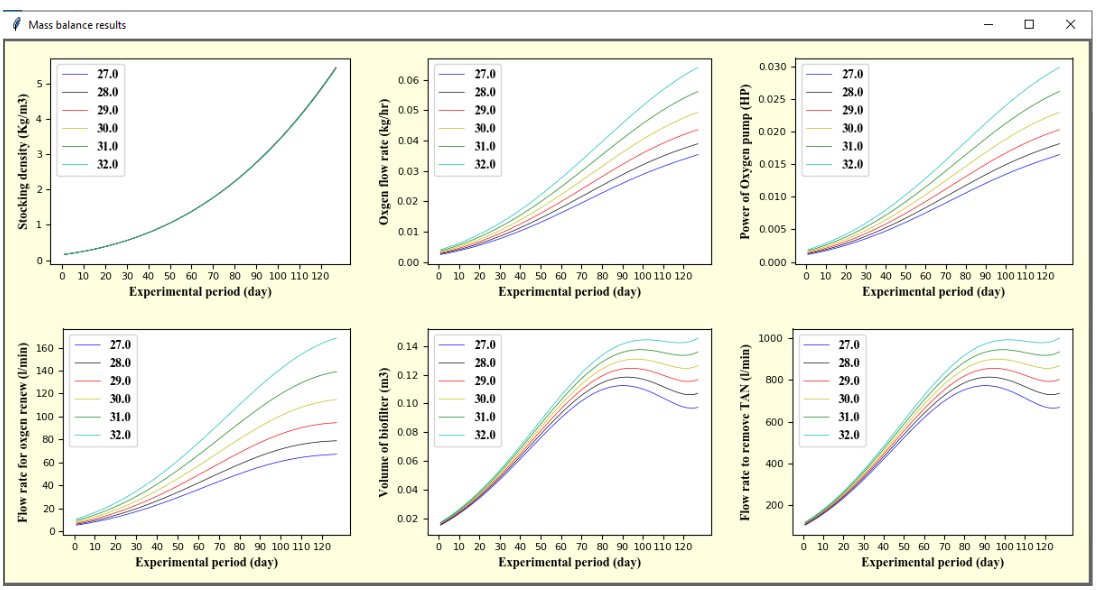

Fig. 4. Stand-alone GUI: mass balance inputs screen

Oxygen consumption

Fig. (6) displays the expected and the actual fish oxygen intakes. It can be observed that the expected oxygen intake values ranged from 1830.24 to 23615.26 mg O_2

h^{-1} and the actual oxygen intake value were in the ranges from 1836.76 to 24350.48 mg O_2 h^{-1}. The expected and the actual oxygen fish intake patterns were similar.

The expected and the actual expressive relation (Fig. 7) is shown in the next formula:

$$OC_P = = 0.9909\ OC_A - 991.76 \qquad R^2 = 0.9761 \qquad (28)$$

Where, OC_P is the expected oxygen intake, mg O_2 h^{-1}, OC_A is the actual oxygen intake, mgO_2 h^{-1}.

3.1.1. Effect of fish weight on oxygen intake

When fish size grows larger, their rate of oxygen consumption lowers (Fig. 8). Hence, a rise in system biomass does not record an increase in the feeding rate. The optimum ratio of feeding (percent of the fish mass.day^{-1}) falls as fish grow up and temperature drops.

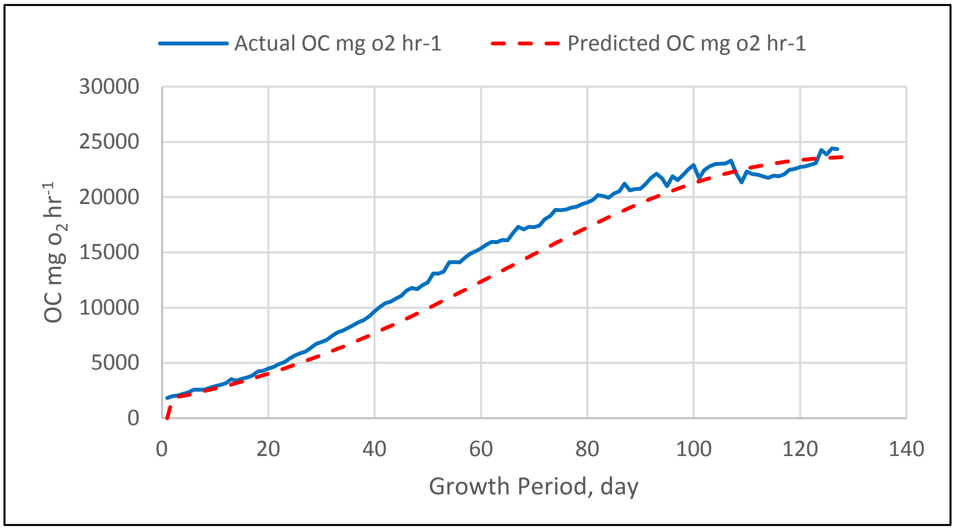

Fig. 6. The comparison between expected and actual fish oxygen intake at same growth periods

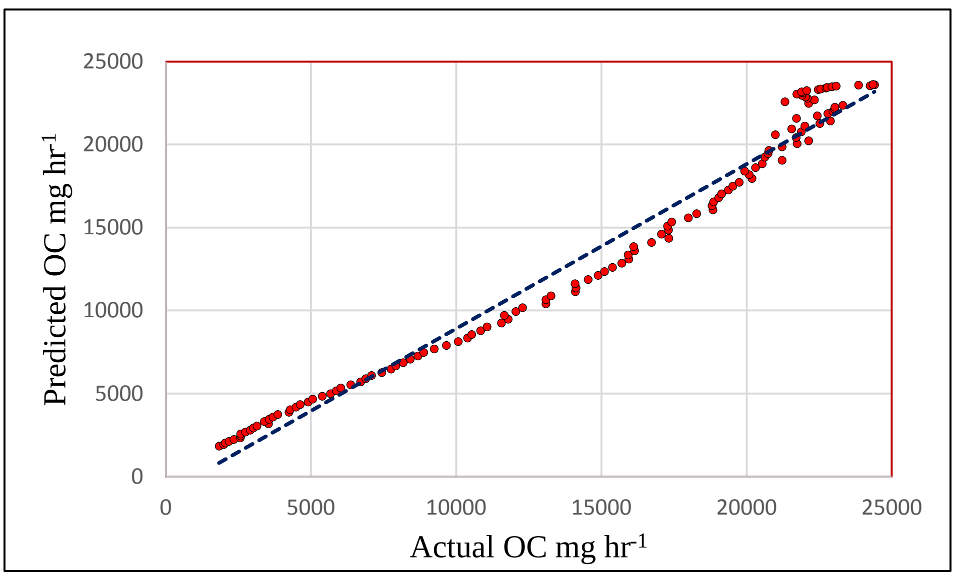

Figure 7. The relationship between expected and actual fish oxygen intake at same growth periods

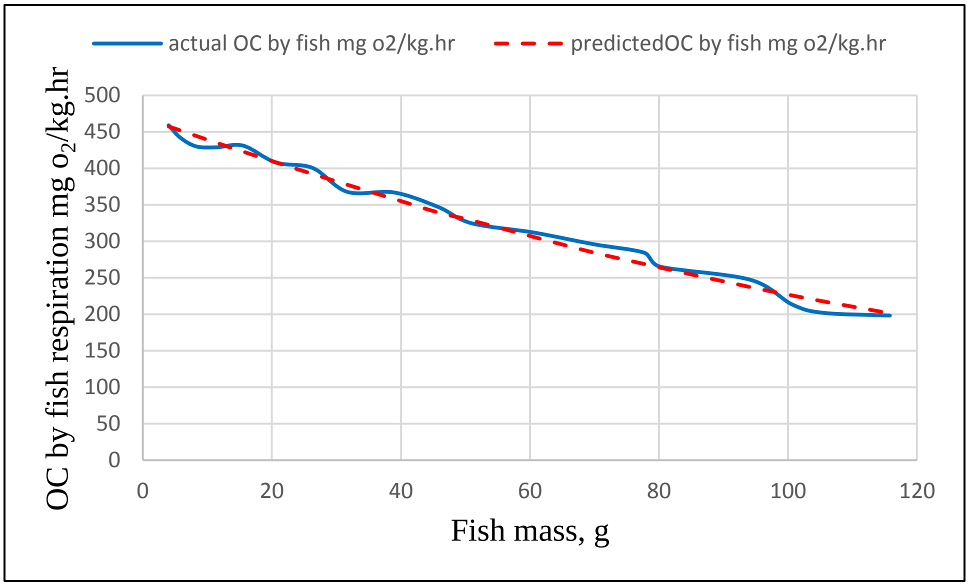

Fig. 8. The comparison between expected and actual fish oxygen intake

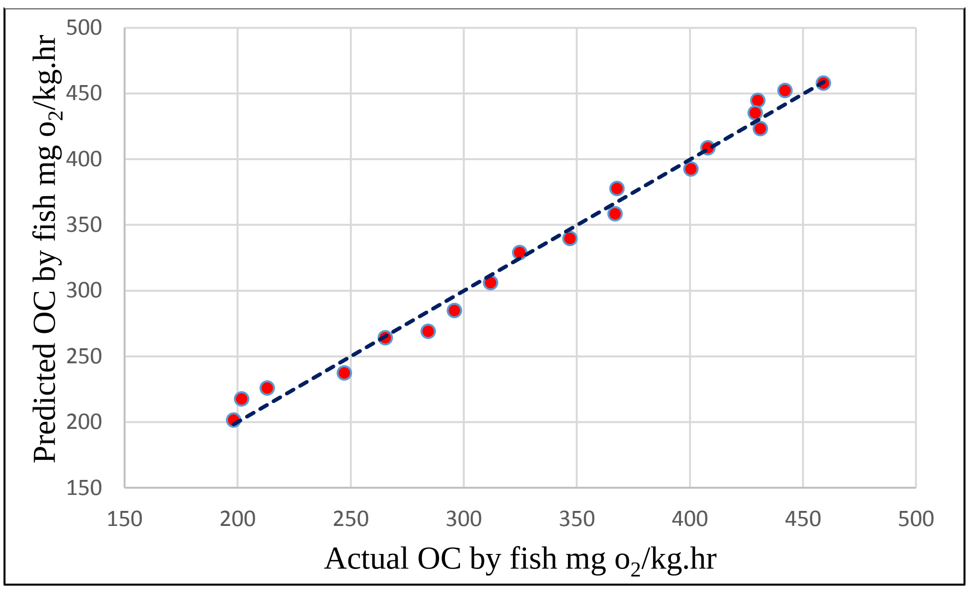

Fig. 9. The relationship between expected and actual fish oxygen intake

Fig. (10) indicates the comparison between the expected and actual fish oxygen intakes for RAS. It is clear that the expected oxygen consumption declines with the increase of average fish weight, where it reduced from 2.71 to 38.70 g O_2 h^{-1}. However, it decreased from 2.70 to 38.95 g O_2 h^{-1} theoretically. Notably, the expected oxygen consumption was similar to the actual oxygen consumption.

The graphical relationship's best match (Fig. 11) between the expected and the actual results were in the next formula:

$$\mathbf{OC_P = 1.0089\ OC_A + 1.7253 \qquad R^2 = 0.9803} \qquad (29)$$

Where, OC_P is the expected oxygen consumption, and g O_2 h^{-1}, OC_A is the actual oxygen consumption, g O_2 h^{-1}.

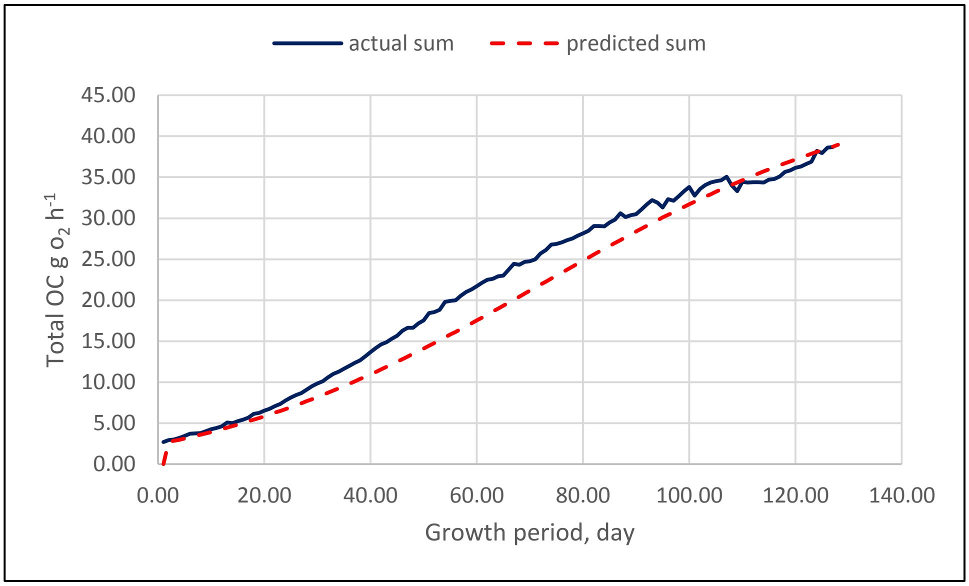

Fig. 10. The relationship between the expected and the actual total oxygen consumption in RAS

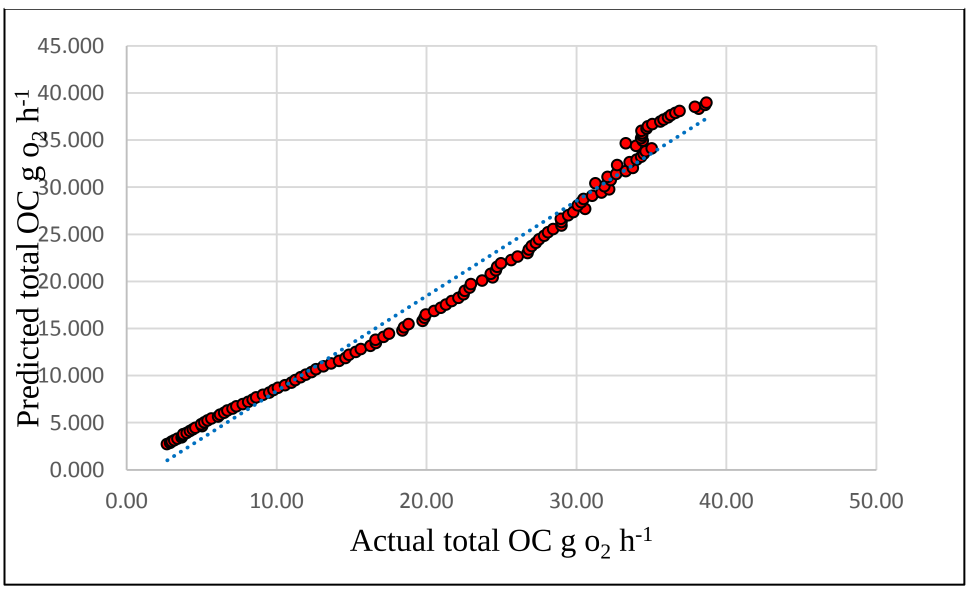

Fig. 11. The relationship between expected and actual total oxygen consumption in RAS

Ammonia Production

The model was able to expect ammonia concentration changes in RASs. Fig. (12) displays the expected and the actual ammonia production (AP) from the RAS. It is clear that the AP decreased with increased growth periods actually and hypothetically, the average ammonia excretion ranged actually from 193.36 to 1699.41 mg h^{-1}; while, it was theoretically from 194.44 to 1345.50 mg O_2 h^{-1}.

Fig. (13) displays the difference between the expected and the actual. It shows that the expected and the actual ammonia production is in reasonable agreement. The relation appeared in the next formulae:

$$\mathbf{AP_P = 0.763\ AP_A - 97.875 \qquad R^2 = 0.8995} \tag{30}$$

Where, AP_P is the expected ammonia excretion, and mg h^{-1} and AP_A is the actual ammonia excretion, mg h^{-1}.

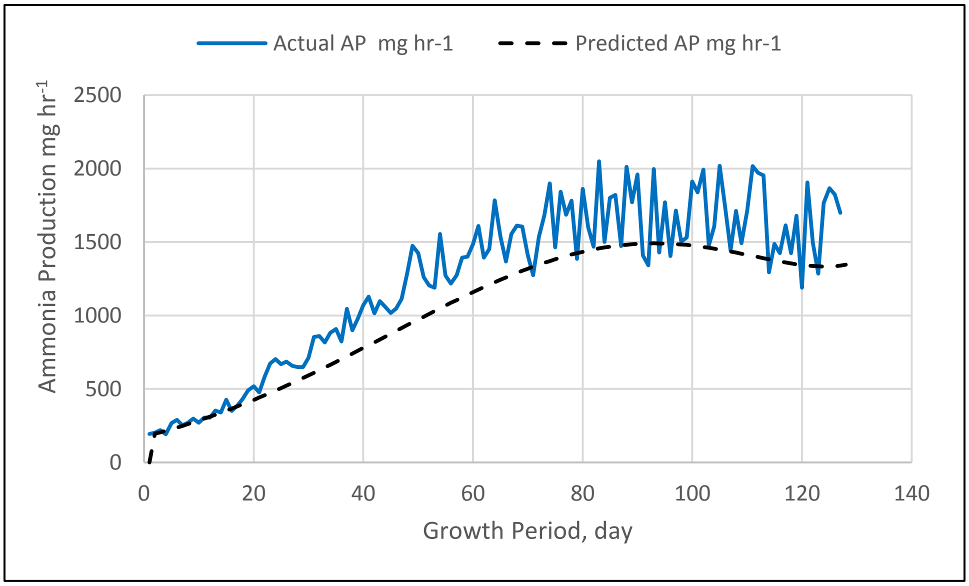

Fig. 12. The expected and the actual ammonia excretion by fish in RAS during the same growth period

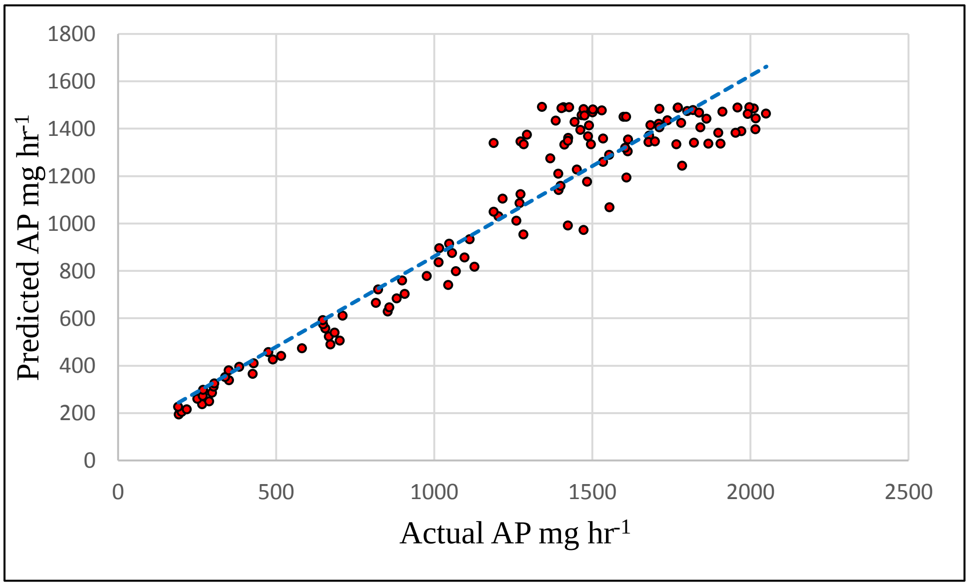

Fig. 13. The relationship between expected and actual ammonia excretion by fish in RAS during the same growth period

3.2.1. Effect of fish weight on ammonia production

Ammonia excretion decreased with the increase of fish weight. Fig. (14) shows the comparison between the expected and the actual ammonia excretion of fish for the (RAS). Remarkably, fish weight increases, while AP reduces. It reduced from 48.34 to 13.84 mg NH_3 $kg^{-1}{}_{fish}$ h^{-1} in the reality, and declined from 48.61 to 11.45 mg NH_3 $kg^{-1}{}_{fish}$ h^{-1} in the model.

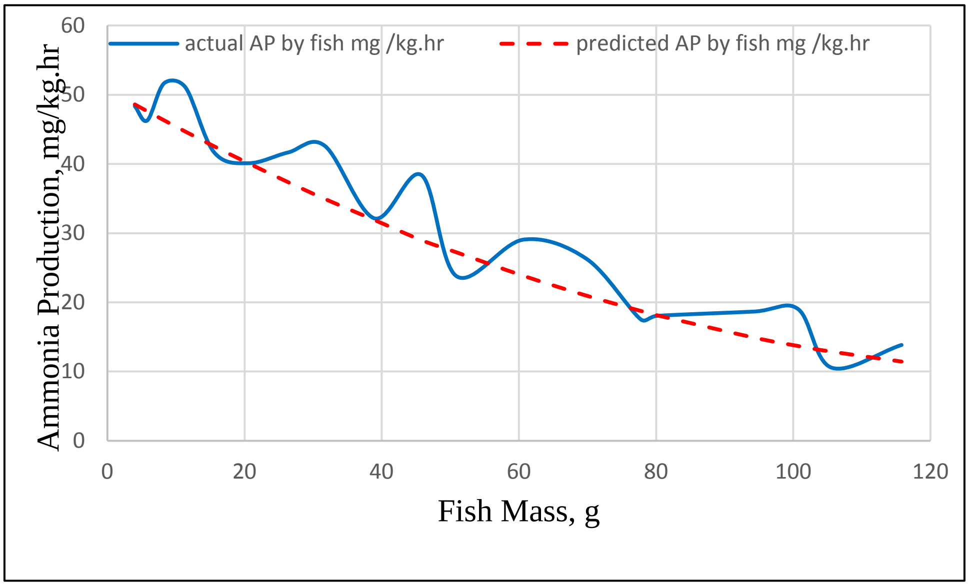

Fig. 14. The expected and the actual ammonia production by fish grown in RAS at different fish mass

3.3. Average fish weight

Figure (15) compare the expected and the actual average fish weight in RAS. The expected average fish weight presented a similar pattern to that of the actual average fish weight.

The equation(31) represents the relation (figure 16) concerning the expected and the actual values:

$$\mathbf{W_p = 1.0641W_A + 5.7437 \qquad R^2 = 0.98} \qquad (31)$$

Where, W_P is the expected average fish weight, g, and W_A is the actual average fish weight, g.

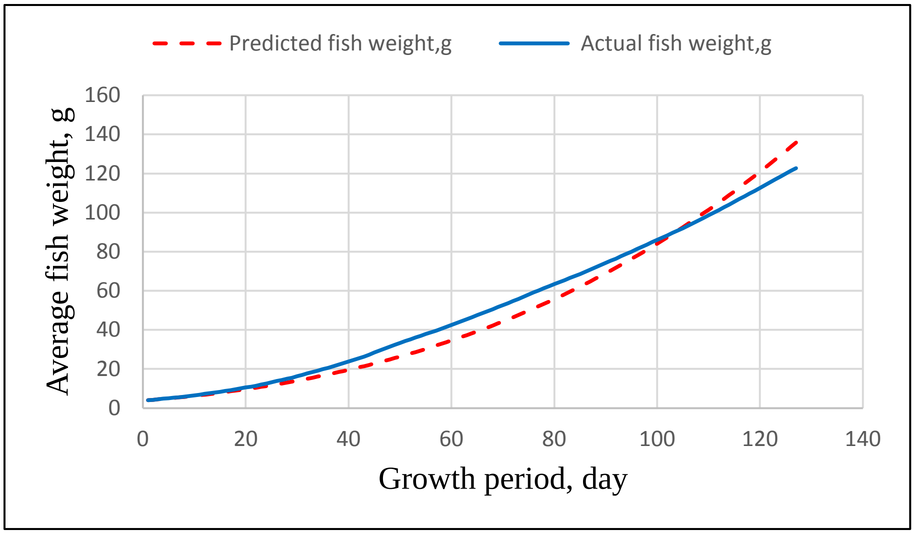

Fig. 15. The comparison between expected and actual average fish weight

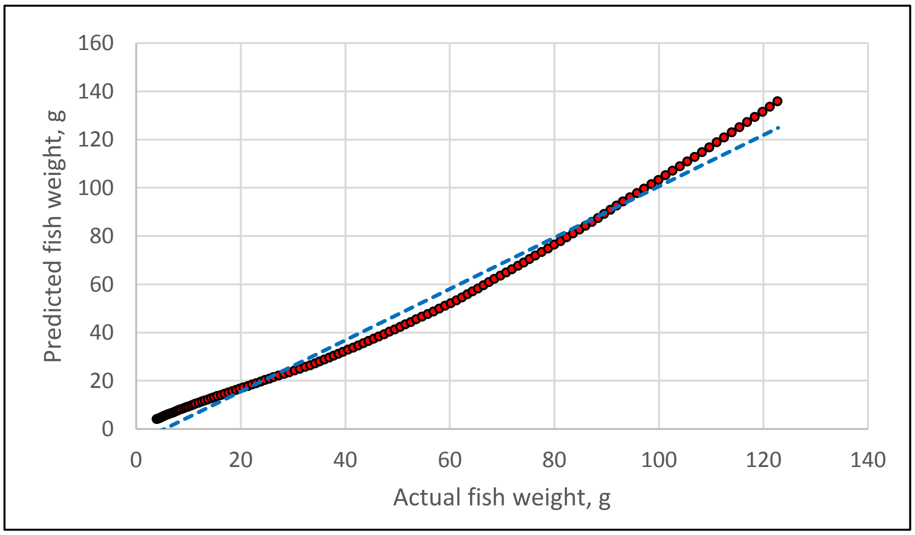

Fig. 16. The relationship between expected and actual average fish weight

DISCUSSION

The model is distinguished from other models mentioned in previous studies by its ease of use. The model is introduced to the user as a stand-alone GUI program and does not require any other program installation. Another feature of the program is the result window, which presents design and operation aiding relations. The model combines dissolved oxygen consumption, ammonia production, and average fish weight predicting which are the most effective parameters, with respect to the productivity of RAS and water quality **(Sri-uam *et al*., 2016; Qiang *et al*., 2019)**.

The model showed that the expected oxygen consumption declined with the growing average of fish weight during the same growth period, which agrees with the actual oxygen consumption at the same growth period. The results of oxygen predicting (R^2 = 0.9803) seem similar to the predicting models of **Tanveer (2020)**, where R^2 = 0.98 and **Khater *et al.* (2021)**, where R^2 = 0.9541.

The model showed that the expected ammonia excretion declined with growing fish weight during the same growth period, which agrees with the actual oxygen consumption at the same growth period. The value of the model ammonia predicted (R^2 = 0.8995) is lower than that of **Wambua *et al.* (2019)**, where R^2 = 0.95 and less than the finding of **Tanveer (2020)**, where R^2 = 0.99. While, it is similar to the result of **Khater (2012)**, where R^2 =0.925.

The model showed that the expected average fish weight increases linearly during the whole growth period, which is logical and in the same manner compared to the actual average fish weight during the same growth period. The performance of the model (R^2 = 0.98**)** is very close to the model of **Khater *et al.* (2021)**, where R^2 = 0.98**,** concerning average fish weight predicting.

The results proved that the model is reliable and valid to predict total oxygen consumption, ammonia production, and average fish weight concerning the Nile tilapia raising in RAS. The model needs more investigation by submitting other validation test with other RASs and different weight ranges. Additionally, it is possible to add other fish species to the model in further researches.

CONCLUSION

A mathematical model was conducted to predict the dissolved oxygen and ammonia for recirculating aquaculture systems for the Nile tilapia raising in terms of the factors that influence it, such as average fish weight and water temperature. The model was developed on a python program with some packages. The product of the work is a stand-alone graphical user interface (GUI) and was named as RAS design and operation assistant. The produced GUI will be available online for any farmer, engineer, researcher, and designer for use and development. At different growth periods and fish weights, the model was able to predict dissolved oxygen and ammonia. The model results and the actual values were in agreement.

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