An experimental study of water quality and balsam growth in minimum dissolved oxygen conditions with aquaponic system

Bharat Mulay, K. Rajasekhara Reddy

Abstract*: *The aquaponic systems are the combination of fish and plant culture. These are recirculating systems with two components: hydroponics and aquaculture. In these systems, the food given to fish is metabolized. This metabolized food fulfills the nutrient requirement of plants. This is achieved by the recirculation of water from the aquaculture component to the hydroponic component and back to the aquaculture component. This experiment is conducted to test the effect of recycling of water in a longer period on the growth of iridescent shark and balsam plant in the aquaponic system. The system developed is 1.08 m^3 area of water in aquaponic component and 1 m^2 for plant growth. In the hydroponic component course aggregate of 0.1m diameter was selected to support the plants. Coconut husk and sand particle layers of 0.03m and 0.06m are used for the growth and development of nitrifying bacteria. An average quantity of 1 kg of balsam plant leaves was produced in 60 days of plant growth. It has been found that balsam plant and iridescent shark species in this system has a faster and better growth compared to the conventional growth. The water used in the system is completely replaced once in three months after 45 days. Also, it was recirculated once in 3 days during experimentation. The DO level of fish tank water was dropped below 2 ppm during the span of two successive recirculations. No direct sunlight was available for the plants and no other artificial light source was used in cloudy and humid atmospheric conditions. The experiment also tested the success of the aquaponic system in adverse conditions like unavailability of fresh water for replacement, poor sunlight and minimum DO condition. The combination of balsam and iridescent shark proved to be suitable for the aquaponic system under such adverse conditions.

Index Terms*: *Aquaponic, biofilter, TAN, DO, Nitrates.

I. INTRODUCTION

Aquaponic, from the last few decades, has become the fastest growing mechanism for integrated plant and fish production system[14]. There were 54.8 million people working in the fish production sector in the year of 2010. Aquaculture and fisheries developed income source and food for them. In the world, Asia has more than 87 percent of the fish farmers and China has nearly 14 million people (26 percent of the world total) as fishers and fish farmers. The percentage in Africa is more than 7 percent, with Latin America and the Caribbean contribute 3.6 percent [14]. In the year 1950-51, India produced 0.75 million tonnes of aquaculture and fisheries production. In the year 2013-14, it increased to 9.6 million tonnes. With respect to the aquaculture production, India is in the second place after China [14]. Aquaponics is a form of aquaculture that follows soil less production of plants and development of fish species. Thus aquaponics is an integrated and combined form of aquaculture [1]. It is a dynamic interaction between the fish, plant, nitrifying bacteria and corresponding aquatic environmental factors [2]. This combined interaction of aquaculture and hydroponics has the benefit of low demand of nutrients. And low quantity waste output when compared to the systems which run as separate systems [6]. Plants need micronutrients like N, P, K, Ca, S, Mg and micronutrients like Fe, Cl, Mn, Zn, Cu, B and Mo, which are essential for their growth [6]. One of the most important macronutrients required for plant growth is nitrogen. It is supplied through fish waste in the form of ammonia (NH3). Though NH3 is toxic to fish in high concentrations, after oxidizing into nitrite (NO2-) by nitrifying bacteria (Nitrosomonas) and re-oxidized by the second type of nitrifying bacteria known as Nitrobacter, it is converted into nitrate (NO3) and is easily absorbed by plants [10]. To decide the right balance and optimum combinations for a sustainable aquaponic system is the biggest challenge for researchers. To achieve such optimization, it needs the basic knowledge and experiences regarding the factors like types of fish, feeding rates, type of fish food and its composition, protein quantity converted to Total Ammonia Nitrogen (TAN) along with feeding frequency, the design and type of the aquaponic system, the types of cultivated plants, density of plant sowing, and chemical quality of the water during the mineralization rate of fish waste [6]. In recirculating aquaponic systems, the fish, plants and microorganisms stay in a single recirculating cycle. Therefor, for smooth functioning of the system, it is important to set the parameter levels of temperature, pH and mineral concentrations in water at optimum values. With an objective to create a stable system for maximum crop and fish production, and to optimize it, various studies are done [1]. Several methods are implemented for the optimization of the various factors such as pH, temperature, nutrients, dissolved oxygen (DO), total suspended solids and total nitrogen [9]. Since the introduction of the aquaponic system in the late 1980s, their production was increased in volume. Production is also increased in species variety. Now a day more than 10 species are produced in RAS namely turbot, sea bass, salmon and sole as marine species and African catfish, eel, trout as freshwater species [2]. Also, common fish species like Tilapia (Oreochromis spp); Carp (family Cyprinidae) and Catfish (order Siluriformes) are raised in the aquaponic system [7],[11].

Manuscript published on 30 March 2019.
*Correspondence Author(s)
Bharat N. Mulay, Civil Engineering Department, K.L.University, Guntur, A.P., India.
K. Rajasekhara Reddy, Civil Engineering Department, , K.L.University, Guntur, A.P., India.

Basil, cauliflower, lettuce, cucumber, eggplant, peppers, beans and peas, head cabbage, broccoli, mangold, and parsley are the plants grown in the aquaponic systems [10], [11]. Three most common methods used in aquaponics are nutrient film method NFT, media bed method and deep water culture DWC method [10]. For media filled grow beds, clay, pumice and gravel is used as inert substrate. The inert substrate serves as root support and a microbial substrate. Water is supplied in such a way so as to maintain a sequence in nutrition and aeration [6]. In DWC system, the large troughs with perforated floating rafts are provided. The planted pots are inserted in the raft. These pots are generally filled with media like rock wool, coco or gravels of pumice rock that support the roots [10]. The roots are always kept submerged in the water tank. The Nutrient Film Technique (NFT) is practiced with pipes used as narrow channels. These pipes are perforated and a thin layer of streaming water through the channels is allowed to pass through the roots [6],[10]. The NFT technique, the drip irrigation method, the deep water culture and media bed technique are already well known and are in regular practice. To avoid the consequences on the production capacity and operating, before choosing any of the methods,a detailed study is always preferable [12]. The aquaponic systems have been established for the lettuce/tilapia floating raft system, but more long-term research/demonstrations should be conducted on the other aquaponic crop and fish system combinations to reduce the uncertainty in adopting them [6]. The possibility of using new organisms in aquaponics (e.g., terrestrial and aquatic plants, fresh water as well as marine fish, algae and seaweeds, crustaceans etc.) should be further explored to study the ecological cycle and its scope in future development. Also, new aquaculture and plant combinations should be experimented to test its economic viability of the technology [12]. The proper growth of all the components of the aquaponic system like fish, plant and microbial activity could be easily affected by environmental changes [3]. Vigyan ashram, a center of Indian Institute of Education IIE, Pune has done several experimental trials on the terrace garden by aquaponic system on a small scale in the year 2011-12, [5]. These experiment trials showed that the production of vegetables like spinach, tomatoes, brinjal can be successful in an aquaponics system under Indian conditions. The expenses on the particular plant nutrients can be reduced. Selecting a proper fish species is equally important in the design of an aquaponic system. Fish species which can tolerate the varying DO / NH4 levels and fast growing should be selected. This system can be efficiently used in a water scarce area. Selection of proper growing bed, a drainage system, growing media, a suitable irrigation method and the fish species as per water quality is the important criteria to adopt an aquaponic system under Indian context. The experiment is conducted in K. J. College of Engineering and Management Research,Yeolewadi, Pune city. A large part of land use of village Yeolewadi is occupied by forest, hilly region and quarry area with variations of climate and weather. It was necessary to test the success of the new combination of iridescent shark and Balsam plant in an aquaponic system with such conditions. With an indoor arrangement of the system and unavailability of the water to replace the fish tank water completely, the water was replaced after 45 days. No aeration options were used except the aeration while circulating the water every day for different periods.

II. MATERIALS AND METHOD

The unit in the aquaponic tank was having three platforms designed and assembled as shown in the following images. Aquaculture component consists of tank 1.2 m (l) x 1 m (b) x 0.9m (h) resulting in a total volume of 1.08 m^3. Water volume was 1000 lit. The water pump used is 18 watts, 2200 RPM sufficient to achieve a full cycle of filling and emptying the hydroponic component in maximum 1 hour. For emptying of the hydroponic component, a plastic bottle with micropores is fitted at the bottom of the hydroponic component with a 20mm PVC pipe was used which carries the filtered water back to the aquaculture component.

Fig. 1: Fish tank with recirculation arrangement.

Fig. 2: Hydroponic component with an inbuilt biofilter

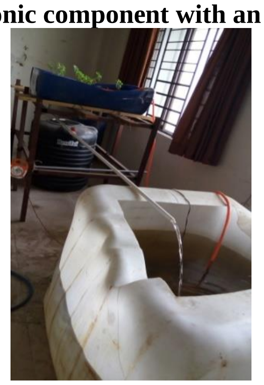

Fig. 3: Aquaponic system setup

The hydroponic component has an inbuilt biofilter with Length kept 0.9 m, Depth 0.26 m, and Diameter 0.55 m. The biofilter component consists of layers of coconut coir material and coco pit. Coconut fiber is proved to be a reliable medium in prefilters for removal of grass impurities from highly turbid waters [15].The layers can be seen in the figure, with 1st layer as media bed layer (coarse aggregate) = 0.1 m, 2nd layer (coconut husk) = 0.03 m, 3rd layer (sand particles) = 0.06 m, 4th layer (coconut husk) = 0.03 m, 5th layer (coco pit) = 0.03 m. The plant species selected for growth are Balsam.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The plant Balsam,(Impatiens balsamina) is selected because the plant is reported to contain mainly naphthoquinones, coumarins, phenolic acids, flavonoids, anthocyanidins and steroids, which might be useful in the development of new drugs of the versatile nature to treat various diseases because of their different pharmacological activities [8]. This species, being the impatiens native of India, it is widely distributed all over the country. Impatiens balsamina is known as Rose balsam in English and as Gul Mehendi in Hindi. Locally known as balsam in Kerala belonging to the family Balsaminaceae [8]. Herbal medicines based drugs are commonly used in India. Balsam plant mixed with other herbs is popularly used in a bath after childbirth for general health. The drug made with allium cepa, locally known as onion, and fennel flower known as black cumin, is used for the treatment of joint problems and coughs. The leaves of balsam plants are used as antiarrhythmic, expectorant, antispasmodic, astringent, antigastralgic and anthelmintic [8]. The fish species selected is Pangasianodon hypophthalmus commonly known as iridescent shark. The iridescent shark has earned economic value and become the fishery practices as well as the habitats of many neighbor countries. Iridescent shark is a popular fish in some European areas as a fish food, also in the USA and in Russia [13]. This fish is known to produce a large number of larvae. It is a popular species in aquaculture trade as it can grow to 1300 mm in length and can gain 44kg of weight [13].

III. RESULTS AND DISCUSSION

The experiment was conducted for 60 days from April 1, 2018 to June 14, 2018. Four plants were grown in the hydroponic component. The leaves count was first taken on the 14th day from the plantation. After 60 days the height of the plants was found on an average 24cms. It is an annual plant normally growing to 20–75 cm tall [8]. Therefore, the experimental results are similar to those achieved in earlier research, confirms that this method and combination can be effective. The number of leaves on all the four plants is counted after the periodic intervals of 7 days. At the end of 60 days duration of the experiment, count of leaves on plant A1, A2, A3, and A4 was found to be 78,62,94 and 82 respectively (table1). The variations in pH, total ammonia nitrogen, total solids, nitrates, chlorides, and alkalinity were recorded. It was noted that with the change in pH and time intervals, there is a significant variation in each parameter. With decreasing pH, there is an increase in all the rest of the parameters. When water was completely replaced, the parameters show their average values similar to the values at the beginning of the first recycling of water. The biofilter was observed working in a proper manner in the first 15 days, maintaining the total ammonia in the water below 1 ppm. For the next 15 days, the ammonia level increased to 4.3 ppm. The water was replaced in the aquaponic component on the 30th day of experimentation. As a result, the pH was raised to 7.4 and total ammonia was lowered below 1 ppm.

Table 1: Growth of coconut leaves per plant

Date	No.of leaves			
	Plant A1	Plant A2	Plant A3	Plant A4
14/04/18	07	05	13	9
20/04/18	12	11	17	13
26/04/18	15	14	21	16
30/04/18	20	18	25	22
07/05/18	27	23	34	27
14/05/18	39	35	42	38
22/05/18	52	46	58	48
29/05/18	64	53	72	66
06/06/18	78	62	94	82
14/06/18	82	65	97	86

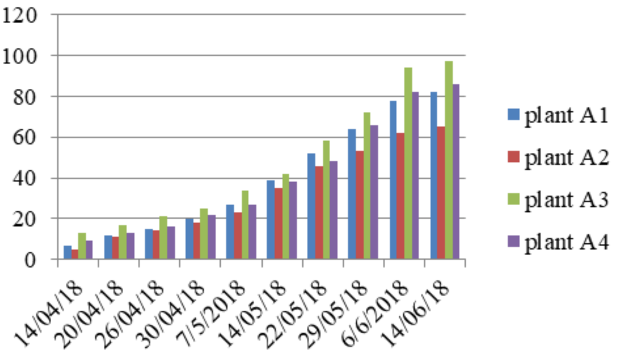

Chart 1: Growth of leaves per plant

From chart 2, it can be concluded that maintaining the pH of water is an important task in the system. The fish excreta started settling down at the bottom of the tank. The quantity was negligible and didn't cause a strong odor in the water. Also, it didn't affect the water quality as it was washed away on the 30th day.

Table 2: Ammonia, nitrogen, nitrates and total solids concentration

Dates	pH	NH_3 (ppm)	N (ppm)	NO_3 (ppm)	K (ppm)
14/04/18	7.5	0.03	0.70	1.40	0.30
20/04/18	7.4	0.055	0.86	1.535	0.65
26/04/18	7.3	0.08	1.02	1.67	1.00
30/04/18	7.2	0.12	1.38	2.37	1.17
07/05/18	6.9	0.27	2.2	2.89	1.54
14/05/18	6.5	0.67	4.3	3.27	1.70
22/05/18	7.4	0.043	0.79	1.37	0.26
29/05/18	7.3	0.05	0.82	1.48	0.61
06/06/18	7.2	0.074	1.23	1.84	0.79
14/06/18	7.2	0.82	1.35	2.21	0.91

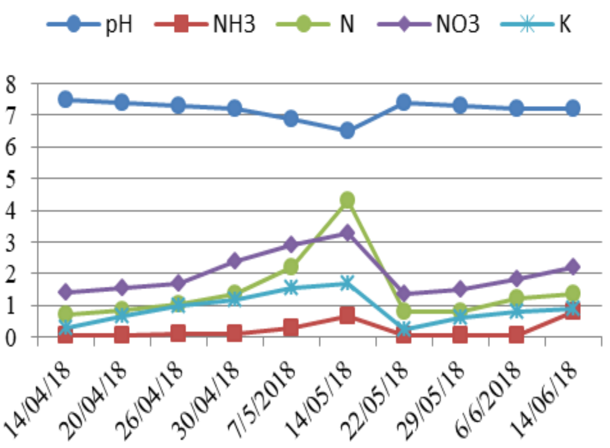

Chart 2: pH, NH_3, N, NO_3 and K concentrations

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

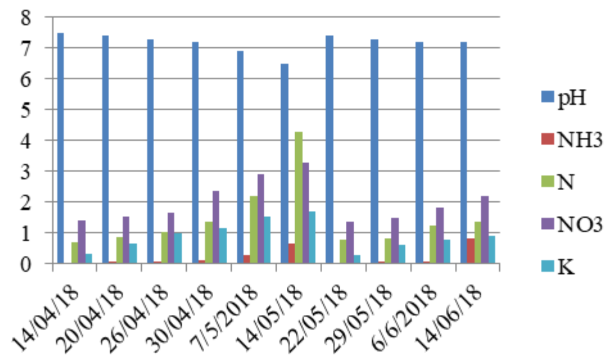

Chart 3: pH, NH_3, N, NO_3 and K concentrations

Table 3: Chlorides, potassium, and total alkalinity

Date	pH	Cl (ppm)	Total Solids (ppm)	Total Alkalinity as $CaCO_3$ (mg/L)
14/04/18	7.5	49.63	550.28	250.00
20/04/18	7.4	51.4	583.25	262.5
26/04/18	7.3	53.17	615.77	275.00
03/04/18	7.1	60.53	690.77	302.17
07/05/18	6.7	76.63	770.77	330.32
14/05/18	6.5	84.17	810.77	347.00
22/05/18	7.4	43.32	475	227
29/05/18	7.3	50.02	554.37	257.5
06/06/18	7.2	51.76	640.23	268.40
14/06/18	7.2	52.42	670	282.00

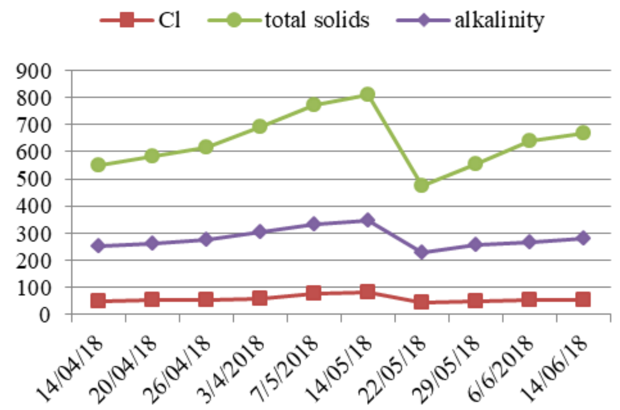

Chart 4: pH, Cl, total solids and alkalinity levels

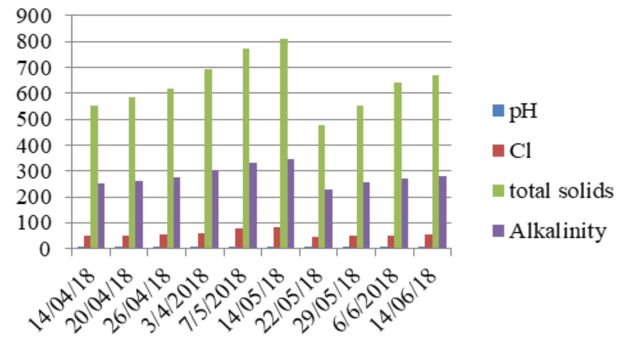

Chart 5: pH, Cl, total solids and alkalinity levels

Table 4: DO concentrations

Date	pH	Total DO Ppm Before circulation	Total DO Ppm After circulation
14/4/18	7.5	0.5	7
17/4/18	7.5	0.5	6
20/4/18	7.4	0.5	6
23/4/18	7.4	0.4	7
26/4/18	7.3	0.2	7
30/4/18	7.2	0.2	7
03/4/18	7.1	nil	7
07/5/18	6.9	nil	6
10/5/18	6.7	nil	7
14/5/18	6.5	nil	7
22/5/18	7.4	1.4	7
25/5/18	7.3	1.4	7
29/5/18	7.3	1.5	6
02/5/18	7.2	1.3	6
06/6/18	7.2	1.2	5

The dissolved oxygen content was recorded before and after recirculation of water through the biofilter. The records from table 4 show the dissolved oxygen dropped below 1 ppm before recirculation. The dissolved oxygen level increased after recirculation of aquaponic water. It was recorded more than 5 ppm after every recirculation. The recirculation period was kept 3 hours once after 3 days of a span. No death of the fish species observed during the gap of recirculation cycles. The biofilter worked efficiently as the growth of the plant was more rapid than the conventional system in practice.

IV. CONCLUSION

The balsam plant growth was satisfactory with respect to height, number of leaves and flowers. The fish species named iridescent shark proved its high survival strength as the system run with less dissolved oxygen for 45 days. The fish length increased from 10cm to almost 18 cm in the span of 45 days. No death was observed out of 20 fish within the experimentation cycle. It can be concluded that in the condition of very less dissolved oxygen like 0.5 ppm, 0.2 ppm and zero ppm, varying pH values from 7.5 to 7.2, and high nitrogen levels (4.3 ppm) the iridescent sharks can survive. For almost 45 days, the biofilter without maintenance, proved its efficiency of working satisfactory for longer duration. With 1000 lit of water replaced only once in 3 months, the issue of availability fresh water can be solved to some extent by implementing this system. Recirculation done once in 3 days also benefits by reducing the demand for electricity and thereby reduces operational cost. This system can be effective in areas like beed, Yeotmal and Latur districts where water deficiency is at its peak. Recycling and reuse of water to the plant and fish growth can be effective in such districts particularly in Maharashtra.

V. LIMITATIONS AND SCOPE

There are some consequences with the working of biofilter as it couldn't control the rising ammonia and lowering pH of the system water. Though the pH value didn't show considerable decrease, as it dropped to 7.2 from 7.5, it still makes significant changes in TAN levels. So maintaining pH for better quality control is the scope of this experimental investigation. The removal of the solids settled at the bottom of the fish tank is another area of the future scope for this type of recirculating systems. After recirculation, the DO levels recorded around 7 ppm and were decreased below 1.5

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

ppm, whereas sometimes less than 0.5 ppm. An hourly investigation should be done to detect a particular time when the DO level falls below 4 ppm. The recirculation can be scheduled more accurately with respect to these records. The system needs to be tested with varying recirculation periods to examine the effects on plant growth. Specific research apart from experimenting with different filtering media is required in hydroponic cum biofilter media. There should be some innovation in further research in microbial activities involved in the aquaponic system and its optimization.

ACKNOWLEDGMENT

This experimentation is carried in K. J. College of engineering and research institute. We are thankful to those researchers whose valuable research helped us to make our objectives more clear and also those researchers whose work we couldn't cite. We appreciate Vigyan ashram, Pune for their important suggestions and support. Thanks to the civil department of K.L.University for providing guidance in this work.

REFERENCES

1. D. C. Love, M. S. Uhl, and L. Genello,"Energy and water use of a small-scale raft aquaponics system in Baltimore, Maryland, United States". *Aquacultural Engineering.*, 2015, vol. 68, pp. 19–27.
2. C. I. M. Martin, "New developments in recirculating aquaculture systems in Europe : A perspective on environmental sustainability", *Aquacultural Engineering*, vol. 43, no. 3, 2010, pp. 83–93.
3. Y. Zou, Z. Hu, J. Zhang, C. Guimbaud, and Q. Wang, "Effect of seasonal variation on nitrogen transformations in aquaponics of northern China," *Ecol. Eng.*, vol. 94, 2016, pp. 30–36.
4. S. Ratnoji and N.Singh, "A study of coconut shell - activated carbon for filtration and its comparison with sand filtration," *International Journal of Renewable Energy and Environmental Engineering*, ISSN 2348-0157, Vol. 02, No. 03, July 2014, pp. 201-204.
5. Ranjeet Shanbag, "Aquaponics – Vigyan ashram experience," 2012, https://vigyanashram.files.wordpress.com/2012/07/vigyan-ashram-ex peri ment1.pdf
6. E. Okemwa (2015),"Challenges and Opportunities to Sustainability in Aquaponic and Hydroponics Systems", *International Journal of Scientific Research and Innovative Technology*, vol. 2, no. 11, pp. 54–76.
7. L. E. Wilson, N. C. Duncan, and D. A. Crain , "Comparison of Aquaponics and Hydroponics on Basil (Ocimum basilicum) Morphometrics and Essential Oil Composition", *RURALS: Review of Undergraduate Research in Agricultural and Life Sciences*, vol. 11: Iss. 1, Article 3,2017, pp. 1-16.
8. B. Meenu, E. D. Neeraja, G. Rejimon, and A. Varghese ,"Review Article Impatiens balsamina : An overview",*Journal of Chemical and Pharmaceutical Research*, vol. 7, no. 9, 2015, pp. 16–21.
9. J. E. Rakocy, M. P. Masser, and T. M. Losordo, "Recirculating Aquaculture Tank Production Systems : Aquaponics — Integrating Fish and Plant Culture", *southern regional aquaculture center publication*, no. 454, 2006, pp 1-16.
10. Somerville, C., Cohen, M., Pantanella, E., Stankus, A. & Lovatelli, A. "Small-scale aquaponic food production. Integrated fish and plant farming", *FAO Fisheries and Aquaculture Technical Paper* No. 589. Rome, FAO, 2014, pp. 262.
11. E. Elia and C. Nicolae, "Startup stages of a low-tech aquaponic system", *Scientific Papers, Series D. Animal Science*. Vol..VII, 2014, pp 263-269.
12. R. Junge, B. Konig, M. Villarroel, T. Komives, and M. H. Jijakli, "Strategic Points in Aquaponics",*Water*, 9, 182, doi:10.3390/w9030182, 2017, pp. 1–9.
13. FAO Fisheries and Aquaculture Department. Technical Paper. No. 500/1. Rome, FAO. 2011. 105 pp.
14. FAO. 2012. The State of World Fisheries and Aquaculture 2012. Rome. 209 pp.
15. Durgananda Singh Chaudhary, Saravanamuthu Vigneswaran†, Huu-Hao Ngo, Wang Geun Shim* and Hee Moon,"Biofilter in water and wastewater treatment", *Korean J. Chem. Eng.*,20(6),2003, pp. 1054-1065

AUTHORS PROFILE

Dr. K. Rajasekhar Reddy is working as Associate Professor in Koneru Lakshmaiah Education Foundation, Civil Engineering Department, K.L.University, Guntur Andhra Pradesh, since 2008. He completed his PhD from Karnataka University in 1991.

Bharat N. Mulay is doing his PhD in Koneru Lakshmaiah Education Foundation, Civil Engineering Department, K.L.University, Guntur, Andhrapradesh. He is Assistant Professor in Civil Department, K.J. College of Engineering, Pune, Maharashtra.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)