

WATER ENVIRONMENT &amp; TECHNOLOGY

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# WET

OPERATIONS &amp; ENGINEERING

# PRECISE COUNT

NEW INSTRUMENTATION IMPROVES MEASUREMENT



# Food for Thought





# Technological advances in determining the true food-to-microorganism ratio obviate the need to measure surrogates

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**T**he food-to-microorganism ratio (F:M) has served as a widely used process control parameter for monitoring and servicing activated sludge systems.

Operators can use the F:M to adjust the biomass as necessary to optimize oxidation of organic material in incoming wastewater. Generally accepted guidelines for F:M values have been established for municipal and industrial applications based on surrogate parameters. However, these calculated values have been translated or adjusted loosely based on site-specific conditions.

Recent technological advances enable the measurement of the “true” F:M using dissolved organic carbon (DOC) concentrations and adenosine triphosphate (ATP), the energy carrier in all living organisms. Therefore, traditional surrogate measurements such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and mixed liquor volatile suspended solids (MLVSS) are no longer necessary. As a result, quick, reliable, and more accurate measurements may be used, leading to improved process-control decisions. Eliminating the need for surrogate measurements potentially will reduce reliance on site-specific baselines.

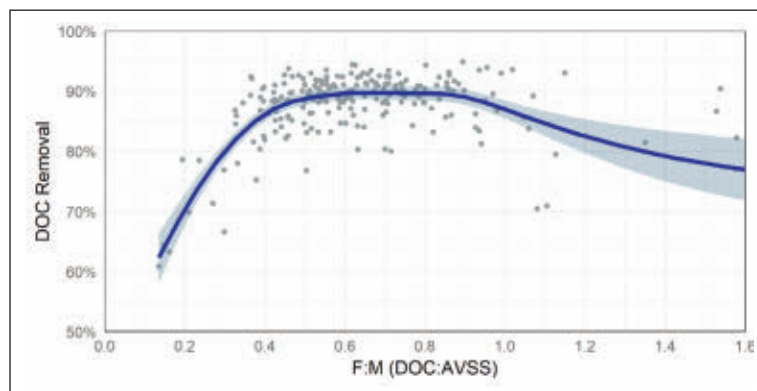
## F:M Theory

Traditionally, the food portion of the F:M has been calculated as either BOD or, perhaps more accurately, carbonaceous biochemical oxygen demand (CBOD). COD and soluble COD also have served as common surrogates for BOD values.

Active biomass, or the microorganism portion of the F:M, has been calculated conventionally either as mixed liquor suspended solids (MLSS) or MLVSS. This lack of consistency and the highly variable ratios of active biomass to solids add to the site-specific application of F:M targets that traditionally range from 0.2 to 0.6 kg of BOD per kilogram of MLSS/d.

Therefore, specifying acceptable food and microorganism values is complicated and inherently presents

**Figure 1. New F:M Protocol**



This chart shows dissolved organic carbon (DOC) removal as a function of the food-to-microorganism ratio (F:M), calculated using DOC and active volatile suspended solids (AVSS). Note: data with F:M > 2.0 was omitted for scale (n=4). The curve was fit using LOWESS regression with a 95% confidence interval.

significant drawbacks. As the parameter names describe, BOD and CBOD measure biological oxygen consumption, which is then correlated to the amount of organic matter present in a given wastestream. These analyses require 5 days to complete and are subject to numerous interferences that cause inaccurate and imprecise results. These limitations make the F:M difficult to use for real-time, process-based, decision-making, particularly at water resource recovery facilities that experience widely fluctuating organic loadings. Under such conditions, these facilities require a much faster feedback time to make process adjustments based on the F:M.

Like BOD, COD and soluble COD measure oxygen consumption rather than directly determining the carbon loading to the system. Unlike the more time-consuming process for measuring BOD, COD can be determined in hours instead of days. However, COD does not differentiate between biodegradable and non-biodegradable compounds. For this reason, the method can include additional oxidizable inorganic compounds, leading to inaccurate results. In addition, the COD test uses and requires the disposal of hazardous chemicals.

MLSS and MLVSS also present problems for determining the F:M. Because they include active

and dead biomass as well as other nonbiological inert material, the measurements poorly represent active biomass levels. For example, the biologically active portion of the suspended solids fluctuates heavily based on food availability. Therefore, a reduction in available food would result in a decrease in the active biomass because of starvation. However, MLSS and MLVSS would remain constant because the dead biomass would continue to contribute to the measurements.

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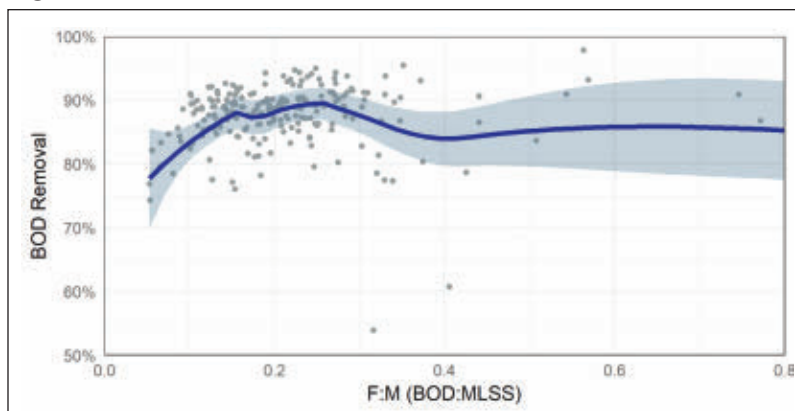
### New Tools, New Approach

Recent technological advances have facilitated the new approach for determining the F:M by measuring DOC and ATP concentrations. Improvements have been made in measuring total organic carbon and DOC for the purpose of determining the actual organic loading to an activated sludge system. Another key improvement involves the use of cellular ATP (cATP) to represent the actual living component of biomass.

These advancements in measuring DOC and cATP have made calculating the true F:M practical. Both constituents can be measured rapidly — in less than 10 minutes — and they accurately represent actual food and microorganism process parameters.

In a case study conducted by the authors, TOC and DOC were measured by means of a state-of-the-art analyzer that uses supercritical water oxidation technology, in which samples are subjected to high pressure and high temperature. Because it eliminates analyzer fouling that typically is associated with

**Figure 2. Conventional F:M Protocol**



This chart shows biochemical oxygen demand (BOD) removal as a function of the food-to-microorganism ratio (F:M), calculated using BOD and mixed liquor suspended solids (MLSS). Note: data with F:M > 0.80 was omitted for scale (n=5). The curve was fit using LOWESS regression with a 95% confidence interval.

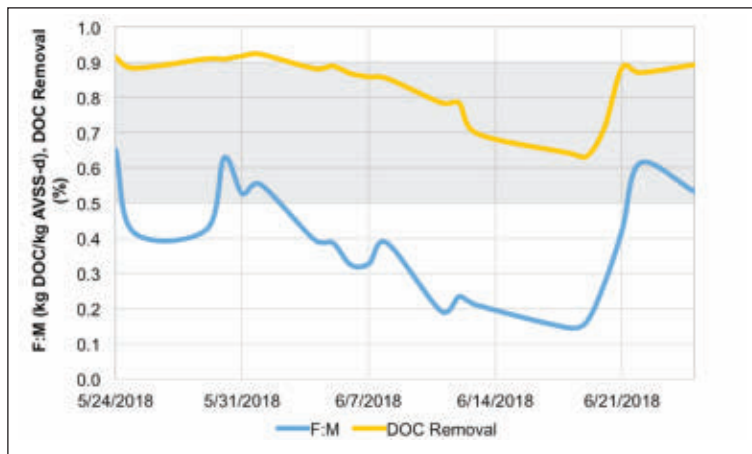
**ATP is the energy carrier in all living organisms; therefore, quantification of cATP directly measures active biomass.**

instruments used to measure organic carbon within wastewater and process water, supercritical water oxidation technology prevents the occurrence of residual contamination from one measurement to the next.

Because it directly measures organic content, DOC represents the potential food in a wastestream. Compared to COD, DOC offers several potential advantages, including accurate, precise, complete oxidation and quantitation of all organic matter; continuous online measurement capabilities; and no known interferences. In a test of gage repeatability and reproducibility involving nearly 1000 calibration check measurements, the system displayed a relative percent standard deviation of less than 3%.

As noted earlier, ATP is the energy carrier in all living organisms; therefore, quantification of cATP directly measures active biomass. For their case study, the authors conducted a benchtop analysis using commercially available ATP monitoring technology specifically designed for wastewater. This technology uses a luciferase enzyme to produce a biochemi-luminescent response that can be measured by means of a benchtop luminometer. This analysis takes only minutes to perform and requires no culturing, incubation, or specific training. The technology can measure separately both cATP contained in living organisms and dissolved ATP that is associated with dead and

### Figure 3. Event No. 1 - Treatment Results



dying biomass. Having both measurements enables operators to determine the quantity of active biomass and the level of stress being imparted to it.

For F:M calculations, cATP (ng/mL) was converted to active volatile suspended solids (AVSS) measured as mg/L according to established conversion factors.

## Finding the F:M in Practice

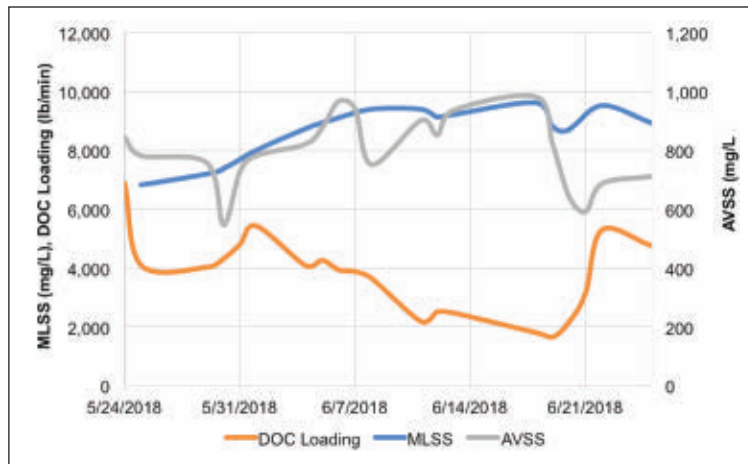
The case study involved a conventional activated sludge water resource recovery facility with nitrification. Treatment processes consist of dissolved-air flotation, multiple plugflow activated sludge bioreactors, and secondary clarification.

Process data covering a period of 12 months (May 2018 to April 2019) was reviewed and analyzed. COD, DOC, MLSS, and cATP were measured daily, along with a full suite of other parameters, including ammonia, nitrite, nitrate, conductivity, pH, and dissolved oxygen.

Figures 1 and 2 (p. 30) show the relationship between the F:M and treatment performance. Figure 1 demonstrates the new F:M protocol, which was calculated on the basis of the ratio of DOC to AVSS (DOC:AVSS). By contrast, Figure

**This shows food-to-microorganism ratio (F:M) and dissolved organic carbon (DOC) removal during a period with suboptimal F:M ratio and no process intervention. The gray area represents the optimal F:M range.**

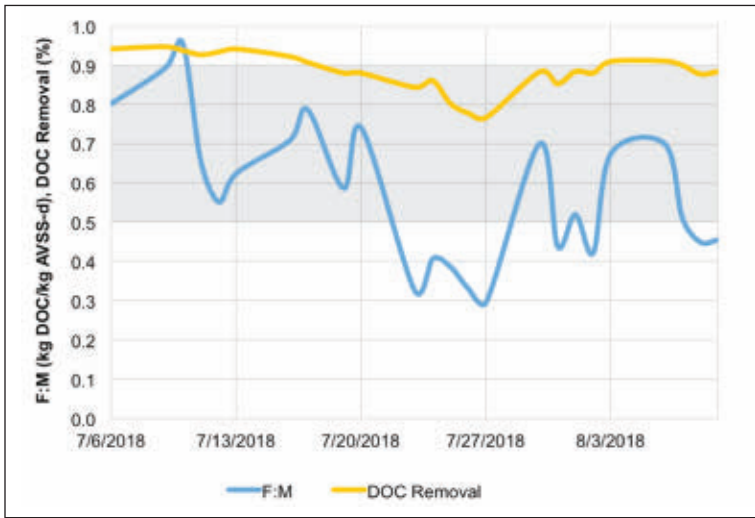
### Figure 4. Event No. 1 - Process Conditions



This show process conditions during a period with suboptimal food-to-microorganism (F:M) ratio and no process intervention.  
DOC = dissolved organic carbon.  
MLSS = mixed liquor suspended solids.  
AVSS = active volatile suspended solids.



**Figure 5. Event No. 2 - Treatment Results**



This shows the results when a suboptimal F:M ratio triggered a process intervention (reduced MLSS and AVSS). The gray area represents the optimal F:M range.

2 shows the conventional protocol, which was calculated on the basis of the ratio of BOD to MLSS (BOD:MLSS). BOD was estimated as 70% of the COD concentration.

Poor treatment performance was expected at F:M values below and above a previously undefined optimal range. At a low F:M — that is, less than the optimal range — the biomass is driven toward endogenous respiration, reducing treatment performance. At a high F:M — that is, greater than the optimal range — insufficient biomass exists to consume the food.

The new protocol in which the F:M was determined by the DOC:AVSS was able to replicate this observation. The optimal range appeared to be 0.5 to 0.9 kg of DOC per kilogram of AVSS per day. Within this range, the average DOC removal was 90% ± 3% (n=148). Removal efficiencies dropped below 85% when measurements beyond this optimal range were observed.

This level of process improvement may not

seem significant. However, by examining the standard deviations and developing a regression line using the locally weighted scatterplot smoothing (LOWESS) regression analysis tool, it becomes evident that within the optimal F:M range the activated sludge treatment removal efficiencies were highly stable and predictable. By contrast, outside the optimal range, treatment performance varies significantly more and has a much larger range of potential treatment outcomes.

As shown in Figure 2, the relationship between the F:M and treatment performance was less evident when the conventional F:M protocol that relies on the BOD:MLSS was used. This approach found no stable, optimal range, and the confidence interval was much wider.

### Using the F:M To Improve

To understand further how this F:M protocol could be used to improve process control and increase treatment efficiencies, two suboptimal F:M events were examined. In the first event (May 24, 2018 to June 25, 2018), actions were not taken to correct the F:M ratio, while in the second event (July 6, 2018 to August 9, 2018), actions were taken quickly to correct the F:M ratio.

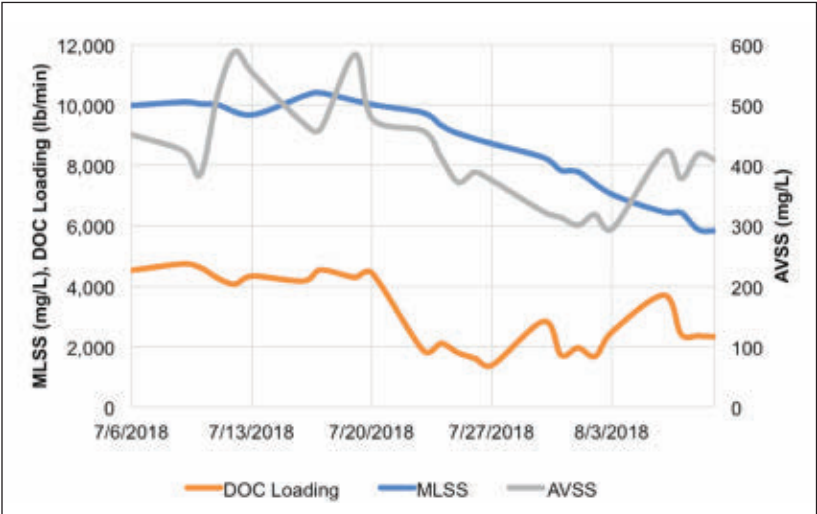
Figures 3 and 4 (p. 31) depict the conditions that prevailed during the first event. During this period, the following observations were made:

- **June 4, 2018.** A suboptimal F:M measurement — 0.4 kg DOC per kilogram of AVSS per day — was recorded.
- **June 6, 2018.** While DOC loading to the facility steadily decreased, DOC removal declined from 86% to 63%. The F:M remained suboptimal as DOC loading decreased and AVSS and MLSS remained fairly constant.
- **June 20 to 25, 2018.** DOC loading to the water resource recovery facility increased rapidly,

enabling the F:M to return to the optimal range. DOC removal returned to the baseline.

During this event, no process changes were made to reduce the population of microorganisms, as measured by AVSS, in the system. This non-intervention, coupled with the decreased DOC loading, resulted in suboptimal F:M ratios and poor DOC removal.

**Figure 6. Event No. 2 - Process Conditions**



The process conditions during a time when a suboptimal food-to-microorganism (F:M) ratio triggered a process intervention that included reduced mixed liquor suspended solids (MLSS) and active volatile suspended solids (AVSS).

# This new method for determining the F:M can obviate the need for antiquated, ineffective surrogate measurements.

These outcomes likely were caused by a shift to endogenous decay. The system corrected itself with no process interventions as influent DOC levels increased rapidly, returning to previous levels.


Figures 5 and 6 (p. 32) illustrate the second event. Observations similar to those of the first event were made initially: A low F:M measurement was observed as DOC loading decreased rapidly. However, the suboptimal F:M measurement during the second event triggered a response. Return activated sludge rates were decreased, reducing AVSS and MLSS concentrations. This change compensated for the reduced DOC loading and quickly corrected the F:M.

The DOC removal performance reflects these actions. Compared to the first event, DOC removal performed better, dipping below 80% for fewer than 5 days and never going below 77%.

## Benefits of New Advances

The rapid F:M protocol described here demonstrates several advantages to traditional F:M parameters. DOC proved to be a good measurement of the “food” entering the treatment system. The ability to measure DOC rapidly and accurately using the online monitor was a distinct improvement over the measurement of BOD and COD. AVSS, as quantified using cATP, provided a much more accurate representation of the treatment system’s microbiological content relative to MLSS. With the use of AVSS, an optimal F:M range was approximated as 0.5 to 0.9 kg of DOC per kilogram of AVSS per day. By contrast, an obvious relationship was not found between the conventional approach for determining the F:M by means of the BOD:MLSS and BOD removal.

This new method for determining the F:M

can obviate the need for antiquated, ineffective surrogate measurements. By understanding the effect that the F:M has on treatment performance, operators can optimize their process routinely and in real time, reducing the probability and duration of process upsets, and decrease treatment variability. In the long term, such improvements may decrease operational costs associated with troubleshooting and rectifying poor treatment performance and potentially forestall the need for capital upgrades as facility capacity is expanded through routine process optimization. 

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