Management Analysis of Paddle Wheel For Efficiency Operational Cost Shrimp Culture Based on Oxygen Budget Capacity

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The aims of this research is to determine the optimal management of the paddle wheel based on the availability and balance of dissolved oxygen in shrimp ponds for efficiency in aquaculture operational costs. The methods employed are : (i) Field Observation for Oxygent Budget on included inputs oxygen and Outputs Oxygent and; (ii) Electricity usage during rearing periode. Results of analysis to Shrimp Culture (50 shrimp/m^2) which obtained efficiency for paddle wheel electricity/kg shrimp as 1.04 kwh/kg shrimp/cyclus or 2.08 kwh/kg shrimp/years. Operational Cost is decreased as IDR 119 046 879/hectare/MT or IDR 238 093 758/hectare/years and profitable which obtained is increased to as IDR 55 788 853/hectare/cyclus atau IDR 111 577 707/hectare/years. While to shrimp culture (126 shrimp/m^2) which obtained efficiency for paddle wheel electricity/kg shrimp as 1.61 kwh/kg shrimp/cyclus atau 3.22 kwh/kg shrimp/years. Operational Cost is decreased as IDR 355 936 618/hectare/cyclus atau IDR 711 873 235/hectare/years and profitable which obtained is increased to as IDR 186 435 278/hectare/cyclus or IDR 372 870 557/hectare/years.

Introduction

Paddle wheel have a very important role in the management of shrimp farming, apart from being a supplier of dissolved oxygen as well as being a waste of oxygen from ponds in the event of over-saturation conditions. This supersaturated oxygen condition often occurs during the day with a high density of phytoplankton, along with the length of shrimp rearing. On the other hand, at night, the availability of dissolved oxygen is often depleted due to increased shrimp biomass in ponds and increased respiration of phytoplankton (Rachmansyah et al. 2005). Optimal paddle wheel management based on estimation of dissolved oxygen availability (input and output) in shrimp ponds is very important to maintain the availability of dissolved oxygen and operational cost efficiency.

Research purposes

The aims of this research is to determine the optimal management of the paddle wheel based on the availability and balance of dissolved oxygen in shrimp ponds for efficiency in aquaculture operational costs.

Methodology

The optimal management and utilization of the paddle wheel in shrimp farming is estimated by taking into account aspects of availability and balance (input and output of dissolved oxygen) in shrimp ponds. In general, the equation for the balance of dissolved oxygen input and output in shrimp aquaculture refers to a modified formula (Teichert-Coddington et al. 1996):

$$K + I + F + A \approx U + R + O + S \qquad (1)$$

where : K = Paddle Wheel ; I = volume of water inflow (m^3); F = photosynthesis; A = ambient; U = shrimp oxygen consumption; R = oxygen consumption for plankton respiration (water column); O = volume of water outflow (m^3); S = oxygen consumption of shrimp pond sediment

Oxygen input and output in shrimp ponds can be estimated by referring to the modified formula (Rachmansyah et al. 2008) :

1. Dissolved oxygen input from photosynthesis (F) during maintenance can be formulated as :

$$F_n = (f_n \, x VTB) \, x 1000 \qquad (2)$$

2. Dissolved oxygen input from inflow (water change) during maintenance can be formulated as: In = $(O_{kolom\,air}\ x VTA_n)\ x 1000$ ....(3)
3. Ambient dissolved oxygen (without pinwheel) during maintenance can be formulated as : A_n : $(OTK_n\ x VTB)\ x 1000$ ....(4)
4. The dissolved oxygen input from the wheel during maintenance is determined by the oxygen transfer value, the operating time of the wheel, and the dissolved oxygen saturation correction value. The dissolved oxygen input of the wheel during maintenance is determined using the formula K_n = $(1.80\ x WOK_n)\ x 0.90$ ....(5)

So that the total dissolved oxygen that enters (input) into the shrimp pond system during maintenance can be determined by the formula: $IOT_n = K_n + F_n + I_n + A_n$ .... (6)

5. Dissolved oxygen output used by shrimp during rearing period can be formulated : Un = $(BU_n\ x OU_n\ x 24)/1000$ .... (7)
6. The output of dissolved oxygen used for column respiration during maintenance can be formulated as : Rn = $(ORP_n\ x VTB)/1000$ .... (8)
7. Dissolved oxygen output used for sediment respiration during maintenance can be formulated: Sn = $(OS_n\ x VTB\ x 24)/1000$ .... (9)
8. Output oksigen terlarut outflow (water exchange) selama pemeliharaan dapat dirumsukan : O_n = $(OTK_n\ x VBA_n)\ x 1000$ .... (10)

So that the total dissolved oxygen utilized (output) in the shrimp pond system during maintenance can be determined by the formula: $UOT_n = O_n + U_n + R_n + S_n$ .... (11)

Based on the above, the availability and balance of dissolved oxygen in shrimp ponds is formulated : $OT_n = IOT_n - OUT_n$ .... (12)

where :1.80 = oxygen transfer of the paddle wheel at standard conditions (kgO_2/ton/hour); WOK = mill operating time (hours); 0,90 = oxygen saturation correction under standard conditions; F = photosynthetic dissolved oxygen (mg/l); VTB = volume of shrimp pond water (m^3); VTA = volume of addition of water (m^3); OTK = dissolved oxygen in unmilled shrimp ponds (mg/l); VBA = volume of discarded shrimp pond water (m^3); OU = dissolved oxygen in shrimp ponds (kgO_2/ton/hour); OR = dissolved oxygen in water column respiration (mg/L/day); OS = dissolved oxygen of shrimp pond sediment (gO_2/m^2/hour); IOT = dissolved oxygen input (kg); UOT= dissolved oxygen output (kg); OT = availability of dissolved oxygen in shrimp ponds (kg); n = 1,2,3,............, harvest (days).

Based on the estimation of the availability and balance of dissolved oxygen above, an analysis of the efficiency of the operational costs of the mill is carried out through the use of electricity during maintenance. The use of the electric power of the wheel during the maintenance period can be formulated as follows: $TL_k = J_k\ x JO_k\ x LO_k\ x 0.764$ .... (13)

where : TLk = electric power wheel (kwh)
Jk = number of operating wheels (units)
JOk = mill operation (hours/day)
LOk = length of operation of the wheel (days)
0,764 = amount of electric power per HP (kwh)

If the basic electricity cost per kwh is X, then the amount of costs used for the operation of the mill is:

$BO_k = TL_k\ x\ X$ ....(14)

where : BOk = mill operating costs (IDR); TL_k = electric power wheel (kwh) ; X = basic electricity tariff (IDR/kwh)

Results

Optimal paddle wheel management is based on estimating the availability of dissolved oxygen (input and output) in shrimp ponds using supporting data in the estimation process. The supporting data used can be seen in Table 1.

Table 1. The data used in estimating the availability and balance of dissolved oxygen (input and output) in shrimp ponds.

Parameter	Satuan	Nilai
Oxygen of Photosynthesis [1)]	mg/L/day	2,28 – 17,32 (12,15 ± 3,56)
Water column respiration [2)]	mg/L/day	4,01 – 27,62 (15,13 ± 7,30)
Sedimen oxygen consumption [3)]	gO_2/m^2/hour	0,05 – 0,23 (0,11 ± 0,04)
vannamei shrimp oxygen consumption [4)]	kgO_2/ton/hour	0,61 – 1,99 (0,76 ± 0,35)
Oxygen transfer paddle wheel (standart) [5)]	kgO_2/kwh	1,80
Dissolved oxygen saturation correction [6)]	-	0,90
Oxygen of coastal water column [7)]	mg/l	6,56
Eelectric power paddle wheel [8)]	kwh/HP	0,764
Shrimp pond ambient oxygen (50 seeds/m^2) [9)]	mg/l	3,35 – 6,20 (4,89 ± 0,62)
Shrimp pond ambient oxygen (126 seeds/m^2) [10)]	mg/l	3,96 – 6,45 (4,82 ± 0,82)
Intensive shrimp pond water exchange [11)]	%	3 % (1st month dan 2nd month); 10 %(3rd month); 15 % (4th month)

Sumber: Rachmansyah *et al* (2008) [1) 2) 3) 4)] ; Riyanto (1989), Boyd (1991), McIntosh (2000) [5) 6) 8)] ; Field measurements (2020) [7) 9) 10)] ; Widigdo dan Soewardi (2002)[10)] , Field observation (2020) [11);]

The optimal Paddle Wheel management of intensive shrimp ponds (50 seeds/m^2) is based on the estimation of the availability and balance of oxygen in the shrimp pond culture system which is largely determined by the presence of oxygen input and output. Based on the analysis during rearing period, the available dissolved oxygen (oxygen input) in shrimp ponds ranged from 27,96 to 91,27 kg O_2/day (73,68 ± 14,48). Dissolved oxygen input comes from pond ambient oxygen of 13,40 – 24,80 kg O_2/day (19,54 ± 2,50), inflow (water change) of 0,00 – 3,94 kg O_2/day (1,67 ± 1,00) and photosynthesis results of 9,12 – 69,28 kg O_2/day (52,47 ± 14,24). Dissolved oxygen utilized (oxygen output) in shrimp ponds during rearing was 20,89 – 153,74 kg O_2/day (85,46 ± 43,43). Dissolved oxygen in the pond system used by shrimp is 0,05 – 34,37 kg O_2/day (14,99 ± 10,96), outflow (water removed during water changes) is 0,00 – 2,47 kg O_2/day (1,05 ± 0,63), water column respiration is 16,04 – 110,48 kg O_2/day (60,02 ± 31,30), and sediment respiration of 4,80 – 15,36 kg O_2/day (9,40 ± 1,87).

Based on the oxygen input and output, the optimal management of the paddle wheel is estimated according to the needs and availability of dissolved oxygen in the shrimp pond, as follows: (i) The operation of one paddle wheel (1 HP) at the beginning of maintenance until the 28th day is enough to be carried out 4 hours/day, where until the 28th day both oxygen input and oxygen output are quite increased (input 97,19 kg O_2/day and output 47,80 kg O_2 /day); (ii) On day 29, paddle wheel 1 is operated for 4 - 12 hours/day to maintain and increase oxygen until day 57 (input is 98,14 kgO_2/day and output is 95,93 kg O_2/day); (iii) On day 58, the dissolved oxygen input reached 97,54 kg O_2/day while the dissolved oxygen output reached 99,57 kg O_2/day, resulting in an oxygen deficit of – 1,03 kg O_2/day. This shows that the dissolved oxygen input is starting to be disproportionate to the dissolved oxygen demand in the shrimp ponds; (iii) On the 58th day, it is necessary to operate the 2nd wheel. Starting from the 58th day, the 2nd paddle wheel is operated for 12 – 16 hours/day and the 1st paddle wheel is 4 – 12 hours/day. The operation of 2 paddle wheel (1 HP power) is only able to maintain and increase oxygen until the 67th day (input 125,14 kg O_2/day and output 123,18 kg O_2/day), where on day 68 there is an oxygen deficit of -1,25 kg O_2/ day (input 124,30 kg O2/day and output 125,56 kgO2/day); (iv) On the 68th day, it is necessary to operate the 3rd Paddle wheel for 16 – 20 hours (paddle wheel 1 for 4 - 12 hours/day, the 2nd paddle wheel for 12-16 hours/day). The operation of three paddle wheel with 1 HP each is able to maintain and balance dissolved oxygen in the shrimp pond until the end of the rearing period (input 148,78 kg O_2/day and output 139,38 kg O_2/day). Intensive shrimp pond (50 seeds/m^2) in the coastal area of Mangara Bombang Sub-district that during shrimp rearing use three paddle wheel (1 paddle wheel with a power of 1 HP), where on day 1 to day 30 operate 1 paddle wheel for 24 hours/day.

Starting from day 30, 2 paddle wheel will be operated again for 24 hours/day until the end of maintenance. In this condition, from the beginning to the end of the maintenance, the electric power is 3.920,98 kwh/planting season or 7.841,95 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 1,67 kwh/kg shrimp/planting season or 3,34 kwh/kg shrimp/II planting season. Meanwhile, with the management of the paddle wheel based on the estimated dissolved oxygen input and output, from the beginning to the end of the maintenance using electricity of 1.483,05 kwh/planting season or 2.966,10 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 0,63 kwh/kg shrimp/planting season or 1,26 kwh/kg shrimp/II planting season. The magnitude of the difference or efficiency in the use of electricity for the operation of the paddle wheel under current conditions and based on the estimated input and output of oxygen is 2.437,93 kwh/planting season or 4.875,86 kwh/II planting season, where for the production of 1 kg of shrimp there is a difference or efficiency of 1,04 kwh/kg of shrimp/planting season or 2,08 kwh/kg shrimp/II planting season.

The cost of using electricity in the current condition for the operation of the paddle wheel each planting season (MT) is 3.920,98 kwh x Rp. 640,-/kwh (TDL Subsidy) = IDR 2.509.427/planting season or IDR 5.018.854/II MT. Meanwhile, based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 1.483,05 x IDR 640/kwh (TDL Subsidy) = IDR 949.152/MT or IDR 1.898.304/II MT. Based on this, there is a difference or efficiency in the use of electricity for the paddle wheel as much as: IDR 2.509.427/MT – 949.152/MT = IDR 1.560.275/MT or IDR 3.120. 550/II MT. Furthermore, if using the non-subsidized basic electricity rate (TDL) of IDR 1.380 (PLN 2020), then the costs incurred for operating the paddle wheel each planting season (MT) at its current condition are 3.920,98 kwh x Rp. 1.380/kwh = IDR 5. 410. 953/ planting season or IDR 10.821.905/II planting season. Meanwhile, based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 1.483.05 x IDR 1.380/kwh = IDR 2. 046. 609/Planting season or IDR 4.093.218/II planting season. The difference or efficiency in the use of electricity for the paddle wheel is IDR 5.410.952,-/planting season – 2.046.609/planting season = IDR 3.364.343/planting season or IDR 6.728. 687/II planting season. The results of the analysis above, if it is associated with the level of business feasibility, then the total costs incurred decrease to IDR 119.046.879/ha/planting season or IDR 238. 093.758/ha/year. Meanwhile, the profit earned increased to IDR 55.788.853/ha/planting season or IDR 111.577.707/ha/year, with an R/C value of 1,47 and a payback period of 1,87 years. Net Present Value (NPV) is IDR 284. 955. 649 (shrimp production, total costs incurred, and profits are the same every year) and Net Benefit Cost Ratio (Net B/C) is 2,36. While the value of the Internal Rate of Return (IRR) obtained is 52,93%.

Optimal management of intensive shrimp ponds (126 seeds/m^2), The available dissolved oxygen (oxygen input) in shrimp ponds ranged from 30,19 to 86,54 kg O_2/day (66,93 ± 12,96). Dissolved oxygen input comes from pond ambient oxygen of 14,85 – 24,19 kg O_2/day (18,08 ± 3,07), inflow (water introduced at water change) of 0,00 – 3,69 kg O_2/day (1,74 ± 1,19) and photosynthesis yield of 8,55 – 64,95 kg O_2/day (46,95 ± 13,35).

Dissolved oxygen utilized (oxygen output) in the shrimp pond system during rearing was 19.78 – 200.19 kg O2/day (115.72 ± 54.10). Dissolved oxygen in shrimp ponds utilized by shrimp is 0.24 – 100.26 kg O2/day (47.38 ± 27.29), outflow (water removed during water changes) is 0.00 – 3.11 kg O2/day (1.22 ± 0.83), water column respiration is 15.04 – 103.58 kg O2/day (56.74 ± 27.37), and sediment consumption is 4.50 – 20.70 kg O2/day (10.28 ± 3.87). Dissolved oxygen input and output data illustrates the availability and balance of dissolved oxygen utilization in shrimp aquaculture.

Based on this data and information, an estimation of the optimal management or utilization of the wheel during the shrimp farming process is carried out as follows: (i) The operation of 1 paddle wheel (1 HP power) at the beginning of maintenance until the 26th day is enough to be carried out 4 hours / day, where until the 26th day both oxygen input and oxygen output are quite increased (input 92,19 kgO_2/day and output 58,67 kgO_2 /day); (ii) Starting from the 27th day of operation the 1st paddle wheel was increased to 4-5 hours/day to maintain oxygen until the 45th day (input 87,36 kgO_2/day and output 86,43 kgO_2/day). On day 46, the dissolved oxygen input reached 86,69 kg O_2/day while the dissolved oxygen output reached 88.81 kg O2/day, resulting in an oxygen deficit of –2,13 kg O_2/day.

This shows that the dissolved oxygen input is starting to be disproportionate to the dissolved oxygen demand in the shrimp ponds; (iii) On day 46 it is necessary to operate the 2nd wheel for 5 – 12 hours/day (paddle wheel 1 for 4 - 5 hours/day). The operation of 2 paddle wheel (1 HP power) is only able to maintain and increase dissolved oxygen until the 54th day, where on the 55th day there is a dissolved oxygen deficit of -1,82 kg O2/day (input 111,43 kgO_2/day and output 113,25 kgO_2 /day); (iv) On the 55th day, it is necessary to operate the 3rd wheel for 12 – 16 hours/day (wheel 1 for 4 – 5 hours/day and paddle wheel 2 for 5 – 12 hours/day); (v) The operation of 3 paddle wheel is only able to increase and maintain dissolved oxygen until the 65th day, where on the 66th day there is a dissolved oxygen deficit of –2,2 kg O2/day (input 145,17 kgO_2/day and output 147.59 kgO_2/day); (vi) On the 66th day it is necessary to operate the 4th, 5th and 6th paddle wheel for 16 – 24 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day).

The operation of 6 paddle wheel is only able to increase dissolved oxygen up to day 99, where on day 100 there is an oxygen deficit of –4,43 kgO_2/day (input 144,35 kgO_2/day and output 148,77 kgO_2/day); (vii) On the 100th day, the 7th wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4 -5-6 for 16 – 24 hours/day). The operation of 7 paddle wheel was only able to increase and maintain oxygen for 3 days (until day 102) and on day -103 there was an oxygen deficit of -4,59 kgO_2/day (input 159,11 kgO_2/day and output 163,70 kgO_2/day); (viii) On the 103rd day, the 8th wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4- 5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day), where the operation of 8 paddle wheel is only able to increase and maintain dissolved oxygen until day 104 and on day 105 there is a dissolved oxygen deficit of -0,54 kgO_2/ day (input 173,99 kgO_2/day and output 174,53 kgO_2/day); (ix) Starting from the 105th day, the 9th paddle wheel is operated for 9 hours/day (paddle wheel 1 for 4-5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12-16 hours/day, paddle wheel 4- 5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day, paddle wheel 8 for 9 hours/day).

The operation of 9 paddle wheel to increase and maintain dissolved oxygen until the 107th day. On the 108th day there was a dissolved oxygen deficit of -0,74 kgO_2/day (input 188,65 kg O_2/day and output 189,39 kg O_2/day); (x) On the 109th day, the 10th paddle wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4 -5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day, paddle wheel 8 for 9 hours/day, paddle wheel 9 for 9 hours/day), where the operation of 10 paddle wheels with 1 HP each is capable of maintain and balance dissolved oxygen in shrimp ponds until the end of the rearing period. Intensive shrimp pond cultivators (126 seeds/m^2) in the coastal area of Mangara Bombang District during shrimp rearing period use 10 paddle wheels (1 paddle wheel with a power of 1 HP), where on day 1 to day 30 operate 2 paddle wheels for 24 hours/day . Starting from day 30, 8 paddle wheel were operated for 24 hours/day until the end of maintenance (Results of interviews and field observations 2020). Based on the results of the analysis, it was found that the management of the paddle wheel (1 HP) in its current condition, from the beginning to the end of the maintenance using electricity of 15.397,44 kwh/planting season or 30.794,88 kwh/II planting season. In the existing condition, each production of 1 kg of shrimp uses an electric power of 2,25 kwh/kg shrimp/planting season or 4,49 kwh/kg shrimp/II planting season. Meanwhile, with the management of the mill based on the estimated availability and balance of dissolved oxygen (input and output), from the beginning to the end of the maintenance using electricity of 4.356,64 kwh/planting season or 8.713,28 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 0,64 kwh /kg shrimp/planting season or 1,28 kwh/kg shrimp/II planting season.

The amount of the difference or efficiency in the use of electricity for the operation of the paddle wheel in the current conditions and based on the estimated input and output of oxygen is 11.040,80 kwh/planting season or 22.081,60 kwh/II planting season, where for the production of 1 kg of shrimp there is a difference or efficiency of 1,61 kwh/ kg shrimp/planting season or 3,22 kwh/kg shrimp/II planting season. In the current condition, the cost of using electricity is 15.397,44 kwh/planting season kwh and if the subsidized basic electricity rate (TDL) is IDR 640/kwh (PLN 2020), the costs incurred for the operation of the paddle wheel each planting season (MT) are 15.397,44 kwh x IDR 640/kwh = IDR 9.854.362/planting season or IDR 19.708.723/II planting season. Meanwhile, based on the estimated balance of dissolved oxygen input and output in shrimp ponds, the costs incurred for the operation of the paddle wheel each planting season (MT) are 4.356,64 kwh x IDR 640 = IDR 2.788 .250/planting season or IDR 5.576.499/II planting season. Based on this, the efficient use of electricity for the paddle wheel is IDR 9.854.362/planting season – IDR 2.788.250/planting season = IDR 7.066. 112/planting season or IDR 14.132.224/II planting season. Furthermore, if using a non-subsidized electricity basis (TDL) of IDR 1.380 (PLN 2020), then the costs incurred for the operation of the paddle wheel each planting season (MT) at its current condition are 15.397,44 kwh x IDR 1.380/kwh = IDR 21. 248.467 /planting season or IDR 42.496.934/II planting season. Based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 4.356,64 kwh x IDR 1.380 = IDR 6.012.163/planting season or IDR 12.024.326/II planting season. Based on this, the efficient use of electricity for the planting season is IDR 21.248. 467/planting season – IDR 6.012.163/planting season = IDR 15.236.304/planting season or IDR 30. 472. 608/II planting season. The results of the analysis above, if it is associated with the level of business feasibility, the total operating costs incurred for cultivation have decreased to IDR 355.936. 618/ha/planting season or IDR 711.873.235/ha/year. Meanwhile, the profit earned increased to IDR 186. 435.278/ha/planting season or IDR 372.870.557/ha/year, with an R/C value of 1,52 and a payback period of 2,66 years. Net Present Value (NPV) is IDR 679.791.064 (shrimp production, total costs incurred, and profits are the same every year) and Net Benefit Cost Ratio (Net B/C) is 1,69. While the value of the Internal Rate of Return (IRR) obtained is 36,61%.

Conclusion

Proper placement of the wheel should also be a concern to maximize the oxygenated pond area and minimize the oxygen-deficient pond area.

In this study, the production level of shrimp (126 seeds/m^2) was 684.8 kg/HP and the production level of shrimp (50 seeds/m^2) was 784.90 kg/HP

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The aims of this research is to determine the optimal management of the paddle wheel based on the availability and balance of dissolved oxygen in shrimp ponds for efficiency in aquaculture operational costs. The methods employed are : (i) Field Observation for Oxygent Budget on included inputs oxygen and Outputs Oxygent and; (ii) Electricity usage during rearing periode. Results of analysis to Shrimp Culture (50 shrimp/m^2) which obtained efficiency for paddle wheel electricity/kg shrimp as 1.04 kwh/kg shrimp/cyclus or 2.08 kwh/kg shrimp/years. Operational Cost is decreased as IDR 119 046 879/hectare/MT or IDR 238 093 758/hectare/years and profitable which obtained is increased to as IDR 55 788 853/hectare/cyclus atau IDR 111 577 707/hectare/years. While to shrimp culture (126 shrimp/m^2) which obtained efficiency for paddle wheel electricity/kg shrimp as 1.61 kwh/kg shrimp/cyclus atau 3.22 kwh/kg shrimp/years. Operational Cost is decreased as IDR 355 936 618/hectare/cyclus atau IDR 711 873 235/hectare/years and profitable which obtained is increased to as IDR 186 435 278/hectare/cyclus or IDR 372 870 557/hectare/years.

Introduction

Paddle wheel have a very important role in the management of shrimp farming, apart from being a supplier of dissolved oxygen as well as being a waste of oxygen from ponds in the event of over-saturation conditions. This supersaturated oxygen condition often occurs during the day with a high density of phytoplankton, along with the length of shrimp rearing. On the other hand, at night, the availability of dissolved oxygen is often depleted due to increased shrimp biomass in ponds and increased respiration of phytoplankton (Rachmansyah et al. 2005). Optimal paddle wheel management based on estimation of dissolved oxygen availability (input and output) in shrimp ponds is very important to maintain the availability of dissolved oxygen and operational cost efficiency.

Research purposes

The aims of this research is to determine the optimal management of the paddle wheel based on the availability and balance of dissolved oxygen in shrimp ponds for efficiency in aquaculture operational costs.

Methodology

The optimal management and utilization of the paddle wheel in shrimp farming is estimated by taking into account aspects of availability and balance (input and output of dissolved oxygen) in shrimp ponds. In general, the equation for the balance of dissolved oxygen input and output in shrimp aquaculture refers to a modified formula (Teichert-Coddington et al. 1996):

$$K + I + F + A \approx U + R + O + S \quad \text{...(1)}$$

where : K = Paddle Wheel ; I = volume of water inflow (m^3); F = photosynthesis; A = ambient; U = shrimp oxygen consumption; R = oxygen consumption for plankton respiration (water column); O = volume of water outflow (m^3); S = oxygen consumption of shrimp pond sediment

Oxygen input and output in shrimp ponds can be estimated by referring to the modified formula (Rachmansyah et al. 2008) :

1. Dissolved oxygen input from photosynthesis (F) during maintenance can be formulated as :

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F_n = $(f_n \ x VTB) \ x 1000$ ....(2)

2. Dissolved oxygen input from inflow (water change) during maintenance can be formulated as: In = $(O_{kolom\,air} \ x VTA_n) \ x 1000$ ....(3)
3. Ambient dissolved oxygen (without pinwheel) during maintenance can be formulated as : A_n : $(OTK_n \ x VTB) \ x 1000$ ....(4)
4. The dissolved oxygen input from the wheel during maintenance is determined by the oxygen transfer value, the operating time of the wheel, and the dissolved oxygen saturation correction value. The dissolved oxygen input of the wheel during maintenance is determined using the formula K_n = $(1.80 \ x WOK_n) \ x 0.90$ ....(5)

So that the total dissolved oxygen that enters (input) into the shrimp pond system during maintenance can be determined by the formula: $IOT_n = K_n + F_n + I_n + A_n$ .... (6)

5. Dissolved oxygen output used by shrimp during rearing period can be formulated : Un = $(BU_n \ x OU_n \ x 24) / 1000$ .... (7)
6. The output of dissolved oxygen used for column respiration during maintenance can be formulated as : Rn = $(ORP_n \ x VTB) / 1000$ .... (8)
7. Dissolved oxygen output used for sediment respiration during maintenance can be formulated: Sn = $(OS_n \ x VTB \ x 24) / 1000$ .... (9)
8. Output oksigen terlarut outflow (water exchange) selama pemeliharaan dapat dirumsukan : O_n = $(OTK_n \ x VBA_n) \ x 1000$ .... (10)

So that the total dissolved oxygen utilized (output) in the shrimp pond system during maintenance can be determined by the formula: $UOT_n = O_n + U_n + R_n + S_n$ .... (11)

Based on the above, the availability and balance of dissolved oxygen in shrimp ponds is formulated : $OT_n = IOT_n - OUT_n$ .... (12)

where :1.80 = oxygen transfer of the paddle wheel at standard conditions (kgO_2/ton/hour); WOK = mill operating time (hours); 0,90 = oxygen saturation correction under standard conditions; F = photosynthetic dissolved oxygen (mg/l); VTB = volume of shrimp pond water (m^3); VTA = volume of addition of water (m^3); OTK = dissolved oxygen in unmilled shrimp ponds (mg/l); VBA = volume of discarded shrimp pond water (m^3); OU = dissolved oxygen in shrimp ponds (kgO_2/ton/hour); OR = dissolved oxygen in water column respiration (mg/L/day); OS = dissolved oxygen of shrimp pond sediment (gO_2/m^2/hour); IOT = dissolved oxygen input (kg); UOT= dissolved oxygen output (kg); OT = availability of dissolved oxygen in shrimp ponds (kg); n = 1,2,3,............, harvest (days).

Based on the estimation of the availability and balance of dissolved oxygen above, an analysis of the efficiency of the operational costs of the mill is carried out through the use of electricity during maintenance. The use of the electric power of the wheel during the maintenance period can be formulated as follows: $TL_k = J_k \ x JO_k \ x LO_k \ x 0.764$ .... (13)

where : TLk = electric power wheel (kwh)

Jk = number of operating wheels (units)

JOk = mill operation (hours/day)

LOk = length of operation of the wheel (days)

0,764 = amount of electric power per HP (kwh)

If the basic electricity cost per kwh is X, then the amount of costs used for the operation of the mill is:

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$$BO_k = TL_k \; x \; X \qquad (14)$$

where : BOk = mill operating costs (IDR); TL_k = electric power wheel (kwh) ; X = basic electricity tariff (IDR/kwh)

Results

Optimal paddle wheel management is based on estimating the availability of dissolved oxygen (input and output) in shrimp ponds using supporting data in the estimation process. The supporting data used can be seen in Table 1.

Table 1. The data used in estimating the availability and balance of dissolved oxygen (input and output) in shrimp ponds.

Parameter	**Satuan**	**Nilai**
Oxygen of Photosynthesis [1]	mg/L/day	2,28 – 17,32 (12,15 ± 3,56)
Water column respiration [2]	mg/L/day	4,01 – 27,62 (15,13 ± 7,30)
Sedimen oxygen consumption [3]	gO_2/m^2/hour	0,05 – 0,23 (0,11 ± 0,04)
vannamei shrimp oxygen consumption [4]	kgO_2/ton/hour	0,61 – 1,99 (0,76 ± 0,35)
Oxygen transfer paddle wheel (standart) [5]	kgO_2/kwh	1,80
Dissolved oxygen saturation correction [6]	-	0,90
Oxygen of coastal water column [7]	mg/l	6,56
Eelectric power paddle wheel [8]	kwh/HP	0,764
Shrimp pond ambient oxygen (50 seeds/m^2) [9]	mg/l	3,35 – 6,20 (4,89 ± 0,62)
Shrimp pond ambient oxygen (126 seeds/m^2) [10]	mg/l	3,96 – 6,45 (4,82 ± 0,82)
Intensive shrimp pond water exchange [11]	%	3 % (1st month dan 2nd month); 10 %(3rd month); 15 % (4th month)

Sumber: Rachmansyah *et al* (2008) [1) 2) 3) 4)] ; Riyanto (1989), Boyd (1991), McIntosh (2000) [5) 6) 8)] ; Field measurements (2020) [7) 9) 10)] ; Widigdo dan Soewardi (2002)[10)] , Field observation (2020) [11)];

The optimal Paddle Wheel management of intensive shrimp ponds (50 seeds/m^2) is based on the estimation of the availability and balance of oxygen in the shrimp pond culture system which is largely determined by the presence of oxygen input and output. Based on the analysis during rearing period, the available dissolved oxygen (oxygen input) in shrimp ponds ranged from 27,96 to 91,27 kg O_2/day (73,68 ± 14,48). Dissolved oxygen input comes from pond ambient oxygen of 13,40 – 24,80 kg O_2/day (19,54 ± 2,50), inflow (water change) of 0,00 – 3,94 kg O_2/day (1,67 ± 1,00) and photosynthesis results of 9,12 – 69,28 kg O_2/day (52,47 ± 14,24). Dissolved oxygen utilized (oxygen output) in shrimp ponds during rearing was 20,89 – 153,74 kg O_2/day (85,46 ± 43,43). Dissolved oxygen in the pond system used by shrimp is 0,05 – 34,37 kg O_2/day (14,99 ± 10,96), outflow (water removed during water changes) is 0,00 – 2,47 kg O_2/day (1,05 ± 0,63), water column respiration is 16,04 – 110,48 kg O_2/day (60,02 ± 31,30), and sediment respiration of 4,80 – 15,36 kg O_2/day (9,40 ± 1,87).

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Based on the oxygen input and output, the optimal management of the paddle wheel is estimated according to the needs and availability of dissolved oxygen in the shrimp pond, as follows: (i) The operation of one paddle wheel (1 HP) at the beginning of maintenance until the 28th day is enough to be carried out 4 hours/day, where until the 28th day both oxygen input and oxygen output are quite increased (input 97,19 kg O_2/day and output 47,80 kg O_2 /day); (ii) On day 29, paddle wheel 1 is operated for 4 - 12 hours/day to maintain and increase oxygen until day 57 (input is 98,14 kgO_2/day and output is 95,93 kg O_2/day); (iii) On day 58, the dissolved oxygen input reached 97,54 kg O_2/day while the dissolved oxygen output reached 99,57 kg O_2/day, resulting in an oxygen deficit of – 1,03 kg O_2/day. This shows that the dissolved oxygen input is starting to be disproportionate to the dissolved oxygen demand in the shrimp ponds; (iii) On the 58th day, it is necessary to operate the 2nd wheel. Starting from the 58th day, the 2nd paddle wheel is operated for 12 – 16 hours/day and the 1st paddle wheel is 4 – 12 hours/day. The operation of 2 paddle wheel (1 HP power) is only able to maintain and increase oxygen until the 67th day (input 125,14 kg O_2/day and output 123,18 kg O_2/day), where on day 68 there is an oxygen deficit of -1,25 kg O_2/ day (input 124,30 kg O2/day and output 125,56 kgO2/day); (iv) On the 68th day, it is necessary to operate the 3rd Paddle wheel for 16 – 20 hours (paddle wheel 1 for 4 - 12 hours/day, the 2nd paddle wheel for 12-16 hours/day). The operation of three paddle wheel with 1 HP each is able to maintain and balance dissolved oxygen in the shrimp pond until the end of the rearing period (input 148,78 kg O_2/day and output 139,38 kg O_2/day). Intensive shrimp pond (50 seeds/m^2) in the coastal area of Mangara Bombang Sub-district that during shrimp rearing use three paddle wheel (1 paddle wheel with a power of 1 HP), where on day 1 to day 30 operate 1 paddle wheel for 24 hours/day.

Starting from day 30, 2 paddle wheel will be operated again for 24 hours/day until the end of maintenance. In this condition, from the beginning to the end of the maintenance, the electric power is 3.920,98 kwh/planting season or 7.841,95 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 1,67 kwh/kg shrimp/planting season or 3,34 kwh/kg shrimp/II planting season. Meanwhile, with the management of the paddle wheel based on the estimated dissolved oxygen input and output, from the beginning to the end of the maintenance using electricity of 1.483,05 kwh/planting season or 2.966,10 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 0,63 kwh/kg shrimp/planting season or 1,26 kwh/kg shrimp/II planting season. The magnitude of the difference or efficiency in the use of electricity for the operation of the paddle wheel under current conditions and based on the estimated input and output of oxygen is 2.437,93 kwh/planting season or 4.875,86 kwh/II planting season, where for the production of 1 kg of shrimp there is a difference or efficiency of 1,04 kwh/kg of shrimp/planting season or 2,08 kwh/kg shrimp/II planting season.

The cost of using electricity in the current condition for the operation of the paddle wheel each planting season (MT) is 3.920,98 kwh x Rp. 640,-/kwh (TDL Subsidy) = IDR 2.509.427/planting season or IDR 5.018.854/II MT. Meanwhile, based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 1.483,05 x IDR 640/kwh (TDL Subsidy) = IDR 949.152/MT or IDR 1.898.304/II MT. Based on this, there is a difference or efficiency in the use of electricity for the paddle wheel as much as: IDR 2.509.427/MT – 949.152/MT = IDR 1.560.275/MT or IDR 3.120. 550/II MT. Furthermore, if using the non-subsidized basic electricity rate (TDL) of IDR 1.380 (PLN 2020), then the costs incurred for operating the paddle wheel each planting season (MT) at its current condition are 3.920,98 kwh x Rp. 1.380/kwh = IDR 5. 410. 953/ planting season or IDR 10.821.905/II planting season. Meanwhile, based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 1.483.05 x IDR 1.380/kwh = IDR 2. 046. 609/Planting season or IDR 4.093.218/II planting season. The difference or efficiency in the use of electricity for the paddle wheel is IDR 5.410.952,-/planting season – 2.046.609/planting season = IDR 3.364.343/planting season or IDR 6.728. 687/II planting season. The results of the analysis above, if it is associated with the level of business feasibility, then the total costs incurred decrease to IDR 119.046.879/ha/planting season or IDR 238.

093.758/ha/year. Meanwhile, the profit earned increased to IDR 55.788.853/ha/planting season or IDR 111.577.707/ha/year, with an R/C value of 1,47 and a payback period of 1,87 years. Net Present Value (NPV) is IDR 284. 955. 649 (shrimp production, total costs incurred, and profits are the same every year) and Net Benefit Cost Ratio (Net B/C) is 2,36. While the value of the Internal Rate of Return (IRR) obtained is 52,93%.

Optimal management of intensive shrimp ponds (126 seeds/m^2), The available dissolved oxygen (oxygen input) in shrimp ponds ranged from 30,19 to 86,54 kg O_2/day (66,93 ± 12,96). Dissolved oxygen input comes from pond ambient oxygen of 14,85 – 24,19 kg O_2/day (18,08 ± 3,07), inflow (water introduced at water change) of 0,00 – 3,69 kg O_2/day (1,74 ± 1,19) and photosynthesis yield of 8,55 – 64,95 kg O_2/day (46,95 ± 13,35).

Dissolved oxygen utilized (oxygen output) in the shrimp pond system during rearing was 19.78 – 200.19 kg O2/day (115.72 ± 54.10). Dissolved oxygen in shrimp ponds utilized by shrimp is 0.24 – 100.26 kg O2/day (47.38 ± 27.29), outflow (water removed during water changes) is 0.00 – 3.11 kg O2/day (1.22 ± 0.83), water column respiration is 15.04 – 103.58 kg O2/day (56.74 ± 27.37), and sediment consumption is 4.50 – 20.70 kg O2/day (10.28 ± 3.87). Dissolved oxygen input and output data illustrates the availability and balance of dissolved oxygen utilization in shrimp aquaculture.

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Based on this data and information, an estimation of the optimal management or utilization of the wheel during the shrimp farming process is carried out as follows: (i) The operation of 1 paddle wheel (1 HP power) at the beginning of maintenance until the 26th day is enough to be carried out 4 hours / day, where until the 26th day both oxygen input and oxygen output are quite increased (input 92,19 kgO_2/day and output 58,67 kgO_2 /day); (ii) Starting from the 27th day of operation the 1st paddle wheel was increased to 4-5 hours/day to maintain oxygen until the 45th day (input 87,36 kgO_2/day and output 86,43 kgO_2/day). On day 46, the dissolved oxygen input reached 86,69 kg O_2/day while the dissolved oxygen output reached 88.81 kg O2/day, resulting in an oxygen deficit of –2,13 kg O_2/day.

This shows that the dissolved oxygen input is starting to be disproportionate to the dissolved oxygen demand in the shrimp ponds; (iii) On day 46 it is necessary to operate the 2nd wheel for 5 – 12 hours/day (paddle wheel 1 for 4 - 5 hours/day). The operation of 2 paddle wheel (1 HP power) is only able to maintain and increase dissolved oxygen until the 54th day, where on the 55th day there is a dissolved oxygen deficit of -1,82 kg O2/day (input 111,43 kgO_2/day and output 113,25 kgO_2 /day); (iv) On the 55th day, it is necessary to operate the 3rd wheel for 12 – 16 hours/day (wheel 1 for 4 – 5 hours/day and paddle wheel 2 for 5 – 12 hours/day); (v) The operation of 3 paddle wheel is only able to increase and maintain dissolved oxygen until the 65th day, where on the 66th day there is a dissolved oxygen deficit of –2,2 kg O2/day (input 145,17 kgO_2/day and output 147.59 kgO_2/day); (vi) On the 66th day it is necessary to operate the 4th, 5th and 6th paddle wheel for 16 – 24 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day).

The operation of 6 paddle wheel is only able to increase dissolved oxygen up to day 99, where on day 100 there is an oxygen deficit of –4,43 kgO_2/day (input 144,35 kgO_2/day and output 148,77 kgO_2/day); (vii) On the 100th day, the 7th wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4 -5-6 for 16 – 24 hours/day). The operation of 7 paddle wheel was only able to increase and maintain oxygen for 3 days (until day 102) and on day -103 there was an oxygen deficit of -4,59 kgO_2/day (input 159,11 kgO_2/day and output 163,70 kgO_2/day); (viii) On the 103rd day, the 8th wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4- 5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day), where the operation of 8 paddle wheel is only able to increase and maintain dissolved oxygen until day 104 and on day 105 there is a dissolved oxygen deficit of -0,54 kgO_2/ day (input 173,99 kgO_2/day and output 174,53 kgO_2/day); (ix) Starting from the 105th day, the 9th paddle wheel is operated for 9 hours/day (paddle wheel 1 for 4-5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12-16 hours/day, paddle wheel 4- 5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day, paddle wheel 8 for 9 hours/day).

The operation of 9 paddle wheel to increase and maintain dissolved oxygen until the 107^{th} day. On the $108t^{h}$ day there was a dissolved oxygen deficit of -0,74 kgO_2/day (input 188,65 kg O_2/day and output 189,39 kg O_2/day); (x) On the 109^{th} day, the 10^{th} paddle wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4 -5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day, paddle wheel 8 for 9 hours/day, paddle wheel 9 for 9 hours/day), where the operation of 10 paddle wheels with 1 HP each is capable of maintain and balance dissolved oxygen in shrimp ponds until the end of the rearing period. Intensive shrimp pond cultivators (126 seeds/m^2) in the coastal area of Mangara Bombang District during shrimp rearing period use 10 paddle wheels (1 paddle wheel with a power of 1 HP), where on day 1 to day 30 operate 2 paddle wheels for 24 hours/day . Starting from day 30, 8 paddle wheel were operated for 24 hours/day until the end of maintenance (Results of interviews and field observations 2020). Based on the results of the analysis, it was found that the management of the paddle wheel (1 HP) in its current condition, from the beginning to the end of the maintenance using electricity of 15.397,44 kwh/planting season or 30.794,88 kwh/II planting season. In the existing condition, each production of 1 kg of shrimp uses an electric power of 2,25 kwh/kg shrimp/planting season or 4,49 kwh/kg shrimp/II planting season. Meanwhile, with the management of the mill based on the estimated availability and balance of dissolved oxygen (input and output), from the beginning to the end of the maintenance using electricity of 4.356,64 kwh/planting season or 8.713,28 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 0,64 kwh /kg shrimp/planting season or 1,28 kwh/kg shrimp/II planting season.

The amount of the difference or efficiency in the use of electricity for the operation of the paddle wheel in the current conditions and based on the estimated input and output of oxygen is 11.040,80 kwh/planting season or 22.081,60 kwh/II planting season, where for the production of 1 kg of shrimp there is a difference or efficiency of 1,61 kwh/ kg shrimp/planting season or 3,22 kwh/kg shrimp/II planting season. In the current condition, the cost of using electricity is 15.397,44 kwh/planting season kwh and if the subsidized basic electricity rate (TDL) is IDR 640/kwh (PLN 2020), the costs incurred for the operation of the paddle wheel each planting season (MT) are 15.397,44 kwh x IDR 640/kwh = IDR 9.854.362/planting season or IDR 19.708.723/II planting season. Meanwhile, based on the estimated balance of dissolved oxygen input and output in shrimp ponds, the costs incurred for the operation of the paddle wheel each planting season (MT) are 4.356,64 kwh x IDR 640 = IDR 2.788 .250/planting season or IDR 5.576.499/II planting season. Based on this, the efficient use of electricity for the paddle wheel is IDR 9.854.362/planting season – IDR 2.788.250/planting season = IDR 7.066. 112/planting season or IDR 14.132.224/II planting season. Furthermore, if using a non-subsidized electricity basis (TDL) of IDR 1.380 (PLN 2020), then the costs incurred for the operation of the paddle wheel each planting season (MT) at its current condition are 15.397,44 kwh x IDR 1.380/kwh = IDR 21. 248.467 /planting season or IDR 42.496.934/II planting season. Based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 4.356,64 kwh x IDR 1.380 = IDR 6.012.163/planting season or IDR 12.024.326/II planting season. Based on this, the efficient use of electricity for the planting season is IDR 21.248. 467/planting season – IDR 6.012.163/planting season = IDR 15.236.304/planting season or IDR 30. 472. 608/II planting season. The results of the analysis above, if it is associated with the level of business feasibility, the total operating costs incurred for cultivation have decreased to IDR 355.936. 618/ha/planting season or IDR 711.873.235/ha/year. Meanwhile, the profit earned increased to IDR 186. 435.278/ha/planting season or IDR 372.870.557/ha/year, with an R/C value of 1,52 and a payback period of 2,66 years. Net Present Value (NPV) is IDR 679.791.064 (shrimp production, total costs incurred, and profits are the same every year) and Net Benefit Cost Ratio (Net B/C) is 1,69. While the value of the Internal Rate of Return (IRR) obtained is 36,61%.

Conclusion

Proper placement of the wheel should also be a concern to maximize the oxygenated pond area and minimize the oxygen-deficient pond area.

In this study, the production level of shrimp (126 seeds/m^2) was 684.8 kg/HP and the production level of shrimp (50 seeds/m^2) was 784.90 kg/HP

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Management Analysis of Paddle Wheel For Efficiency Operational Cost Shrimp Culture Based on Oxygen Budget Capacity

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The aims of this research is to determine the optimal management of the paddle wheel based on the availability and balance of dissolved oxygen in shrimp ponds for efficiency in aquaculture operational costs. The methods employed are : (i) Field Observation for Oxygent Budget on included inputs oxygen and Outputs Oxygent and; (ii) Electricity usage during rearing periode. Results of analysis to Shrimp Culture (50 shrimp/m^2) which obtained efficiency for paddle wheel electricity/kg shrimp as 1.04 kwh/kg shrimp/cyclus or 2.08 kwh/kg shrimp/years. Operational Cost is decreased as IDR 119 046 879/hectare/MT or IDR 238 093 758/hectare/years and profitable which obtained is increased to as IDR 55 788 853/hectare/cyclus atau IDR 111 577 707/hectare/years. While to shrimp culture (126 shrimp/m^2) which obtained efficiency for paddle wheel electricity/kg shrimp as 1.61 kwh/kg shrimp/cyclus atau 3.22 kwh/kg shrimp/years. Operational Cost is decreased as IDR 355 936 618/hectare/cyclus atau IDR 711 873 235/hectare/years and profitable which obtained is increased to as IDR 186 435 278/hectare/cyclus or IDR 372 870 557/hectare/years.

Introduction

Paddle wheel have a very important role in the management of shrimp farming, apart from being a supplier of dissolved oxygen as well as being a waste of oxygen from ponds in the event of over-saturation conditions. This supersaturated oxygen condition often occurs during the day with a high density of phytoplankton, along with the length of shrimp rearing. On the other hand, at night, the availability of dissolved oxygen is often depleted due to increased shrimp biomass in ponds and increased respiration of phytoplankton ~~(Rachmansyah et al. 2005)~~[1]. Optimal paddle wheel management based on estimation of dissolved oxygen availability (input and output) in shrimp ponds is very important to maintain the availability of dissolved oxygen and operational cost efficiency.

Research purposes

The aims of this research is to determine the optimal management of the paddle wheel based on the availability and balance of dissolved oxygen in shrimp ponds for efficiency in aquaculture operational costs.

~~**Methodology**~~

Materials and Methods

The optimal management and utilization of the paddle wheel in shrimp farming is estimated by taking into account aspects of availability and balance (input and output of dissolved oxygen) in shrimp ponds. In general, the equation for the balance of dissolved oxygen input and output in shrimp aquaculture refers to a modified formula (Teichert-Coddington et al. 1996):

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$$K+I+F+A \approx U+R+O+S \quad \text{..} (1)$$

where : K = Paddle Wheel ; I = volume of water inflow (m^3); F = photosynthesis; A = ambient; U = shrimp oxygen consumption; R = oxygen consumption for plankton respiration (water column); O = volume of water outflow (m^3); S = oxygen consumption of shrimp pond sediment

Oxygen input and output in shrimp ponds can be estimated by referring to the modified formula (Rachmansyah et al. 2008) :

1. Dissolved oxygen input from photosynthesis (F) during maintenance can be formulated as :
   $F_n = (f_n \, xVTB)\, x1000$ ....(2)
2. Dissolved oxygen input from inflow (water change) during maintenance can be formulated as:
   In = $(O_{Waters}\, xVTA_n)x1000$ $(O_{kolom\,air}\, xVTA_n)\, x1000$
   ....(3)
   2.
3. Ambient dissolved oxygen (without pinwheel) during maintenance can be formulated as :
   A_n : $(OTK_n \, xVTB)\, x1000$ ....(4)
4. The dissolved oxygen input from the wheel during maintenance is determined by the oxygen transfer value, the operating time of the wheel, and the dissolved oxygen saturation correction value. The dissolved oxygen input of the wheel during maintenance is determined using the formula K_n = $(1.80\, xWOK_n)\, x\,0.90$ ....(5)

So that the total dissolved oxygen that enters (input) into the shrimp pond system during maintenance can be determined by the formula: $IOT_n = K_n + F_n + I_n + A_n$ .... (6)

5. Dissolved oxygen output used by shrimp during rearing period can be formulated :
   Un = $(BU_n \, xOU_n \, x24)/1000$ ....(7)
6. The output of dissolved oxygen used for column respiration during maintenance can be formulated as : Rn = $(ORP_n \, xVTB)/1000$ ....(8)
7. Dissolved oxygen output used for sediment respiration during maintenance can be formulated:
   Sn = $(OS_n \, xVTB\, x24)/1000$ ....(9)
8. Output oksigen terlarut outflow (water exchange) selama pemeliharaan dapat dirumsukan : O_n = $(OTK_n \, xVBA_n)\, x1000$ .... (10)

So that the total dissolved oxygen utilized (output) in the shrimp pond system during maintenance can be determined by the formula: $UOT_n = O_n + U_n + R_n + S_n$ ....(11)

Based on the above, the availability and balance of dissolved oxygen in shrimp ponds is formulated : $OT_n = IOT_n - OUT_n$ ....(12)

where :1.80 = oxygen transfer of the paddle wheel at standard conditions (kgO_2/ton/hour); WOK = mill operating time (hours); 0,90 = oxygen saturation correction under standard conditions; F = photosynthetic dissolved oxygen (mg/l); VTB = volume of shrimp pond water (m^3); VTA = volume of addition of water (m^3); OTK = dissolved oxygen in unmilled shrimp ponds (mg/l); VBA = volume of discarded shrimp pond water (m^3); OU = dissolved oxygen in shrimp ponds (kgO_2/ton/hour); OR = dissolved oxygen in water column respiration (mg/L/day); OS = dissolved oxygen of shrimp pond sediment (gO_2/m^2/hour); IOT = dissolved oxygen input (kg); UOT= dissolved oxygen output (kg); OT = availability of dissolved oxygen in shrimp ponds (kg); n = 1,2,3,............, harvest (days).

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Based on the estimation of the availability and balance of dissolved oxygen above, an analysis of the efficiency of the operational costs of the mill is carried out through the use of electricity during maintenance. The use of the electric power of the wheel during the maintenance period can be formulated as follows: $TL_k = J_k \ x \ JO_k \ x \ LO_k \ x \, 0.764$ .... (13)

where : TLk = electric power wheel (kwh)

Jk = number of operating wheels (units)

JOk = mill operation (hours/day)

LOk = length of operation of the wheel (days)

0,764 = amount of electric power per HP (kwh)

If the basic electricity cost per kwh is X, then the amount of costs used for the operation of the mill is:

$$BO_k = TL_k \ x \ X \quad (14)$$

where : BOk = mill operating costs (IDR); TL_k = electric power wheel (kwh) ; X = basic electricity tariff (IDR/kwh)

Results

Optimal paddle wheel management is based on estimating the availability of dissolved oxygen (input and output) in shrimp ponds using supporting data in the estimation process. The supporting data used can be seen in Table 1.

Table 1. The data used in estimating the availability and balance of dissolved oxygen (input and output) in shrimp ponds.

Parameters	Units~~Satuan~~	~~Nila~~Values~~i~~
Oxygen of Photosynthesis [1]	mg/L/day	2,28 – 17,32 (12,15 ± 3,56)
Water column respiration [2]	mg/L/day	4,01 – 27,62 (15,13 ± 7,30)
Sedimen oxygen consumption [3]	gO_2/m^2/hour	0,05 – 0,23 (0,11 ± 0,04)
vannamei shrimp oxygen consumption [4]	kgO_2/ton/hour	0,61 – 1,99 (0,76 ± 0,35)
Oxygen transfer paddle wheel (standart) [5]	kgO_2/kwh	1,80
Dissolved oxygen saturation correction [6]	-	0,90
Oxygen of coastal water column [7]	mg/l	6,56
Eelectric power paddle wheel [8]	kwh/HP	0,764
Shrimp pond ambient oxygen (50 seeds/m^2) [9]	mg/l	3,35 – 6,20 (4,89 ± 0,62)
Shrimp pond ambient oxygen (126 seeds/m^2) [10]	mg/l	3,96 – 6,45 (4,82 ± 0,82)
Intensive shrimp pond water exchange [11]	%	3 % (1st month dan 2nd month); 10 %(3rd month); 15 % (4th month)

Sumber: Rachmansyah *et al* (2008) [1) 2) 3) 4)] ; Riyanto (1989), Boyd (1991), McIntosh (2000) [5) 6) 8)] ; Field measurements (2020) [7) 9) 10)] ; Widigdo dan Soewardi (2002)[10)] , Field observation (2020) [11);]

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The optimal Paddle Wheel management of intensive shrimp ponds (50 seeds/m^2) is based on the estimation of the availability and balance of oxygen in the shrimp pond culture system which is largely determined by the presence of oxygen input and output. Based on the analysis during rearing period, the available dissolved oxygen (oxygen input) in shrimp ponds ranged from 27,96 to 91,27 kg O_2/day (73,68 ± 14,48). Dissolved oxygen input comes from pond ambient oxygen of 13,40 – 24,80 kg O_2/day (19,54 ± 2,50), inflow (water change) of 0,00 – 3,94 kg O_2/day (1,67 ± 1,00) and photosynthesis results of 9,12 – 69,28 kg O_2/day (52,47 ± 14,24). Dissolved oxygen utilized (oxygen output) in shrimp ponds during rearing was 20,89 – 153,74 kg O_2/day (85,46 ± 43,43). Dissolved oxygen in the pond system used by shrimp is 0,05 – 34,37 kg O_2/day (14,99 ± 10,96), outflow (water removed during water changes) is 0,00 – 2,47 kg O_2/day (1,05 ± 0,63), water column respiration is 16,04 – 110,48 kg O_2/day (60,02 ± 31,30), and sediment respiration of 4,80 – 15,36 kg O_2/day (9,40 ± 1,87).

Based on the oxygen input and output, the optimal management of the paddle wheel is estimated according to the needs and availability of dissolved oxygen in the shrimp pond, as follows: (i) The operation of one paddle wheel (1 HP) at the beginning of maintenance until the 28th day is enough to be carried out 4 hours/day, where until the 28th day both oxygen input and oxygen output are quite increased (input 97,19 kg O_2/day and output 47,80 kg O_2 /day); (ii) On day 29, paddle wheel 1 is operated for 4 - 12 hours/day to maintain and increase oxygen until day 57 (input is 98,14 kgO_2/day and output is 95,93 kg O_2/day); (iii) On day 58, the dissolved oxygen input reached 97,54 kg O_2/day while the dissolved oxygen output reached 99,57 kg O_2/day, resulting in an oxygen deficit of – 1,03 kg O_2/day. This shows that the dissolved oxygen input is starting to be disproportionate to the dissolved oxygen demand in the shrimp ponds; (iii) On the 58th day, it is necessary to operate the 2nd wheel. Starting from the 58th day, the 2nd paddle wheel is operated for 12 – 16 hours/day and the 1st paddle wheel is 4 – 12 hours/day. The operation of 2 paddle wheel (1 HP power) is only able to maintain and increase oxygen until the 67th day (input 125,14 kg O_2/day and output 123,18 kg O_2/day), where on day 68 there is an oxygen deficit of -1,25 kg O_2/ day (input 124,30 kg O2/day and output 125,56 kgO2/day); (iv) On the 68th day, it is necessary to operate the 3rd Paddle wheel for 16 – 20 hours (paddle wheel 1 for 4 - 12 hours/day, the 2nd paddle wheel for 12-16 hours/day). The operation of three paddle wheel with 1 HP each is able to maintain and balance dissolved oxygen in the shrimp pond until the end of the rearing period (input 148,78 kg O_2/day and output 139,38 kg O_2/day). Intensive shrimp pond (50 seeds/m^2) in the coastal area of Mangara Bombang Sub-district that during shrimp rearing use three paddle wheel (1 paddle wheel with a power of 1 HP), where on day 1 to day 30 operate 1 paddle wheel for 24 hours/day.

Starting from day 30, 2 paddle wheel will be operated again for 24 hours/day until the end of maintenance. In this condition, from the beginning to the end of the maintenance, the electric power is 3.920,98 kwh/planting season or 7.841,95 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 1,67 kwh/kg shrimp/planting season or 3,34 kwh/kg shrimp/II planting season. Meanwhile, with the management of the paddle wheel based on the estimated dissolved oxygen input and output, from the beginning to the end of the maintenance using electricity of 1.483,05 kwh/planting season or 2.966,10 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 0,63 kwh/kg shrimp/planting season or 1,26 kwh/kg shrimp/II planting season. The magnitude of the difference or efficiency in the use of electricity for the operation of the paddle wheel under current conditions and based on the estimated input and output of oxygen is 2.437,93 kwh/planting season or 4.875,86 kwh/II planting season, where for the production of 1 kg of shrimp there is a difference or efficiency of 1,04 kwh/kg of shrimp/planting season or 2,08 kwh/kg shrimp/II planting season.

The cost of using electricity in the current condition for the operation of the paddle wheel each planting season (MT) is 3.920,98 kwh x Rp. 640,-/kwh (TDL Subsidy) = IDR 2.509.427/planting season or IDR 5.018.854/II MT. Meanwhile, based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 1.483,05 x IDR 640/kwh (TDL Subsidy) = IDR 949.152/MT or IDR 1.898.304/II MT. Based on this, there is a difference or efficiency in the use of electricity for the paddle wheel as much as: IDR 2.509.427/MT – 949.152/MT = IDR 1.560.275/MT or IDR 3.120. 550/II MT. Furthermore, if using the non-subsidized basic electricity rate (TDL) of IDR 1.380 (PLN 2020), then the costs incurred for operating the paddle wheel each planting season (MT) at its current condition are 3.920,98 kwh x Rp. 1.380/kwh = IDR 5. 410. 953/ planting season or IDR 10.821.905/II planting season. Meanwhile, based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 1.483.05 x IDR 1.380/kwh = IDR 2. 046. 609/Planting season or IDR 4.093.218/II planting season. The difference or efficiency in the use of electricity for the paddle wheel is IDR 5.410.952,-/planting season – 2.046.609/planting season = IDR 3.364.343/planting season or IDR 6.728. 687/II planting season. The results of the analysis above, if it is associated with the level of business feasibility, then the total costs incurred decrease to IDR 119.046.879/ha/planting season or IDR 238. 093.758/ha/year. Meanwhile, the profit earned increased to IDR 55.788.853/ha/planting season or IDR 111.577.707/ha/year, with an R/C value of 1,47 and a payback period of 1,87 years. Net Present Value (NPV) is IDR 284. 955. 649 (shrimp production, total costs incurred, and profits are the same every year) and Net Benefit Cost Ratio (Net B/C) is 2,36. While the value of the Internal Rate of Return (IRR) obtained is 52,93%.

Optimal management of intensive shrimp ponds (126 seeds/m^2), The available dissolved oxygen (oxygen input) in shrimp ponds ranged from 30,19 to 86,54 kg O_2/day (66,93 ± 12,96). Dissolved oxygen input comes from pond ambient oxygen of 14,85 – 24,19 kg O_2/day (18,08 ± 3,07), inflow (water introduced at water change) of 0,00 – 3,69 kg O_2/day (1,74 ± 1,19) and photosynthesis yield of 8,55 – 64,95 kg O_2/day (46,95 ± 13,35).

Dissolved oxygen utilized (oxygen output) in the shrimp pond system during rearing was 19.78 – 200.19 kg O_2/day (115.72 ± 54.10). Dissolved oxygen in shrimp ponds utilized by shrimp is 0.24 – 100.26 kg O_2/day (47.38 ± 27.29), outflow (water removed during water changes) is 0.00 – 3.11 kg O_2/day (1.22 ± 0.83), water column respiration is 15.04 – 103.58 kg O_2/day (56.74 ± 27.37), and sediment consumption is 4.50 – 20.70 kg O_2/day (10.28 ± 3.87). Dissolved oxygen input and output data illustrates the availability and balance of dissolved oxygen utilization in shrimp aquaculture.

Based on this data and information, an estimation of the optimal management or utilization of the wheel during the shrimp farming process is carried out as follows: (i) The operation of 1 paddle wheel (1 HP power) at the beginning of maintenance until the 26^{th} day is enough to be carried out 4 hours / day, where until the 26^{th} day both oxygen input and oxygen output are quite increased (input 92,19 kgO_2/day and output 58,67 kgO_2 /day); (ii) Starting from the 27^{th} day of operation the 1st paddle wheel was increased to 4-5 hours/day to maintain oxygen until the 45th day (input 87,36 kgO_2/day and output 86,43 kgO_2/day). On day 46, the dissolved oxygen input reached 86,69 kg O_2/day while the dissolved oxygen output reached 88.81 kg O2/day, resulting in an oxygen deficit of –2,13 kg O_2/day.

This shows that the dissolved oxygen input is starting to be disproportionate to the dissolved oxygen demand in the shrimp ponds; (iii) On day 46 it is necessary to operate the 2^{nd} wheel for 5 – 12 hours/day (paddle wheel 1 for 4 - 5 hours/day). The operation of 2 paddle wheel (1 HP power) is only able to maintain and increase dissolved oxygen until the 54^{th} day, where on the 55^{th} day there is a dissolved oxygen deficit of -1,82 kg O2/day (input 111,43 kgO_2/day and output 113,25 kgO_2 /day); (iv) On the 55th day, it is necessary to operate the 3rd wheel for 12 – 16 hours/day (wheel 1 for 4 – 5 hours/day and paddle wheel 2 for 5 – 12 hours/day); (v) The operation of 3 paddle wheel is only able to increase and maintain dissolved oxygen until the 65^{th} day, where on the 66^{th} day there is a dissolved oxygen deficit of –2,2 kg O2/day (input 145,17 kgO_2/day and output 147.59 kgO_2/day); (vi) On the 66^{th} day it is necessary to operate the 4^{th}, 5^{th} and 6^{th} paddle wheel for 16 – 24 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day).

The operation of 6 paddle wheel is only able to increase dissolved oxygen up to day 99, where on day 100 there is an oxygen deficit of –4,43 kgO_2/day (input 144,35 kgO_2/day and output 148,77 kgO_2/day);

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(vii) On the 100th day, the 7th wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4 -5-6 for 16 – 24 hours/day). The operation of 7 paddle wheel was only able to increase and maintain oxygen for 3 days (until day 102) and on day -103 there was an oxygen deficit of -4,59 kgO_2/day (input 159,11 kgO_2/day and output 163,70 kgO_2/day); (viii) On the 103rd day, the 8th wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4- 5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day), where the operation of 8 paddle wheel is only able to increase and maintain dissolved oxygen until day 104 and on day 105 there is a dissolved oxygen deficit of -0,54 kgO_2/ day (input 173,99 kgO_2/day and output 174,53 kgO_2/day); (ix) Starting from the 105th day, the 9th paddle wheel is operated for 9 hours/day (paddle wheel 1 for 4-5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12-16 hours/day, paddle wheel 4- 5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day, paddle wheel 8 for 9 hours/day).

The operation of 9 paddle wheel to increase and maintain dissolved oxygen until the 107th day. On the 108th day there was a dissolved oxygen deficit of -0,74 kgO_2/day (input 188,65 kg O_2/day and output 189,39 kg O_2/day); (x) On the 109th day, the 10th paddle wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4 -5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day, paddle wheel 8 for 9 hours/day, paddle wheel 9 for 9 hours/day), where the operation of 10 paddle wheels with 1 HP each is capable of maintain and balance dissolved oxygen in shrimp ponds until the end of the rearing period. Intensive shrimp pond cultivators (126 seeds/m^2) in the coastal area of Mangara Bombang District during shrimp rearing period use 10 paddle wheels (1 paddle wheel with a power of 1 HP), where on day 1 to day 30 operate 2 paddle wheels for 24 hours/day . Starting from day 30, 8 paddle wheel were operated for 24 hours/day until the end of maintenance (Results of interviews and field observations 2020). Based on the results of the analysis, it was found that the management of the paddle wheel (1 HP) in its current condition, from the beginning to the end of the maintenance using electricity of 15.397,44 kwh/planting season or 30.794,88 kwh/II planting season. In the existing condition, each production of 1 kg of shrimp uses an electric power of 2,25 kwh/kg shrimp/planting season or 4,49 kwh/kg shrimp/II planting season. Meanwhile, with the management of the mill based on the estimated availability and balance of dissolved oxygen (input and output), from the beginning to the end of the maintenance using electricity of 4.356,64 kwh/planting season or 8.713,28 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 0,64 kwh /kg shrimp/planting season or 1,28 kwh/kg shrimp/II planting season.

The amount of the difference or efficiency in the use of electricity for the operation of the paddle wheel in the current conditions and based on the estimated input and output of oxygen is 11.040,80 kwh/planting season or 22.081,60 kwh/II planting season, where for the production of 1 kg of shrimp there is a difference or efficiency of 1,61 kwh/ kg shrimp/planting season or 3,22 kwh/kg shrimp/II planting season. In the current condition, the cost of using electricity is 15.397,44 kwh/planting season kwh and if the subsidized basic electricity rate (TDL) is IDR 640/kwh (PLN 2020), the costs incurred for the operation of the paddle wheel each planting season (MT) are 15.397,44 kwh x IDR 640/kwh = IDR 9.854.362/planting season or IDR 19.708.723/II planting season. Meanwhile, based on the estimated balance of dissolved oxygen input and output in shrimp ponds, the costs incurred for the operation of the paddle wheel each planting season (MT) are 4.356,64 kwh x IDR 640 = IDR 2.788 .250/planting season or IDR 5.576.499/II planting season. Based on this, the efficient use of electricity for the paddle wheel is IDR 9.854.362/planting season – IDR 2.788.250/planting season = IDR 7.066. 112/planting season or IDR 14.132.224/II planting season. Furthermore, if using a non-subsidized electricity basis (TDL) of IDR 1.380 (PLN 2020), then the costs incurred for the operation of the paddle wheel each planting season (MT) at its current condition are 15.397,44 kwh x IDR 1.380/kwh = IDR 21. 248.467 /planting season or IDR 42.496.934/II planting season. Based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 4.356,64 kwh x IDR 1.380 = IDR 6.012.163/planting season or IDR 12.024.326/II planting season. Based on this, the efficient use of electricity for the planting season is IDR 21.248. 467/planting season – IDR 6.012.163/planting season = IDR 15.236.304/planting season or IDR 30. 472. 608/II planting season. The results of the analysis above, if it is associated with the level of business feasibility, the total operating costs incurred for cultivation have decreased to IDR 355.936. 618/ha/planting season or IDR 711.873.235/ha/year. Meanwhile, the profit earned increased to IDR 186. 435.278/ha/planting season or IDR 372.870.557/ha/year, with an R/C value of 1,52 and a payback period of 2,66 years. Net Present Value (NPV) is IDR 679.791.064 (shrimp production, total costs incurred, and profits are the same every year) and Net Benefit Cost Ratio (Net B/C) is 1,69. While the value of the Internal Rate of Return (IRR) obtained is 36,61%.

Conclusion

Proper placement of the wheel should also be a concern to maximize the oxygenated pond area and minimize the oxygen-deficient pond area.
In this study, the production level of shrimp (126 seeds/m^2) was 684.8 kg/HP and the production level of shrimp (50 seeds/m^2) was 784.90 kg/HP

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Management Analysis of Paddle Wheel For Efficiency Operational Cost Shrimp Culture Based on Oxygen Budget Capacity

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The aims of this research is to determine the optimal management of the paddle wheel based on the availability and balance of dissolved oxygen in shrimp ponds for efficiency in aquaculture operational costs. The methods employed are : (i) Field Observation for Oxygent Budget on included inputs oxygen and Outputs Oxygent and; (ii) Electricity usage during rearing periode. Results of analysis to Shrimp Culture (50 shrimp/m^2) which obtained efficiency for paddle wheel electricity/kg shrimp as 1.04 kwh/kg shrimp/cyclus or 2.08 kwh/kg shrimp/years. Operational Cost is decreased as IDR 119 046 879/hectare/MT or IDR 238 093 758/hectare/years and profitable which obtained is increased to as IDR 55 788 853/hectare/cyclus atau IDR 111 577 707/hectare/years. While to shrimp culture (126 shrimp/m^2) which obtained efficiency for paddle wheel electricity/kg shrimp as 1.61 kwh/kg shrimp/cyclus atau 3.22 kwh/kg shrimp/years. Operational Cost is decreased as IDR 355 936 618/hectare/cyclus atau IDR 711 873 235/hectare/years and profitable which obtained is increased to as IDR 186 435 278/hectare/cyclus or IDR 372 870 557/hectare/years.

1. Introduction

Paddle wheel have a very important role in the management of shrimp farming, apart from being a supplier of dissolved oxygen as well as being a waste of oxygen from ponds in the event of over-saturation conditions. This supersaturated oxygen condition often occurs during the day with a high density of phytoplankton, along with the length of shrimp rearing. On the other hand, at night, the availability of dissolved oxygen is often depleted due to increased shrimp biomass in ponds and increased respiration of phytoplankton [1]. Optimal paddle wheel management based on estimation of dissolved oxygen availability (input and output) in shrimp ponds is very important to maintain the availability of dissolved oxygen and operational cost efficiency.

2. Materials and Methods

The optimal management and utilization of the paddle wheel in shrimp farming is estimated by taking into account aspects of availability and balance (input and output of dissolved oxygen) in shrimp ponds. In general, the equation for the balance of dissolved oxygen input and output in shrimp aquaculture refers to a modified formula [2]:

$$K+I+F+A \approx U+R+O+S \quad \text{.......(1)}$$

where : K = Paddle Wheel ; I = volume of water inflow (m^3); F = photosynthesis; A = ambient; U = shrimp oxygen consumption; R = oxygen consumption for plankton respiration (water column); O = volume of water outflow (m^3); S = oxygen consumption of shrimp pond sediment

Oxygen input and output in shrimp ponds can be estimated by referring to the modified formula (Rachmansyah et al. 2008) :

1. Dissolved oxygen input from photosynthesis (F) during maintenance can be formulated as :
   $F_n = (f_n \, x VTB) x 1000$ ....(2)

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2. Dissolved oxygen input from inflow (water change) during maintenance can be formulated as: In = $(O_{kolom\,air}\ xVTA_n)\,x1000$.........(3)
3. Ambient dissolved oxygen (without pinwheel) during maintenance can be formulated as : A_n : $(OTK_n\ xVTB)\,x1000$.........(4)
4. The dissolved oxygen input from the wheel during maintenance is determined by the oxygen transfer value, the operating time of the wheel, and the dissolved oxygen saturation correction value. The dissolved oxygen input of the wheel during maintenance is determined using the formula K_n = $(1.80\,xWOK_n)\,x\,0.90$.........(5)

So that the total dissolved oxygen that enters (input) into the shrimp pond system during maintenance can be determined by the formula: $IOT_n = K_n + F_n + I_n + A_n$......... (6)

5. Dissolved oxygen output used by shrimp during rearing period can be formulated : Un = $(BU_n\ xOU_n\ x24)/1000$.........(7)
6. The output of dissolved oxygen used for column respiration during maintenance can be formulated as : Rn = $(ORP_n\ xVTB)/1000$.........(8)
7. Dissolved oxygen output used for sediment respiration during maintenance can be formulated: Sn = $(OS_n\ xVTB\ x24)/1000$.........(9)
8. Output oksigen terlarut outflow (water exchange) selama pemeliharaan dapat dirumsukan : O_n = $(OTK_n\ xVBA_n)\,x1000$......... .(10)

So that the total dissolved oxygen utilized (output) in the shrimp pond system during maintenance can be determined by the formula: $UOT_n = O_n + U_n + R_n + S_n$.........(11)

Based on the above, the availability and balance of dissolved oxygen in shrimp ponds is formulated : $OT_n = IOT_n - OUT_n$.........(12)

where :1.80 = oxygen transfer of the paddle wheel at standard conditions (kgO_2/ton/hour); WOK = mill operating time (hours); 0,90 = oxygen saturation correction under standard conditions; F = photosynthetic dissolved oxygen (mg/l); VTB = volume of shrimp pond water (m^3); VTA = volume of addition of water (m^3); OTK = dissolved oxygen in unmilled shrimp ponds (mg/l); VBA = volume of discarded shrimp pond water (m^3); OU = dissolved oxygen in shrimp ponds (kgO_2/ton/hour); OR = dissolved oxygen in water column respiration (mg/L/day); OS = dissolved oxygen of shrimp pond sediment (gO_2/m^2/hour); IOT = dissolved oxygen input (kg); UOT= dissolved oxygen output (kg); OT = availability of dissolved oxygen in shrimp ponds (kg); n = 1,2,3,............, harvest (days).

Based on the estimation of the availability and balance of dissolved oxygen above, an analysis of the efficiency of the operational costs of the mill is carried out through the use of electricity during maintenance. The use of the electric power of the wheel during the maintenance period can be formulated as follows: $TL_k = J_k\ x\ JO_k\ x\ LO_k\ x\,0.764$......... .(13)

where : TLk = electric power wheel (kwh)
Jk = number of operating wheels (units)
JOk = mill operation (hours/day)
LOk = length of operation of the wheel (days)
0,764 = amount of electric power per HP (kwh)

If the basic electricity cost per kwh is X, then the amount of costs used for the operation of the mill is:

$BO_k = TL_k\ x\ X$.........(14)

where : BOk = mill operating costs (IDR); TL_k = electric power wheel (kwh) ; X = basic electricity tariff (IDR/kwh)

3. Results and Discussion

Optimal paddle wheel management is based on estimating the availability of dissolved oxygen (input and output) in shrimp ponds using supporting data in the estimation process. The supporting data used can be seen in Table 1.

Table 1. The data used in estimating the availability and balance of dissolved oxygen (input and output) in shrimp ponds.

Parameters	Units	Results
Oxygen of Photosynthesis [1)]	mg/L/day	2,28 – 17,32 (12,15 ± 3,56)
Water column respiration [2)]	mg/L/day	4,01 – 27,62 (15,13 ± 7,30)
Sedimen oxygen consumption [3)]	gO_2/m^2/hour	0,05 – 0,23 (0,11 ± 0,04)
vannamei shrimp oxygen consumption [4)]	kgO_2/ton/hour	0,61 – 1,99 (0,76 ± 0,35)
Oxygen transfer paddle wheel (standart) [5)]	kgO_2/kwh	1,80
Dissolved oxygen saturation correction [6)]	-	0,90
Oxygen of coastal water column [7)]	mg/l	6,56
Eelectric power paddle wheel [8)]	kwh/HP	0,764
Shrimp pond ambient oxygen (50 seeds/m^2) [9)]	mg/l	3,35 – 6,20 (4,89 ± 0,62)
Shrimp pond ambient oxygen (126 seeds/m^2) [10)]	mg/l	3,96 – 6,45 (4,82 ± 0,82)
Intensive shrimp pond water exchange [11)]	%	3 % (1st month dan 2nd month); 10 %(3rd month); 15 % (4th month)

Sources: Rachmansyah *et al* (2008) [1) 2) 3) 4)] ; Riyanto (1989), Boyd (1991), McIntosh (2000) [5) 6) 8)] ; Field measurements (2020) [7) 9) 10)] ; Widigdo dan Soewardi (2002)[10)] , Field observation (2020) [11)];

The optimal Paddle Wheel management of intensive shrimp ponds (50 seeds/m^2) is based on the estimation of the availability and balance of oxygen in the shrimp pond culture system which is largely determined by the presence of oxygen input and output. Based on the analysis during rearing period, the available dissolved oxygen (oxygen input) in shrimp ponds ranged from 27,96 to 91,27 kg O_2/day (73,68 ± 14,48). Dissolved oxygen input comes from pond ambient oxygen of 13,40 – 24,80 kg O_2/day (19,54 ± 2,50), inflow (water change) of 0,00 – 3,94 kg O_2/day (1,67 ± 1,00) and photosynthesis results of 9,12 – 69,28 kg O_2/day (52,47 ± 14,24). Dissolved oxygen utilized (oxygen output) in shrimp ponds during rearing was 20,89 – 153,74 kg O_2/day (85,46 ± 43,43). Dissolved oxygen in the pond system used by shrimp is 0,05 – 34,37 kg O_2/day (14,99 ± 10,96), outflow (water removed during water changes) is 0,00 – 2,47 kg O_2/day (1,05 ± 0,63), water column respiration is 16,04 – 110,48 kg O_2/day (60,02 ± 31,30), and sediment respiration of 4,80 – 15,36 kg O_2/day (9,40 ± 1,87).

Based on the oxygen input and output, the optimal management of the paddle wheel is estimated according to the needs and availability of dissolved oxygen in the shrimp pond, as follows: (i) The operation of one paddle wheel (1 HP) at the beginning of maintenance until the 28th day is enough to be carried out 4 hours/day, where until the 28th day both oxygen input and oxygen output are quite increased (input 97,19 kg O_2/day and output 47,80 kg O_2 /day); (ii) On day 29, paddle wheel 1 is operated for 4 - 12 hours/day to maintain and increase oxygen until day 57 (input is 98,14 kgO_2/day and output is 95,93 kg O_2/day); (iii) On day 58, the dissolved oxygen input reached 97,54 kg O_2/day while the dissolved oxygen output reached 99,57 kg O_2/day, resulting in an oxygen deficit of – 1,03 kg O_2/day. This shows that the dissolved oxygen input is starting to be disproportionate to the dissolved oxygen demand in the shrimp ponds; (iii) On the 58th day, it is necessary to operate the 2nd wheel. Starting from the 58th day, the 2nd paddle wheel is operated for 12 – 16 hours/day and the 1st paddle wheel is 4 – 12 hours/day. The operation of 2 paddle wheel (1 HP power) is only able to maintain and increase oxygen until the 67th day (input 125,14 kg O_2/day and output 123,18 kg O_2/day), where on day 68 there is an oxygen deficit of -1,25 kg O_2/ day (input 124,30 kg O2/day and output 125,56 kgO2/day); (iv) On the 68th day, it is necessary to operate the 3rd Paddle wheel for 16 – 20 hours (paddle wheel 1 for 4 - 12 hours/day, the 2nd paddle wheel for 12-16 hours/day). The operation of three paddle wheel with 1 HP each is able to maintain and balance dissolved oxygen in the shrimp pond until the end of the rearing period (input 148,78 kg O_2/day and output 139,38 kg O_2/day). Intensive shrimp pond (50 seeds/m^2) in the coastal area of Mangara Bombang Sub-district that during shrimp rearing use three paddle wheel (1 paddle wheel with a power of 1 HP), where on day 1 to day 30 operate 1 paddle wheel for 24 hours/day.

Starting from day 30, 2 paddle wheel will be operated again for 24 hours/day until the end of maintenance. In this condition, from the beginning to the end of the maintenance, the electric power is 3.920,98 kwh/planting season or 7.841,95 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 1,67 kwh/kg shrimp/planting season or 3,34 kwh/kg shrimp/II planting season. Meanwhile, with the management of the paddle wheel based on the estimated dissolved oxygen input and output, from the beginning to the end of the maintenance using electricity of 1.483,05 kwh/planting season or 2.966,10 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 0,63 kwh/kg shrimp/planting season or 1,26 kwh/kg shrimp/II planting season. The magnitude of the difference or efficiency in the use of electricity for the operation of the paddle wheel under current conditions and based on the estimated input and output of oxygen is 2.437,93 kwh/planting season or 4.875,86 kwh/II planting season, where for the production of 1 kg of shrimp there is a difference or efficiency of 1,04 kwh/kg of shrimp/planting season or 2,08 kwh/kg shrimp/II planting season.

The cost of using electricity in the current condition for the operation of the paddle wheel each planting season (MT) is 3.920,98 kwh x Rp. 640,-/kwh (TDL Subsidy) = IDR 2.509.427/planting season or IDR 5.018.854/II MT. Meanwhile, based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 1.483,05 x IDR 640/kwh (TDL Subsidy) = IDR 949.152/MT or IDR 1.898.304/II MT. Based on this, there is a difference or efficiency in the use of electricity for the paddle wheel as much as: IDR 2.509.427/MT – 949.152/MT = IDR 1.560.275/MT or IDR 3.120. 550/II MT. Furthermore, if using the non-subsidized basic electricity rate (TDL) of IDR 1.380 (PLN 2020), then the costs incurred for operating the paddle wheel each planting season (MT) at its current condition are 3.920,98 kwh x Rp. 1.380/kwh = IDR 5. 410. 953/ planting season or IDR 10.821.905/II planting season. Meanwhile, based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 1.483.05 x IDR 1.380/kwh = IDR 2. 046. 609/Planting season or IDR 4.093.218/II planting season. The difference or efficiency in the use of electricity for the paddle wheel is IDR 5.410.952,-/planting season – 2.046.609/planting season = IDR 3.364.343/planting season or IDR 6.728. 687/II planting season. The results of the analysis above, if it is associated with the level of business feasibility, then the total costs incurred decrease to IDR 119.046.879/ha/planting season or IDR 238. 093.758/ha/year. Meanwhile, the profit earned increased to IDR 55.788.853/ha/planting season or IDR 111.577.707/ha/year, with an R/C value of 1,47 and a payback period of 1,87 years. Net Present Value (NPV) is IDR 284. 955. 649 (shrimp production, total costs incurred, and profits are the same every year) and Net Benefit Cost Ratio (Net B/C) is 2,36. While the value of the Internal Rate of Return (IRR) obtained is 52,93%.

Optimal management of intensive shrimp ponds (126 seeds/m^2), The available dissolved oxygen (oxygen input) in shrimp ponds ranged from 30,19 to 86,54 kg O_2/day (66,93 ± 12,96). Dissolved oxygen input comes from pond ambient oxygen of 14,85 – 24,19 kg O_2/day (18,08 ± 3,07), inflow (water introduced at water change) of 0,00 – 3,69 kg O_2/day (1,74 ± 1,19) and photosynthesis yield of 8,55 – 64,95 kg O_2/day (46,95 ± 13,35).

Dissolved oxygen utilized (oxygen output) in the shrimp pond system during rearing was 19.78 – 200.19 kg O_2/day (115.72 ± 54.10). Dissolved oxygen in shrimp ponds utilized by shrimp is 0.24 – 100.26 kg O_2/day (47.38 ± 27.29), outflow (water removed during water changes) is 0.00 – 3.11 kg O_2/day (1.22 ± 0.83), water column respiration is 15.04 – 103.58 kg O_2/day (56.74 ± 27.37), and sediment consumption is 4.50 – 20.70 kg O_2/day (10.28 ± 3.87). Dissolved oxygen input and output data illustrates the availability and balance of dissolved oxygen utilization in shrimp aquaculture.Based on this data and information, an estimation of the optimal management or utilization of the wheel during the shrimp farming process is carried out as follows: (i) The operation of 1 paddle wheel (1 HP power) at the beginning of maintenance until the 26th day is enough to be carried out 4 hours / day, where until the 26th day both oxygen input and oxygen output are quite increased (input 92,19 kgO_2/day and output 58,67 kgO_2 /day); (ii) Starting from the 27th day of operation the 1st paddle wheel was increased to 4-5 hours/day to maintain oxygen until the 45th day (input 87,36 kgO_2/day and output 86,43 kgO_2/day). On day 46, the dissolved oxygen input reached 86,69 kg O_2/day while the dissolved oxygen output reached 88.81 kg O2/day, resulting in an oxygen deficit of –2,13 kg O_2/day.

This shows that the dissolved oxygen input is starting to be disproportionate to the dissolved oxygen demand in the shrimp ponds; (iii) On day 46 it is necessary to operate the 2nd wheel for 5 – 12 hours/day (paddle wheel 1 for 4 - 5 hours/day). The operation of 2 paddle wheel (1 HP power) is only able to maintain and increase dissolved oxygen until the 54th day, where on the 55th day there is a dissolved oxygen deficit of -1,82 kg O2/day (input 111,43 kgO_2/day and output 113,25 kgO_2 /day); (iv) On the 55th day, it is necessary to operate the 3rd wheel for 12 – 16 hours/day (wheel 1 for 4 – 5 hours/day and paddle wheel 2 for 5 – 12 hours/day); (v) The operation of 3 paddle wheel is only able to increase and maintain dissolved oxygen until the 65th day, where on the 66th day there is a dissolved oxygen deficit of –2,2 kg O2/day (input 145,17 kgO_2/day and output 147.59 kgO_2/day); (vi) On the 66th day it is necessary to operate the 4th, 5th and 6th paddle wheel for 16 – 24 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day).

The operation of 6 paddle wheel is only able to increase dissolved oxygen up to day 99, where on day 100 there is an oxygen deficit of –4,43 kgO_2/day (input 144,35 kgO_2/day and output 148,77 kgO_2/day); (vii) On the 100th day, the 7th wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4 - 5-6 for 16 – 24 hours/day). The operation of 7 paddle wheel was only able to increase and maintain oxygen for 3 days (until day 102) and on day -103 there was an oxygen deficit of -4,59 kgO_2/day (input 159,11 kgO_2/day and output 163,70 kgO_2/day); (viii) On the 103rd day, the 8th wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4- 5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day), where the operation of 8 paddle wheel is only able to increase and maintain dissolved oxygen until day 104 and on day 105 there is a dissolved oxygen deficit of -0,54 kgO_2/ day (input 173,99 kgO_2/day and output 174,53 kgO_2/day); (ix) Starting from the 105th day, the 9th paddle wheel is operated for 9 hours/day (paddle wheel 1 for 4-5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12-16 hours/day, paddle wheel 4- 5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day, paddle wheel 8 for 9 hours/day).

The operation of 9 paddle wheel to increase and maintain dissolved oxygen until the 107th day. On the 108t^{h} day there was a dissolved oxygen deficit of -0,74 kgO_2/day (input 188,65 kg O_2/day and output

189,39 kg O_2/day); (x) On the 109th day, the 10th paddle wheel is operated for 9 hours/day (paddle wheel 1 for 4 – 5 hours/day, paddle wheel 2 for 5 – 12 hours/day, paddle wheel 3 for 12 – 16 hours/day, paddle wheel 4 -5-6 for 16 – 24 hours/day, paddle wheel 7 for 9 hours/day, paddle wheel 8 for 9 hours/day, paddle wheel 9 for 9 hours/day), where the operation of 10 paddle wheels with 1 HP each is capable of maintain and balance dissolved oxygen in shrimp ponds until the end of the rearing period. Intensive shrimp pond cultivators (126 seeds/m^2) in the coastal area of Mangara Bombang District during shrimp rearing period use 10 paddle wheels (1 paddle wheel with a power of 1 HP), where on day 1 to day 30 operate 2 paddle wheels for 24 hours/day . Starting from day 30, 8 paddle wheel were operated for 24 hours/day until the end of maintenance (Results of interviews and field observations 2020). Based on the results of the analysis, it was found that the management of the paddle wheel (1 HP) in its current condition, from the beginning to the end of the maintenance using electricity of 15.397,44 kwh/planting season or 30.794,88 kwh/II planting season. In the existing condition, each production of 1 kg of shrimp uses an electric power of 2,25 kwh/kg shrimp/planting season or 4,49 kwh/kg shrimp/II planting season. Meanwhile, with the management of the mill based on the estimated availability and balance of dissolved oxygen (input and output), from the beginning to the end of the maintenance using electricity of 4.356,64 kwh/planting season or 8.713,28 kwh/II planting season, where every 1 kg of shrimp production uses electricity of 0,64 kwh /kg shrimp/planting season or 1,28 kwh/kg shrimp/II planting season.

The amount of the difference or efficiency in the use of electricity for the operation of the paddle wheel in the current conditions and based on the estimated input and output of oxygen is 11.040,80 kwh/planting season or 22.081,60 kwh/II planting season, where for the production of 1 kg of shrimp there is a difference or efficiency of 1,61 kwh/ kg shrimp/planting season or 3,22 kwh/kg shrimp/II planting season. In the current condition, the cost of using electricity is 15.397,44 kwh/planting season kwh and if the subsidized basic electricity rate (TDL) is IDR 640/kwh (PLN 2020), the costs incurred for the operation of the paddle wheel each planting season (MT) are 15.397,44 kwh x IDR 640/kwh = IDR 9.854.362/planting season or IDR 19.708.723/II planting season. Meanwhile, based on the estimated balance of dissolved oxygen input and output in shrimp ponds, the costs incurred for the operation of the paddle wheel each planting season (MT) are 4.356,64 kwh x IDR 640 = IDR 2.788 .250/planting season or IDR 5.576.499/II planting season. Based on this, the efficient use of electricity for the paddle wheel is IDR 9.854.362/planting season – IDR 2.788.250/planting season = IDR 7.066. 112/planting season or IDR 14.132.224/II planting season. Furthermore, if using a non-subsidized electricity basis (TDL) of IDR 1.380 (PLN 2020), then the costs incurred for the operation of the paddle wheel each planting season (MT) at its current condition are 15.397,44 kwh x IDR 1.380/kwh = IDR 21. 248.467 /planting season or IDR 42.496.934/II planting season. Based on the estimated balance of dissolved oxygen input and output, the costs incurred for the operation of the paddle wheel each planting season (MT) are 4.356,64 kwh x IDR 1.380 = IDR 6.012.163/planting season or IDR 12.024.326/II planting season. Based on this, the efficient use of electricity for the planting season is IDR 21.248. 467/planting season – IDR 6.012.163/planting season = IDR 15.236.304/planting season or IDR 30. 472. 608/II planting season. The results of the analysis above, if it is associated with the level of business feasibility, the total operating costs incurred for cultivation have decreased to IDR 355.936. 618/ha/planting season or IDR 711.873.235/ha/year. Meanwhile, the profit earned increased to IDR 186. 435.278/ha/planting season or IDR 372.870.557/ha/year, with an R/C value of 1,52 and a payback period of 2,66 years. Net Present Value (NPV) is IDR 679.791.064 (shrimp production, total costs incurred, and profits are the same every year) and Net Benefit Cost Ratio (Net B/C) is 1,69. While the value of the Internal Rate of Return (IRR) obtained is 36,61%.

4. Conclusion

Proper placement of the wheel should also be a concern to maximize the oxygenated pond area and minimize the oxygen-deficient pond area. In this study, the production level of shrimp (126 seeds/m^2) was 684.8 kg/HP and the production level of shrimp (50 seeds/m^2) was 784.90 kg/HP

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