Fish Culture Workshop

"Bio-Engineering" – A qualitative, quantitative approach to "Rationally" determine production and facility design concepts for Intensive fish production systems.

Fish Culturists/Biologists use variable numbers (Life)......

Engineers work with exact numbers...... Therefore "variable" numbers must become "exact" numbers.....

A Choice Must Be Made!
This is what Plato said about fish: "Senseless beings.....which have received the most remote habitation as a punishment for their extreme ignorance."

But consider this: Fish have been very "successful" – about half of all vertebrates are fish.

± 45,000 species

Also: Assertions creating doubt and suspicion are considered "Fishy" in the English language.

We all have our biases! And: Our biases have us!
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“Bio-Engineering” – A qualitative, quantitative approach to rationally determine production and facility design concepts for intensive fish production systems.

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Engineers work with exact numbers... Therefore variable numbers must become exact numbers...

A Choice Must Be Made!
Quantitative Approach

Biologists (Life) Deal with Variability.

In Aquaculture: Mortality rates; Growth rates; Feed conversions; Condition factors; Metabolic rates, etc.

“More or Less” Values

Engineers use exact values: Rearing unit dimensions, Pipe sizes, Pumps, Pressure, etc.
Fish Culturists must select the “best” number (based on empirical data; experience; tradition; personal preferences; etc.) Must be as rational as possible.

“The person with experience is never at the mercy of a person with a theory.”
Intensive Fish Culture

**Biological Processes** governed by two laws of thermodynamics:

1. **Energy** cannot be created nor destroyed but... can be changed into different forms.

2. In the **transformation** – such as food to flesh, there is a "loss" of energy in the form of heat. *(Figure 1-1)*

**Intensity** of production; two variables:

1. **Productivity**: Harvest per unit area.

2. **Technology**: Degree of manipulation.
Systems: Extensive ←→ Intensive

1. Inputs from the outside.
2. Processing within.
3. Outputs to the external environment.

*Extensive*: Internal Control

*Intensive*: External Control
Carrying Capacity and Production

Difficult (to determine) with internally driven systems (such as ponds).

Intensive systems are externally driven...by the actions of the culturist!

Extensive systems:

Production in units per area

kg/ha or lb/acre
**Intensive systems:**

1. Production (carrying capacity) per unit of flow: kg/lpm or lb/gpm.

2. Production per unit of volume:

   kg/m³ or lb/ft³

\[
1.0 \text{ kg/lpm} = 8.33 \text{ lb/gpm} \quad (3.0 \text{ kg/lpm} = 25 \text{ lb/gpm})
\]

\[
1.0 \text{ lb/ft}^3 = 16 \text{ kg/m}^3
\]

(1.0 m³ = 35.3 ft³)  
(1.0 kg = 2.2 lb)
Loading (Ld) And Density

Loading (Ld): Capacity per unit of Flow (Q)

As: \( Ld = \text{kg/lpm} \quad \text{lb/gpm} \)

Density (D): Capacity per unit of Volume (RV)

As: \( D = \text{kg/m}^3 \quad \text{lb/ft}^3 \)

DO NOT USE THE TERM “LOADING DENSITY”
Relationships Ld; D; R

Ld = \((D \times 0.06)/R\) and \((D \times 8)/R\)

D = \((Ld \times R)/0.06\) and \((Ld \times R)/8\)

R = \((D \times 0.06)/Ld\) and \((D \times 8)/Ld\)

R: Water turnover rates in \#/hr

Example: \(R = 2 = \) Every 30 minutes.
"Nothing is ever as bad as it first appears."

\[
0.06 = 1.0 \text{ lpm} \times 60\text{min} = 60\text{l} = 0.06\text{m}^3
\]

\[
8 = 1.0 \text{ gpm} \times 60\text{min} = 60\text{gal} = 8\text{ft}^3
\]

\( R \) is turnover rate in \#/h (60min) and rearing volume (RV) is expressed in \( \text{m}^3 \) or \( \text{ft}^3 \).
**An Exercise** (Application)

Assume loading is 1.5 kg/lpm (12.5 lb)

Density is 96 kg/m$^3$ (6 lb)

What is $R$?

$$R = \frac{(D \times 0.06)}{Ld} \rightarrow \frac{(96 \times 0.06)}{1.5} = 3.84$$

and: $(6 \times 8)/12.5 = 3.84$ (For English)
Assume rearing volume (RV) = 10 m$^3$ (353 ft$^3$)

Maximum Biomass (MBM) is:

$$MBM = D \times RV \longrightarrow 96 \times 10 = 960 \text{kg}$$

**English:** $MBM = 6 \times 353 \longrightarrow 2118 \text{ lb}$

$$Q = \frac{MBM}{Ld} \longrightarrow \frac{960}{1.5} = 640 \text{ lpm}$$

$$Q = \frac{2118}{12.5} = 169.4 \text{ gpm}$$
Equations:

\[ L_d = \frac{(D \times 0.06)}{R} \]

\[ D = \frac{(L_d \times R)}{0.06} \]

\[ R = \frac{(D \times 0.06)}{L_d} \]

\[ MBM = (D \times RV) \]

\[ Q = \frac{MBM}{L_d} \]

\[ Q = \frac{(RV \times R)}{0.06} \text{ or } 8 \]

Loading relates to flow rate \((Q)\)

Density to rearing volume (space) \((RV)\)
Ld, D and R Must Balance

These three are facility design driving forces.

"What you are driving is not important. What's important is what's driving you."
Establishing Loading Values

Dissolved Oxygen (DO) First limiting carrying capacity factor.

Demand for oxygen best expressed in terms of feed!

(OF)

\[ OF = \text{Gram O}_2 \text{ per kg feed} \]
\[ \quad \text{g O}_2/\text{lb} \]

Per kg: 200 to 250g

Per lb: 91 to 114g
These are "Rational" values for salmonids, and seem to fit many other species as well.

But still somewhat controversial and... does not fit RAS! (More Later)

Must select a value

Will use 250 per kg and 114 per lb
Loading Values (II) (Oxygen)

Maximum loading values (MLd) depend on the fish’s tolerance to the quality of the rearing water as it undergoes changes caused by the metabolic actions of the fish – Bioenergetics – (See again Figure 1)

1. **Removing** dissolved oxygen.

2. **Adding** ammonia; carbon dioxide; suspended solids; nitrates.
First Limiting Factor:
Dissolved oxygen depletion – but can correct (can remove as limiting factor) by aeration or oxygenation.

Loading based on oxygen required per unit of feed

(250g/kg; 114g/lb)

\[ LdF = \text{kg feed/lpm} \]

\[ LdF = \text{lb feed/gpm} \]
Loading Values – (Oxygen) III

Available Oxygen (AO)

1.0 lpm @ 1.0 mg/l DO delivers 1440mg

(144g) O₂ Per day

(1.0 × 1.0 × 60 × 24 = 1440)

1.0 gpm @ 1.0 mg/l (ppm):

1.44 × 3.785 = 5.45g O₂/day
\[ \text{LdF} = \frac{(1.44 \text{ AO})}{\text{OF}} (5.45 \text{ AO}) \rightarrow \text{English} \]

Use: \[ \text{LdF} = \frac{\text{AO}}{\text{OF}} \times (3.8 \text{ AO}) \rightarrow \text{English} \]

\[ \text{AO} = \text{DO}_{\text{in}} - \text{DO}_{\text{out}} \quad (\text{DO}_{\text{out}} \text{ is min. DO}) \]

\[ \text{DO}_{\text{in}} = 10 \quad \text{DO}_{\text{out}} = 6 \quad \text{AO} = 4.0 \]

*Greatest metabolic activity during “Feeding Day” – use 16.7 h.

\[ 1.0 \times 1.0 \times 60 \times 16.7 = 1000 = 1.0 \text{ g} \] (Instead of 1.44)

\[ \text{English} \rightarrow 3.8 \text{ g} \] (Instead of 5.45)
Loading Values – (Oxygen) IV

LdF = AO/OF and 3.8 AO/OF

For OF = 250  \[ LdF = \frac{1}{250} = 0.004 \text{ kg/lpm} \]

For OF = 114  \[ LdF = \frac{3.8}{114} = 0.033 \text{ lb/gpm} \]

NOTE: Per AO!

Per AO can feed 0.004 kg/lpm

0.033 lb/gpm
To change to fish loading (Ld) must know how much feed they require (% BW)

\[ Ld = \frac{(AO \times 100)}{(OF \times \% BW)} \]

\[ Ld = \frac{(3.8 \times AO \times 100)}{(OF \times \% BW)} \]

% BW = 1.0 \quad \text{Ld is } 100 \times \text{LdF}

% BW = 10 \quad \text{Ld is } 10 \times \text{LdF, etc.}
Loading Values – (Oxygen) V

\[ \text{DO}_{\text{in}} = 10 \quad \text{DO}_{\text{min}} = 6 \quad \text{AO} = 4.0 \quad \% \text{ BW} = 1.0 \]

\[ \text{Ld} = \frac{(4 \times 100)}{(250 \times 1.0)} = 1.6 \text{ kg/lpm} \]

\[ \text{Ld} = \frac{(3.8 \times 4 \times 100)}{(114 \times 1.0)} = 13.3 \text{ lb/gpm} \]

**The Question:** How much oxygen can be made available before ammonia becomes the limiting water quality factor?

How high can AO be?

Feed "consumes" oxygen (OF = ...?...) 

Feed generates ammonia as total ammonia nitrogen (TAN) (TANF = ...?...)
What is the value (the number) for TANF?

TANF: g TAN per unit food (kg or lb)

A “Rational” number, supported by the literature:

30 g/kg Food

13.6 g/lb Food

Range: 20-35g (11.4-13.6)
Depends on protein content: Quantity; Quality; Ratio-(Energy-Protein)

\[ g_{\text{TAN}} = g F \times \% P_T \times \% N \times \% \text{Ex} \times \% \text{TAN} \times 1.2 \]

Diet: 40% \( P_T \) N = 16% Environment

Nitrogen loss (Ex) = 45% of which 80% is TAN.

Per kg (1000g) feed:

\[ g_{\text{TAN}} = 1000 \times 0.16 \times 0.45 \times 0.80 \times 1.2 = 27.4 \text{ g} \]

30% Protein: 20.7  
50% Protein: 34.6
Loading Values (Ammonia) II

We "collectively" selected a number for TANF: 30 and 13.6 for English.

How much TAN is Toxic Unionized Ammonia (NH$_3$)?

This is pH and Temperature dependent (Table 1)

Will use in our deliberations a pH = 7.6 and Temperature = 14°C (57°F) Resulting in a % UA of 1.0
Must select a number for a safe (healthy) concentration of unionized ammonia, a maximum allowable concentration (MUA)

*No matter how thin you slice it, there are always two sides.*
Loading Values – (Ammonia) III

Recommendations for maximum unionized ammonia (MUA): Ranges 0.010 to 0.035 mg/l

For salmonids – 0.0125 – 0.025

Still controversial Meade’s Review (’85)

Discussion

For our exercise “we” select MUA = 0.025
Provided: High DO; Low CO₂; High Alk (Na⁺)
Now Recall:

\[ LdF = \frac{0.004}{\text{kg/lpm}} \quad \text{and} \quad \frac{0.033}{\text{lb/gpm}} \text{ For English} \]

\[
gTAN = LdF \times TANF
\]

\[
gTAN = 0.004 \times 30 = 0.12\text{g}
\]

and: \[ 0.033 \times 13.6 = 0.45\text{g} \]

This is \( gTAN/d \).

We need to know what the concentration is!!
Loading Values – (Ammonia) IV

Remember: 1.0 lpm @ 1.0 mg/l = 1.44g/d

and 1.0 gpm @ 1.0 mg/l = 5.45g/d

Therefore: 0.12g/1.44 = 0.083 mg/l

and

For English: 0.45g/5.45 = 0.083mg/l

Will use a general rule, and that is that for each AO used we can expect 0.1 mg/l TAN
This equates to a TANF of 36 (16.3 English)

Also: The production of TAN peaks 2 to 4 hours after feeding ... and ... 0.1 can be considered a Rational number.

Therefore, in our deliberation/examples or exercises, we will use 0.1 mg/l TAN for each AO used.
Loading Values – (Ammonia) V

\[ TANC = \frac{(AO \times TANF)}{(1.44 \times OF)} \]

English

\[ TANC = \frac{(3.8 \ AO \times TANF)}{(5.45 \times OF)} \]

We now need to determine the concentration of toxic Unionized Ammonia (UA)

\[ UAC = \frac{(TANC \times \% \ UA)}{100} \]
When we use “our” numbers:
\[ UAC = \frac{(0.083 \times 1.0)}{100} \]

But: We decided 0.083 is 0.1

Therefore:
\[ UAC = \frac{(0.1 \times 1.0)}{100} \]

\[ UAC = 0.001 \text{ mg/l} \]

For TANC = 0.1 and \( \%UA = 1.0 \) (per AO)!
Loading Values – (Ammonia) VI

Now to determine the maximum AO value (MAO)

Recall: UAC of 0.001 mg/l represents concentration per AO

The question then: How many AO’s?

$$\text{MAO} = \frac{\text{MUA}}{\text{UAC}} = \frac{0.025}{0.001} = 25 \text{ mg/l}$$
An equation:

\[
MAO = \frac{(MUA \times OF \times 1.44 \times 100)}{(TANF \times \%UA)}
\]

"Our" numbers:

\[
MAO = \frac{0.025 \times 250 \times 1.44 \times 100}{(36 \times 1.0)}
\]

\[
\text{MAO} = 900/36
\]

\[
\text{MAO} = 25
\]

Based on \[UAC = 0.1\ 	ext{per AO}\]
Maximum Loading (MLd) I

Conclusion: Can use A0 = 25

MLd = (MAO x 100)/(OF x %BW)

MLd = 10 kg/lpm (For %BW = 1.0)

MLd = (25 x 100)/(250 x 1.0)

MLd = 83.3 lbs/gpm (Use 83)

Discussion: What density to select?

Ld = (D x 0.06)/R  D = (Ld x R)/0.06

English: Ld = (D x 8)/R  D = (Ld x R)/8
Maximum Loading – \((MLd)\) II

Must balance the \(Ld\), \(D\), \(R\) Equation.

\[ D = \frac{(Ld \times R)}{0.06} \text{ or } 8 \]

\[ D = \frac{(10 \times 1.0)}{0.06} = 167 \text{ kg/m}^3 \]

\[ D = \frac{(83 \times 1.0)}{(8)} = 10.4 \text{ lb/ft}^3 \]

This is per \(R\) value of 1.

\(R = 2\) \(D = 334 \text{ kg/m}^3\) English: 20.8 \(\text{lb/ft}^3\)

R 2 Ok for circular units but plug flow (raceways) should have 4 or more. Later!
Density Discussion

D.I. ?

Position: See Table 2

Keen Buss: > 500 kg/m³ (31 lb/ft³)

More fish than water.

Need A Number!!

Will return later for more discussion.
Ld – D – R Relationship

Ld = 10kg/I  \hspace{1cm} 83 \text{ lb/gpm}

What we saw – Too High Densities

For R = 2 → D = 334 \text{ kg/m}^3 \hspace{1cm} 20.8 \text{ lb/ft}^3

For R = 4 → D = 668 \text{ kg/m}^3 \hspace{1cm} 41.6 \text{ lb/ft}^3

These exchange values are needed for good hydraulics.
This will be discussed under Rearing Units
Conclusion:

$$D = \frac{(Ld \times R)}{0.06} \text{ or } 8$$

Does Not Fit

Does Not Balance

Will return to this when discussing facility design processes.

For now: Assumed DO not limiting rather unionized ammonia is limiting.

But: What about Carbon Dioxide?
Carbon Dioxide – \((CO_2)\) I

For each AO used about 1.4 mg/l \(CO_2\) is generated.

For \(MAO = 25\) \(\text{MCO}_2 = 35\) mg/l

Maximum \(CO_2\) (MCO) Concentrations
Range from 10 to 60 mg/l

Discussion: pH, Alkalinity, Temp.

\[
\begin{align*}
\text{CO}_2 + \text{H}_2\text{O} &= \text{H}_2\text{CO}_3 \\
&\quad \text{↔} \quad \text{HCO}_3^- \quad \text{↔} \quad \text{CO}_3^{2-}
\end{align*}
\]

\(\text{H}^+\) \(\text{H}^+\)

Lowers \(\text{pH}\) – Alkalinity Resists
A Dynamic Equilibrium

Free CO$_2$ (Gaseous) Is Toxic

How much free CO$_2$? Table I-3

May have to control CO$_2$:

1. Degas

2. Chemical (pH control)
Carbon Dioxide – \((\text{CO}_2)\) II

**Colt:** When COC (cumulative oxygen consumption) is 20, CO\(_2\) must be managed. (COC same as MAO)

**Table I-4** shows impact of pH, temperature and alkalinity on free CO\(_2\).

More discussion about CO\(_2\) later.

**Gas Management** (Unit VII)

**Recirculation** (Unit VI)

Low pH favors unionized ammonia

High pH favors gaseous CO\(_2\) problem

See Figures

Discussion?
Equations Used

1. \( \text{Ld} = (D \times 0.06)/R \quad D = (\text{Ld} \times R)/0.06 \)
   \( R = (D \times 0.06)/\text{Ld} \)

1a. For English: 0.06 is 8

2. \( \text{MBM} = D \times \text{RV} \)

3. \( Q = \text{MBM}/\text{Ld} \) and \( Q = (\text{RV} \times R)/0.06 \) or 8

4. \( \text{LdF} = \text{AO}/\text{OF} \)

4a. \( \text{LdF} = 3.8 \, \text{AO}/\text{OF} \)

5. \( \text{AO} = \text{DO}_{\text{in}} - \text{DO}_{\text{out}} \quad \text{DO}_{\text{out}} = \text{DO}_{\text{min}} \)

6. \( \text{TAN} \, g = \text{LdF} \times \text{TANF} \)
Equations Used

7. \[ TANC = \left( AO \times TANF \right) / \left( 1.44 \times OF \right) \]

7a. \[ TANC = \left( 3.8 \times AO \times TANF \right) / \left( 5.45 \times OF \right) \]

8. \[ UAC = \left( TANC \times \% \ UA \right) / 100 \]

9. \[ MAO = \left( MUA \right) / \left( UAC \right) \]

10. \[ MAO = \left( MUA \times OF \times 1.44 \times 100 \right) / \left( TANF \times \% \ UA \right) \]

11. \[ MCO_2 = MAO \times 1.4 \]

Recall: \[ MAO = \frac{0.025}{0.001} = 25 \]
Equations Used

This is for: 1) % UA = 1.0 and

2) 0.1 mg/l TAN per AO

Other MAO Values: 25 / % UA

\[ 0.0125 \times 1000 = 12.5 \text{and} \]
\[ 0.035 \times 1000 = 35.0 \text{ etc.} \]

\[ \text{MAO} = \frac{\text{MUA} \times 1000}{\% \text{UA}} \]

See Table – MAO Values
Energy In; Lost; Used; Stored.

Feed -> Fish

Fish -> Ingest. G.E.

Ingest. G.E. -> Digest

Digest -> Digest Energy

Digest Energy -> Food Utilization

Food Utilization -> Waste Feed

Waste Feed

$1000 \ g \ @ \ 10\% \ H_2O = 900 \ g$

$80\% \ H_2O$

3-5% 30-50 g

25% 250 g

$NH_3 = 3\%$ (30g)

Fecal Matter

Excret. Products

F-1
Flow diagram of Fish Bioenergetics modified after Ernst (2000)
<table>
<thead>
<tr>
<th>pH</th>
<th>Water Temperature</th>
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<tr>
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<td>0.01</td>
</tr>
<tr>
<td>6.2</td>
<td>0.02</td>
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<tr>
<td>6.4</td>
<td>0.03</td>
</tr>
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<td>0.05</td>
</tr>
<tr>
<td>6.8</td>
<td>0.08</td>
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<tr>
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<td>0.13</td>
</tr>
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<td>7.2</td>
<td>0.20</td>
</tr>
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<td>0.32</td>
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<td>1.24</td>
</tr>
<tr>
<td>8.2</td>
<td>1.96</td>
</tr>
</tbody>
</table>


Highly Recommended!
Table 2  MAO values for six MUA values, based on UA=1%; OF=250; (114); TANF=30; (13.6) and OF=350 (159); OF=450 (205)

<table>
<thead>
<tr>
<th>OF</th>
<th>0.015</th>
<th>0.020</th>
<th>0.025</th>
<th>0.030</th>
<th>0.035</th>
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<td>24</td>
<td>30</td>
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<td>32</td>
<td>43</td>
<td>54</td>
<td>65</td>
<td>76</td>
</tr>
</tbody>
</table>

- MUA -(mg/l)

Must select a number for:

MUA

OF

TANF

(% UA – pH and Temp)
Table 3  Approximate Values for free CO₂  
(In mg/l)  

<table>
<thead>
<tr>
<th>pH</th>
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<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
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<tbody>
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<td>92</td>
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<tr>
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</tr>
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<td>7</td>
<td>9</td>
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<tr>
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<td>.75</td>
<td>1.5</td>
<td>2.3</td>
<td>3.0</td>
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</tbody>
</table>

For practical purposes, CO₂ concentration are negligible above pH 8.4.
Problem Solving Unit I

1. What will be the rearing density in kg/m³; lb/ft³?
   a) OF = 250 gO₂/kg feed 114 lb
   b) AO = 5.0 mg/l
   c) % BW = 2.0
   d) R = 4.0

2. Determine the maximum possible mg/l DO (MAO) under the following conditions:
   a) TANC = 0.1 mg/l per AO
   b) % UA = 0.80
   c) MAUA = 0.020 mg/l
1. **Answer:**

\[
L_d = \frac{100 \times AO}{8F \times 70BW} = \frac{100 \times 5.0}{250 \times 2.0} = 1.0 \text{ kg/lpm}
\]

\[
L_d = \frac{3.8 \times 100 \times AO}{114 \times 2.0} = 8.33 \text{ lb/gpm}
\]

\[
D = \frac{L_d \times R}{0.06} = \frac{1.0 \times 4.0}{0.06} = 66.7 \text{ kg/m}^3
\]

\[
D = \frac{8.33 \times 4}{8} = 4.16 \text{ lb/ft}^3
\]

**Conversions:**

- \(1.0 \text{ lb/ft}^3 = 16 \text{ kg/m}^3\)
- \(1.0 \text{ kg/lpm} = 8.33 \text{ lb/gpm}\)
- \(1.0 \text{ gal} = 3.785 \text{ l and: } 1.0 \text{ l} = 1.057 \text{ quart}\)
- \(1.0 \text{ lpm} = 0.264 \text{ gpm}\)
- \(1.0 \text{ gpm} = 3.785 \text{ lpm}\)
2. **Answer:**

2) \[ MAO = \frac{MU_A \times OF \times 1.44 \times 100}{\tan F \times \% UA} \]

6) \[ MAO = \frac{0.020 \times 200 \times 1.44 \times 100}{36 \times 0.80} = 20.0 \text{ mg/l} \]

**For other OF values:**

- \( OF = 250 \) \( MAO = 25 \)
- \( OF = 300 \) \( MAO = 30 \)
- \( OF = 500 \) \( MAO = 50 \)
- etc.