Calculating the Feed Oxygen Demand (FOD) of Aquafeeds

Claude E. Boyd

ABSTRACT

The biological oxygen demand of aquafeeds will be called the feed oxygen demand (FOD). It is the amount of dissolved oxygen needed to oxidize organic carbon and ammoniacal nitrogen applied to culture systems in feeds and not recovered in biomass of the culture species at harvest. The following equation can be used to estimate FOD:

$$FOD = [C_f - (FCE \quad C_a)]\ 2.67 + [N_f - (FCE \quad N_a)]\ 4.57$$

where, C_f, N_f, C_a, N_a = decimal fractions (% ÷ 100) of carbon and nitrogen in feed and culture animals, respectively; FCE = feed conversion efficiency (1 ÷ FCR). The FOD value will vary with species, feed quality, feeding practices, and feed conversion efficiency, but calculations suggest that FOD usually will be 1.2 to 1.3 kg O_2/kg feed.

The biological oxygen demand or BOD is widely recognized as an important water quality variable. It is used mainly as an index of the pollution strength of municipal, industrial, and agricultural waste waters (Eaton *et al*. 2005). The BOD of an effluent is a measure of the amount of oxygen needed by microorganisms in oxidizing organic carbon to carbon dioxide and ammoniacal nitrogen to nitrate (Sawyer and McCarty 1967). Oxygen required to oxidize organic carbon is referred to as the carbonaceous biological oxygen demand (CBOD), and oxygen needed to oxidize ammoniacal nitrogen is called the nitrogenous oxygen demand (NOD). The two fractions usually are combined and reported as the BOD. The 5-day BOD (BOD_5) is most commonly determined, and for typical wastewater and aquaculture pond water, the BOD_5 concentration is about two-thirds of the quantity of oxygen needed over a longer period of time to completely oxidize the organic carbon and ammoniacal nitrogen (Boyd and Gross 1999). The amount of oxygen needed to satisfy the BOD of an effluent completely is known as the ultimate BOD (BOD_u). For example, suppose that the BOD_u concentration in an effluent averages 200 mg/L (200 g/m^3) and 250 m^3 of this effluent are discharged into a lake each day. The effluent will impose an oxygen demand of 50 kg/day (200 g BOD/m^3 x 250 m^3/day) on the lake.

Dissolved oxygen concentration is likely the single most important water quality variable in aquaculture (Boyd and Tucker 1998). An adequate concentration of dissolved oxygen is needed to avoid stress and to assure good growth of the culture

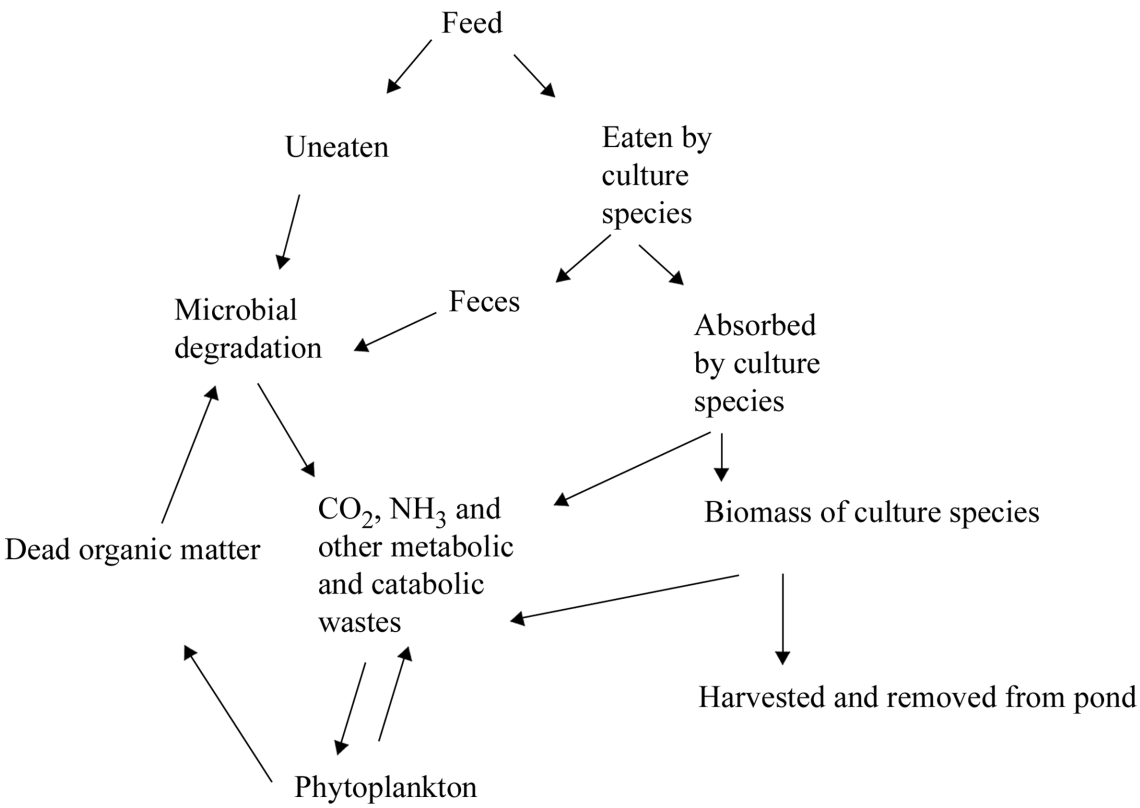
Department of Fisheries and Allied Aquacultures Auburn University, Alabama 36849 USA

species. Moreover, sufficient dissolved oxygen is needed in aquaculture systems to oxidize wastes and prevent them from accumulating to levels harmful to fish, shrimp, and other culture species. The primary wastes in aquaculture systems are organic carbon and ammoniacal nitrogen resulting from the fraction of aquafeeds not converted to biomass of the culture species and harvested. The purpose of this report is to present a method for calculating the oxygen demand of aquafeeds.

The Fate of Aquafeeds

The fate of aquafeeds in ponds is illustrated in Fig. 1. The amount of feed eaten by the culture animals varies with species and feeding practices. When care is exercised to avoid overfeeding, some fish species consume 95 % or more of feed pellets. Shrimp, however, nibble their food and seldom consume more than 85 % of feed pellets. Aquafeeds are comprised of high quality ingredients, and up to 85 or 90 % of the eaten feed will be absorbed by the culture species. The uneaten feed and feces will be degraded by microorganisms to carbon dioxide, ammonia, and other inorganic substances. Some of the feed components absorbed by the culture species will be converted to biomass and removed from the pond at harvest. However, the majority of the absorbed nutrients will be oxidized to carbon dioxide through

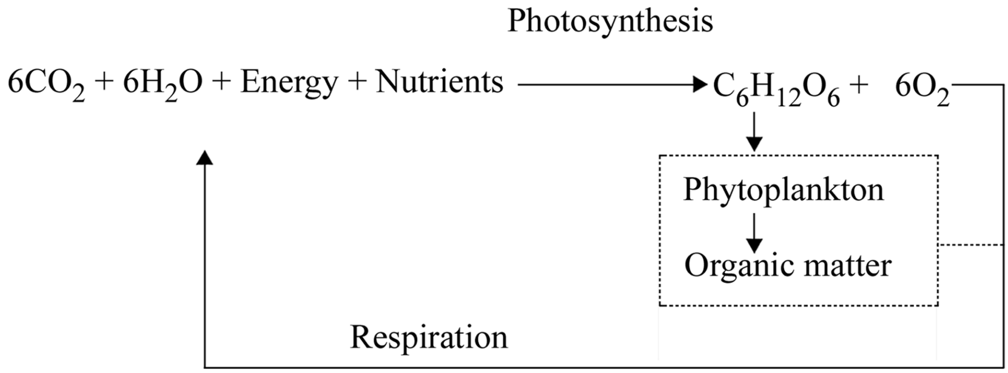
Fig. 1 Fate of Aquafeeds in ponds.



respiration or transformed to ammonia and other metabolic and catabolic wastes and excreted. Usually, no more than 8 to 10 % of the organic carbon and 20 to 30 % of the nitrogen in aquafeeds will be harvested in biomass of the culture species (Boyd *et al.* 2007). Feed nitrogen not recovered in the culture species will be mineralized to ammoniacal nitrogen and oxidized to nitrate by nitrifying bacteria.

Carbon dioxide, inorganic nitrogen, and other nutrients released into pond water following oxidation and mineralization of feed ingredients by the culture species and microorganisms stimulate phytoplankton productivity. In the long run, the amount of oxygen produced in phytoplankton photosynthesis will be equivalent to the amount of oxygen used in respiration by phytoplankton and by microorganisms degrading dead phytoplankton (Fig. 2). Thus, the stimulation of phytoplankton productivity by nutrients from feeding wastes should not be considered as part of the oxygen demand of feed.

Fig.2 As ecological processes, photosynthesis and respiration are equal but opposite reactions. The amounts of organic carbon and oxygen produced in photosynthesis are equal to the quantities of inorganic carbon released and oxygen used in respiration.



Oxygen Demand of Aquafeeds

The oxygen demand of aquafeeds will be called the feed oxygen demand or FOD. It will be defined as the amount of oxygen required to oxidize all organic carbon and ammoniacal nitrogen applied to ponds and other aquaculture systems in feed and not recovered in biomass of the culture species at harvest. The summary equation for oxidation of organic carbon by the culture species or by microorganisms is:

$$\text{Organic C} + O_2 \rightarrow CO_2. \quad (1)$$

The ratio of molecular weights of oxygen to carbon (O_2:C) in the above equation is 32:12 or 2.67:1. The summary equation for oxidation of ammoniacal nitrogen to nitrate nitrogen by nitrifying bacteria is:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O. \quad (2)$$

The ratio of molecular weights of oxygen to ammoniacal nitrogen is $2O_2$:N (64:14 or 4.57:1).

Based upon the stoichiometry of Equations 1 and 2, the simple expression for FOD is:

$$FOD = (\text{Feed C} - \text{Harvest biomass C})\ 2.67 + (\text{Feed N} - \text{Harvest biomass N})\ 4.57. \quad (3)$$

Of course, the value of FOD will vary with the percentages of carbon and nitrogen in aquafeeds and culture species, and with the efficiency with which feed is converted to biomass of the culture species. The calculation of FOD will be illustrated for an example from shrimp aquaculture in which the feed conversion ratio (FCR) was 1.8, the feed contained 6 % nitrogen and 45 % carbon, and the shrimp were 2.75 % nitrogen and 11 % carbon (Boyd and Teichert -Coddington 1995). Each kilogram of feed contained 0.45 kg carbon, 0.06 kg nitrogen and produced 0.556 kg shrimp containing 0.015 kg nitrogen and 0.061 kg carbon. The FOD may be estimated as follows:

$$FOD = (0.45 - 0.061)\ 2.67 + (0.06 - 0.015)\ 4.57 = 1.039 + 0.206 = 1.245 \text{ kg } O_2/\text{kg feed}.$$

Notice that the carbonaceous fraction of the FOD was about five times greater than the nitrogenous fraction of the FOD in this example.

The calculations illustrated above may be combined into the following general equation:

$$FOD = [C_f - (FCE \times C_a)]\ 2.67 + [N_f - (FCE \times N_a)]\ 4.57 \quad (4)$$

where, C_f, N_f, C_a, N_a = decimal fractions (% ÷ 100) of carbon and nitrogen in feed and culture animals, respectively; FCE = feed conversion efficiency (1 ÷ FCR).

Aquafeeds usually contain 45 to 50 % organic carbon and 4.5 to 7 % nitrogen (28 to 44 % crude protein). Carbon and nitrogen concentrations vary with species, but for the present discussion, it will be assumed that culture species are 11 % organic carbon and 2.75 % nitrogen (see shrimp example above). For feeds containing 45 % organic carbon, one with 4.5 % nitrogen would have FOD = 1.176 kg O_2/kg feed, while one with 7 % nitrogen would have FOD = 1.290 kg O_2/kg feed. Feeds for coldwater fish, e.g., trout and salmon, have high percentages of organic carbon and nitrogen, but FCR usually is 1.1 to 1.2 (Boyd *et al*. 2007). At FCR of 1.15, a feed with 50 % C and 7 % N would have FOD = 1.289 kg O_2/kg feed.

The FCR varies with species, feed quality, and method of feeding, and values typically are between 1.5 and 2.5. Using the shrimp example from above, FOD will vary from 1.199 kg O_2/kg feed at FCR = 1.5 to 1.308 kg O_2/kg feed at FCR = 2.5 (Table 1). It is important to note that decreasing (improving) the FCR will reduce the FOD input per kilogram of shrimp production. For example, at a FCR of 2.2, the FOD input is 2.82 kg O_2/kg shrimp, while at a FCR of 1.6, the FOD input is reduced to 1.94 kg O_2/kg shrimp.

The data in Table 1 suggest that the FOD in shrimp culture will be around 1.2

to 1.3 kg O_2/kg feed applied to ponds, and the FOD for culture of most species of fish likely will be similar. Equation 4 can be used to obtain a more exact estimate of FOD from the anticipated FCR and data on the carbon and nitrogen composition of the feed and culture species. The FOD likely is similar across species and types of feed. Thus, the most important action that can be taken to reduce the oxygen demand of feed in aquaculture systems is to improve the efficiency of conversion of feed to culture species.

Table 1. Feed conversion ratio (FCR), feed conversion efficiency (FCE), feed oxygen demand (FOD), and FOD input for culture of shrimp.

FCR	FCE	FOD (kg O_2/kg feed)	FOD input (kg O_2/kg shrimp)
1.5	0.667	1.199	1.80
1.6	0.625	1.214	1.94
1.7	0.588	1.229	2.09
1.8	0.556	1.245	2.24
1.9	0.526	1.257	2.39
2.0	0.500	1.265	2.53
2.1	0.476	1.278	2.68
2.2	0.455	1.283	2.82
2.3	0.435	1.292	2.97
2.4	0.417	1.303	3.13
2.5	0.400	1.308	3.27

LITERATURE CITED

Boyd, C. E. and C. S. Tucker. 1988. Pond Aquaculture Water Quality Management. Kluwer Academic Publishers, Boston, Massachusetts, USA.

Boyd, C. E. and A. Gross. 1999. Biochemical oxygen demand in channel catfish *Ictalurus punctatus* pond waters. Journal of the World Aquaculture Society 30:349-356.

Boyd, C. E., C. S. Tucker, A. McNevin, K. Bostick, and J. Clay. 2007. Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture. Reviews in Fisheries Science 15:327-360.

Eaton, A. D., L. S. Clesceri, E. W. Rice, and A. E. Greenberg (editors). 2005. Standard Methods for the Examination of Water and Wastewater, 21st edition. American Public Health Association, Washington, D.C., USA.

Sawyer, C. N. and P. L. McCarty. 1967. Chemistry for Sanitary Engineers. McGraw-hill Book Company, New York, New York, USA.

Guide for Authors

Contributions

Kasetsart University Fisheries Research Bulletin publishes articles on problems and issues in fisheries science, including aquaculture, in Asia or those relevant to the Asian region. Acceptable topics include ecosystem and population dynamics, resource assessment, fishing gear technology, fish processing, socioeconomics, farming systems, breeding, nutrition, fish health, pollution and aquatic resources management. Articles may be research papers, short communications or invited reviews.

- Research papers must not exceed 20 manuscript pages including Tables and Figures.
- Short communications are results of brief but significant work. Manuscripts must not exceed 8 pages, must have an abstract, but may omit the usual major headings of full papers.
- Invited reviews will solicited by the Editor and the Editorial Board. Manuscripts must have an abstract and must not exceed 40 pages.

Only original, unpublished manuscripts not under consideration for publication elsewhere may be submitted. Articles must be technically sound and written in English. The editors will assist authors for whom English is a second language.

Authors must display good knowledge of the primary scientific literature. Authors must also prepare manuscripts according to the journal's standards and instructions in order to facilitate prompt review and processing of papers.

Preparation of Manuscripts

1. Organize the reseach paper logically and clearly, with sections complementing but not repeating each other, as follows:

- Title page - with concise but specific title and author's name and affiliation
- Abstract - summarizes the study in not more than 200 words, on a page by itself
- Introduction - lays out the problem addressed, current level of knowledge, the aims of the study, and the hypotheses tested
- Materials and methods - includes all crucial information to allow replication of the study
- Results - gives concise summary of data in Tables and Figures
- Discussion - places the study in the larger context of fisheries science and literature
- Conclusion - encapsulates the scientific contribution of the study
- Acknowledgement - credits contributors of thoughts, expertise and funds
- References - must substantially include the peer-reviewed primary literature
- Tables, Figure captions and Figures

2. Type the manuscript using Microsoft Office Word software using letter size page (21.5 cm x 28.0 cm) with 2.5 cm margins all around. Double-space the manuscript throughout, including references, Tables and Figure legends. Use Times New Roman font with font size of 10 or 12 points.

3. Leave a triple space before and after all headings. Use capital and lower case letters, never all capitals. Avoid footnotes, addenda or appendices; if they are really important, incorporate them briefly in the text. Underline only the words to be italicized. Define acronyms or unfamiliar abbreviations at first mention in the text. Do not give any acronym in parenthesis if it is not used later again in the text.

4. Give the Latin name and family of the species at first mention in the manuscript. Subsequent references may use the common name. Italicize (or underline) Latin names. Example: Asian sea bass (*Lates calcarifer,* Centropomidae).

5. Place a (leading) zero before the decimal in numbers less than 1. Give dates in the form 10 January 1994. Spell out numbers less than 10 unless they stand beside standard units of measure (eight fish and 8 kg). Do not spell out numbers lager than 10 unless they are used to start a sentence.

6. use metric units or the International System of Units (with base units meter, gram, second, liter, mole, joule, etc.). Common units such as day, tons, hectare, watts, horsepower, ^{o}C and ppt salinity may be acceptable. Use abbreviations of units only beside numerals (e.g., 5 m); otherwise spell out units (e.g., only meters away). Do not use plural forms or periods for abbreviations of units. Use superscripts and subscripts instead of the bar (/) for compound units; for example, 2 $t \cdot ha^{-1} \cdot year^{-1}$ instead of 2/t/ha/year, 10 $g \cdot m^{-2}$ instead of 10 g/m^2.

7. In designing Tables and Figures, bear in mind the journal's page (17.8 cm x 25.3 cm or 7" x 10") and any reduction needed. Table headings, Figure explanations and other labels must be understandable without reference to the text. Number Tables and Figures consecutively, one per page. Tables must have horizontal lines only at the top and bottom and no vertical lines at all. Leave spaces to indicate groupings of data. Figures must be neat and simple line drawings, computer-generated graphics, or good-quality black and white photographs. Labels or lettering on Figures must be of a size readable after reduction (up to 60%). Send electronic images (.jpeg or .tif format) at first submission and the originals only with the revised manuscript if necessary.

8. Cite references in the text as Author (year). Cite three or more authors as (First Author *et al*. year) and references still in press as (Author, in press). If a reference is unpublished, say (Author, unpubl. data) or (Author, pers. comm.), but avoid such citations. Arrange references in series by year as in (Beta 1980; Omega 1985; Alpha 1990).

9. In the references, arrange papers alphabetically by (first) authors' family names as follows:

(book)	Baradch, J.E., J.H. Ryther and W.O. McLarney. 1972. Aquaculture: the farming and husbandry of freshwater and marine organisms. Wiley Interscience, New York. 100 pp.
(proceedings)	Ronquillo, I.A. 1974. A review of the roundscad fishery of the Philippines. Proceedings Indo-Pacific Fisheries Council 15(3):351-375.
(book chapter)	Smith, I. and K.C. Chong. 1984. Southeast Asia milkfish culture: economic status and prospects. In: Advances in milkfish biology and culture (ed. J.V. Juario, R.P. Ferraris and L.V. Benitez), pp. 1-20. Island Publishing House, Manila.
(journal article)*	Widodo, J. 1991. Maturity and spawning of shortfin scad (*Decapterus macrosoma*) (Carangidae) of the Java Sea. Asian Fisheries Science 4:245-252.
	*Journal titles should be given in full.

10. Number all pages consecutively, including title, Tables and Figures.

Submission

Submit electronic copies of manuscript, including Tables and Figures to the Managing Editor at this email adress: ffiswak@ku.ac.th. To facilitate communication, provide on a separate sheet the corresponding author's complete mailing address, telephone and fax numbers, and e-mail address. After the review, submit electronic copies of the revision via email at the same address. Originals of Figures may be requested to be submitted via airmail if necessary. The computer file must be in Windows format, preferably in Microsoft Word.

Send manuscripts to:

The Managing Editor
Dr. Wanwimol Klaypradit
Kasetsart University Fisheries Research Bulletin
Faculty of Fisheries, Kasetsart University, Thailand 10900
ffiswak@ku.ac.th

For inquiries, authors may also contact Dr. Wanwimol Klayprdit at telephone no. (+66-2) 942-8936, fax (66-2) 942-7447 or e-mail: ffiswak@ku.ac.th; or the Editor, Asst. Prof. Suriyan Tunkijjanukij at telephone (+66-2) 942-8936, fax (+66-2) 942-7447 or e-mail: ffissrt@ku.ac.th

The Editor may return unreviewed any manuscript that falls outside the journal's policy or scope. All other manuscripts will be peer-reviewed by at least two external referees.

Reprints

The final copy of the manuscript in PDF format will be sent to the corresponding author via email.