North Central/Eastern Kentucky Water and Wastewater Operators Association
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# The BOD? Test
# Session 1

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# Agenda
# The BOD? Test – Organic Loading
## The Carbon Source to Drive Nitrogen and Phosphorus Reactions

- Some Basics / Terms
- Historical Perspective
- Problems with $BOD_5$ and NPDES Permitting
  - Defining Decay Rates
  - Decay Rates and Stream Modeling
  - Cheese House NPDES Permitting
- Treatability
  - Terre Haute, Indiana
  - Splenda @ Terre Haute, Indiana
  - Miller Beer, Trenton, Ohio

# Biochemical Oxygen Demand



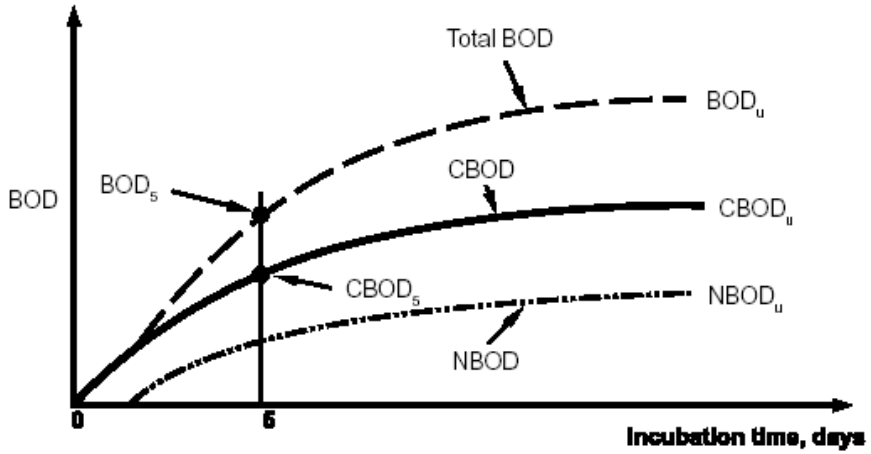
# The $BOD_?$ Test

- $BOD_5$, $CBOD_5$, $BOD_{st}$, $BOD_{20}$, $BOD_u$, $SBOD_5$, …..
  - 5 day BOD (includes nitrification oxygen demand)

**Figure 2-7**

Relationship between the carbonaceous, nitrogenous, and total BOD.

*Source: Thomann and Mueller, 1987.*




  - $CBOD_5$: Trichloro-Methyl Pyridine (TCMP) is added to suppress nitrification – in theory measuring only organic oxygen demand. Since ammonia can be measured directly, measuring this oxygen demand directly can be added to the organic demand.

# The $BOD_?$ Test

- $BOD_5$, $CBOD_5$, $BOD_{st}$, $BOD_{20}$, $BOD_u$, $SBOD_5$, …..
  - Short Term BOD. Approved for NPDES reporting for Arthur Technology respirometry in a few states. Challenge, BioScience and other firms – all automated respirometers have various "methodologies" for estimating or predicting 5 day BOD results.

  - The 20 day BOD test is typically used by EPA for modeling. The 20 day test is used to estimate the ultimate oxygen demand. Typically, a factor is used for municipal wastewater while industrial wastewater has some testing conducted and ultimate oxygen demand is estimated from the 20 day BOD result and applied as a ratio to five (5) day CBOD.

# The $BOD_?$ Test

- $BOD_5$, $CBOD_5$, $BOD_{st}$, $BOD_{20}$, $BOD_u$, $SBOD_5$, …..

  - Ultimate BOD ($BOD_u$). Conducted with a diluted wastewater to allow oxygen consumption until the sample stabilizes – as opposed to stopping the test after an elapsed time – 5 days or 20 days.

  - Soluble $BOD_5$: Settled or filtered to take out particulate demand. Typically, the higher the percentage of the sample that is characterized as soluble, the higher the decay rate. The increased portion of BOD due to particulate loading, the lower the decay rate.

# Historical Perspective

- 1854 – Dr. Snow was first to link cholera epidemic to drinking water intakes downstream of a London, England wastewater discharge – 14,600 Londoners died of cholera.
- The death rate for those downstream of a wastewater discharge was 8.5 times that of people using water upstream.
- Year of the *Big Stink*: 1858 – thousands had to leave London and Parliament had to use curtains soaked in chloride of lime (Bleaching Powder) to stay in session. Polluting wastewater discharges had finally reached the point where the government began regulating discharges.

# Historical Perspective

- Treatment processes were proposed without an accepted criterion or standard of practice for measuring performance. There was a blossoming of technology and public attention with the onset of regulations.
- The British Royal Commission (1898-1915) established the 5 day BOD test as a step towards standards. The British Royal Commission was set up as an arbitrator between local government boards who wanted loans and to build artificial filters (treatment) versus land application of wastewater – the accepted no risk option.
- A standard of performance was developed to be judge acceptable technologies and make those technologies accountable for performance.

# Historical Perspective

- The British Royal Commission did not recommend treatment but focused on the methods of measuring performance.
- It was known that sewage used up oxygen dissolved in waterways when it decomposed and so it was decided that the amount of dissolved oxygen absorbed by a particular effluent in 5 days at 65° Fahrenheit gave the best single test index of the polluting potential of that effluent. English streams did not have a flow duration longer than 5 days before reaching the sea.
- The same $BOD_5$ test, as it became known, is used today and the 20:30 standard of $BOD_5$ and suspended solids concentration was recommended by the Commission and the basis of the early 30:30 standards of the U.S. NPDES System – 1972.

# Historical Perspective

- In 1912 the Royal Commission on Sewage Disposal took the view that the five day Biochemical Oxygen Demand (BOD) test was the most reliable chemical index of river water quality. The $BOD_5$ figures recommended by the committee became known as the "Royal Commission river classification".
- Note that the BOD test was not introduced to measure the strength of raw wastewater, rather the effect upon the receiving waters. Interestingly, the 5-day duration for BOD determination has no theoretical grounding but is based on historical convention (Tchobanoglous & Schroeder, 1985).
- $BOD_5$ is pushed further outside of the intended purpose of the test when raw wastewater strength and treatability are assumed from the test results.

# Using the Test for NDPES Permitting

- The Glucose/Glutamic acid (GGA) BOD standardization which uses the 300 mg/L biodegradable mixed primary standard, should have an average $BOD_5$ of 198 mg/L with a standard deviation of not greater than 30.5 $mgL^{-1}$ ($\pm$15.4%).
- Variation is present with a known standard and stable rate of decay. Errors inherent in the procedure (including seed addition) make accuracy an inherent problem with the test.
- One of the most significant problems in applying the test and "measuring" the treatability of raw wastewater is the difference in decay rates.

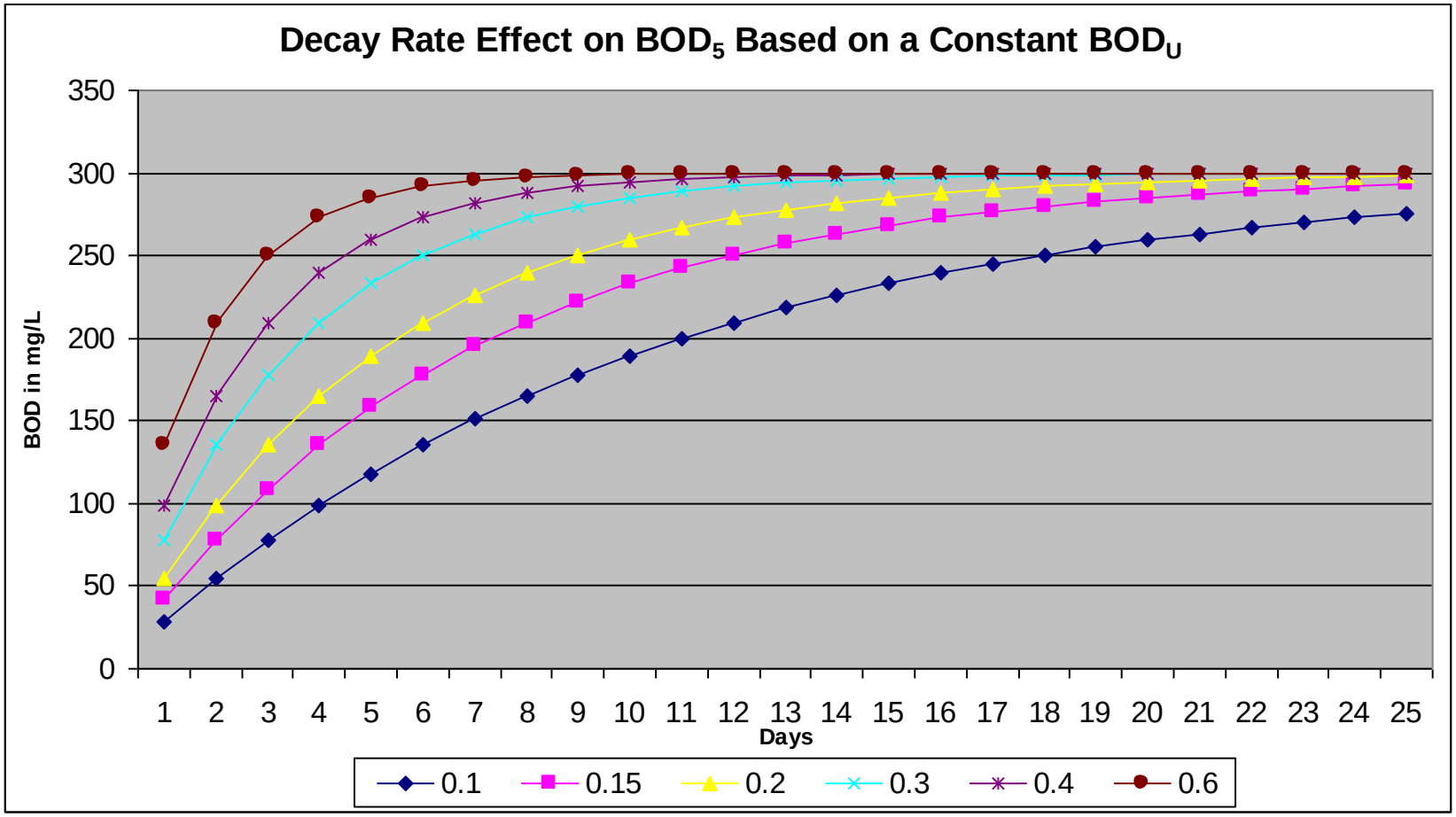
# Using the Test for NDPES Permitting

| Varying $CBOD_5$ values for samples of $BOD_u$ 300 $mg/L^{-1}$ | | | |
|---|---|---|---|
| kBOD $d^{-1}$ | $CBOD_5$, $mg/L^{-1}$ | % of BODu | $BOD_u/BOD_5$ |
| 0.10 | 118 | 39 | 2.54 |
| 0.15 | 158 | 53 | 1.90 |
| 0.20 | 190 | 63 | 1.58 |
| 0.30 | 233 | 78 | 1.29 |
| 0.40 | 259 | 87 | 1.16 |
| 0.60 | 285 | 95 | 1.05 |

- Ohio EPA, for example, uses default values for municipal wastewater if specific testing is not available:
  1. 1.5 - $BOD_u/BOD_5$ ratio for Primary Effluent Discharge
  2. 2.0 - $BOD_u/BOD_5$ ratio for Secondary Effluent Discharge
  3. 2.3 - $BOD_u/BOD_5$ ratio for “Advanced” Effluent Discharge

# Using the Test for NDPES Permitting

## Decay Rate Treatability Curves @ 300 mg/L $BOD_u$



# Examples of BODu/BOD5 Ratios for Modeling

- BODu/BOD5 ratio: 10.34 to 1.8 in a Maine Watershed – Aroostook River Modeling Report – 2004.
- Saint George modeling used a default of 7.8 to 1 ($BOD_u$ to $BOD_5$): Maine DEP.
- Savannah River – 3.91 was a combined ratio from 10 dischargers. Applied by the Georgia Port Authority.
- Georgia DNR – Satilla River Basin – $BOD_u$:$BOD_5$ is 4.0.
- $BOD_5$ had been thought of as 80% of $BOD_u$, as data became available – the expected value has been lowered to 60% of $BOD_u$. Today, it is typical to be considered less than 60% when considering wastewater constituents.

# Case Study for Food Grade Discharge

- Ohio EPA was using a $BOD_u/BOD_5$ Ratio of 7.2 in evaluating the Holmes Cheese discharge. The 7.2 factor was applied in the QUAL2E Stream modeling software.
- Ohio EPA had conducted 20 day BOD testing and estimated an ultimate BOD ratio of 7.2 and applied that ratio to the model.
- Based on treatability testing that was conducted to modify the plant operation and design; the decay rate appeared too low (or ratio too high) for a food grade wastewater.

# Case Study for Food Grade Discharge

- The treatability signature using an Automated Large Volume Respirometer showed treatment of a $BOD_5$ of 2,500 was less than eight (8) hours with a MLSS of 4,500 mg/L.
- A procedure was developed and reviewed with OEPA. It was agreed to conduct ultimate BOD testing on four (4) samples. The ratio of $BOD_u/BOD_5$ was actually 3.7.
- The QUAL2E program created a stream model simulation of dissolved based on ultimate BOD. An ultimate BOD of 111 mg/L was used based on a ratio of 3.7.

# Case Study for Food Grade Discharge

- A $BOD_u/BOD_5$ ratio of 3.7 resulted in an NPDES permit limit of 30 mg/L with a $CBOD_5$ value of 25 mg/L.
- The $BOD_u/BOD_5$ ratio of 7.2 would have resulted in an NPDES limit of 15 mg/L $BOD_5$ with a $CBOD_5$ of 12 mg/L (originally proposed for NPDES limits).
- The same ultimate BOD was applied in the modeling, but different decay rates result in different NPDES limits.
- As the decay rate increases, the overall biodegradability of the wastewater increases (the rate of oxidation) increases. More oxygen is consumed in a shorter time resulting in the $BOD_5$ representing a larger fraction of the $BOD_u$.

# Case Study for Food Grade Discharge

- As slowly biodegradable and/or particulate BOD portion of the sample increases, the rate of decay decreases and the $CBOD_5$ represents a smaller portion of the ultimate $BOD_u$.
- The ratio of $BOD_u/BOD_5$ is applied to dissolved oxygen simulations for carbonaceous or organic loading and the NPDES Permit values are determined from the ratio.
- If the decay rate of the $BOD_5$ test is higher than the default values used by OEPA (or higher than the values determined by OEPA if industrial or special waste), the NPDES permit values can be increased.

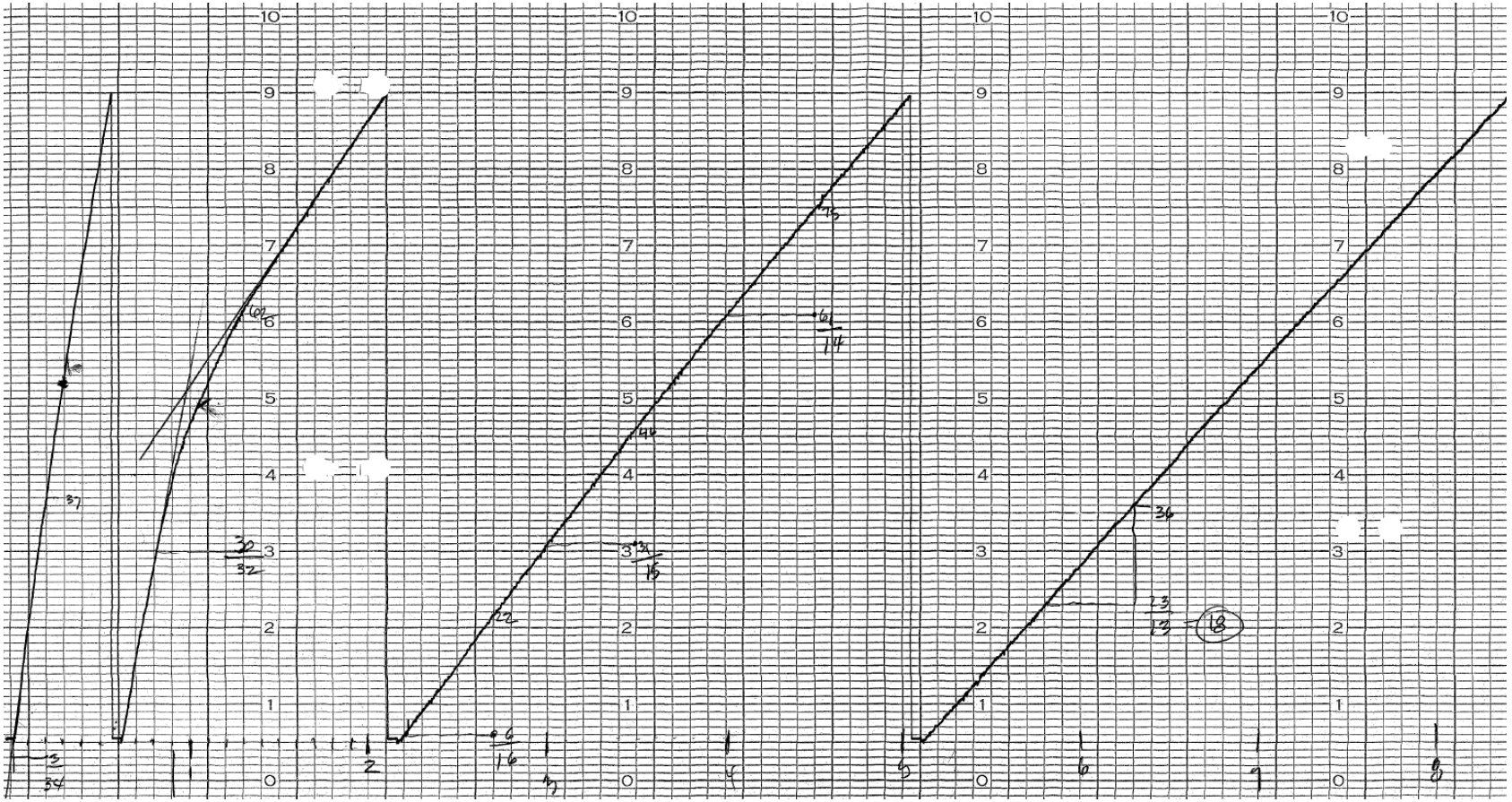
# Oxygen Uptake Rates: BOD5 versus Respirometery

- BOD testing is a diluted sample that operates at a very slow rate – days. The oxygen uptake rate is not indicative of plant treatment rates.
- Sample dilution further introduces error with both a diluted biological population and diluted sample strength. The respiration is reduced by the limited population and waste strength to allow the oxygen contained in the BOD bottle to supply the total oxygen demand through 5 days.
- No mixing and temperature is held @ 20$^{o}$C
- Respiration testing is done at a rate that is determined by actual waste strength and plant MLSS population and can be conducted at the actual operating temperature.

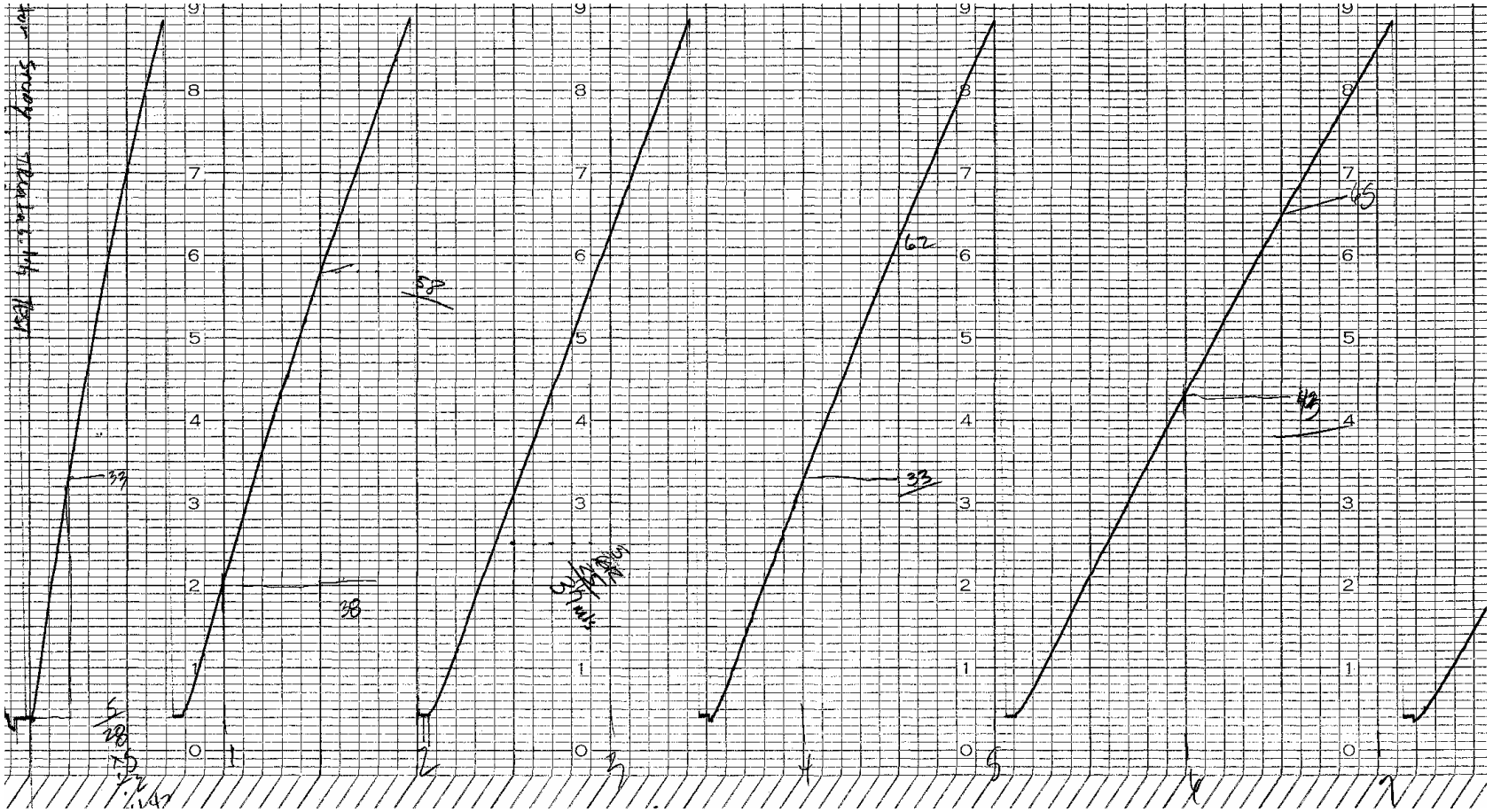
# Treatability versus $BOD_5$

- Three (3) respiration test samples for approximately 7 hours of oxygen demand testing:
    1. City of Terre Haute, Indiana. The initial chart shows respiration at a MLSS concentration of ~2,700 mg/L. Flow rates at ~ 11 MGD only domestic wastewater. $BOD_5$ concentrations ~ 127 mg/L (primary effluent).
    2. City of Terre Haute, Indiana RAS blended at a MLSS concentration of ~3,100 mg/L treated an industrial wastewater (discharge from Splenda Processing) at a $BOD_5$ of 1,450 mg/L.
    3. The Miller Brewery process wastewater is treated at a MLSS concentration of ~ 10,000 mg/L (over 40% of the MLSS is diatomaceous earth). $BOD_5$ testing of ~ 3,100 mg/L $BOD_5$.

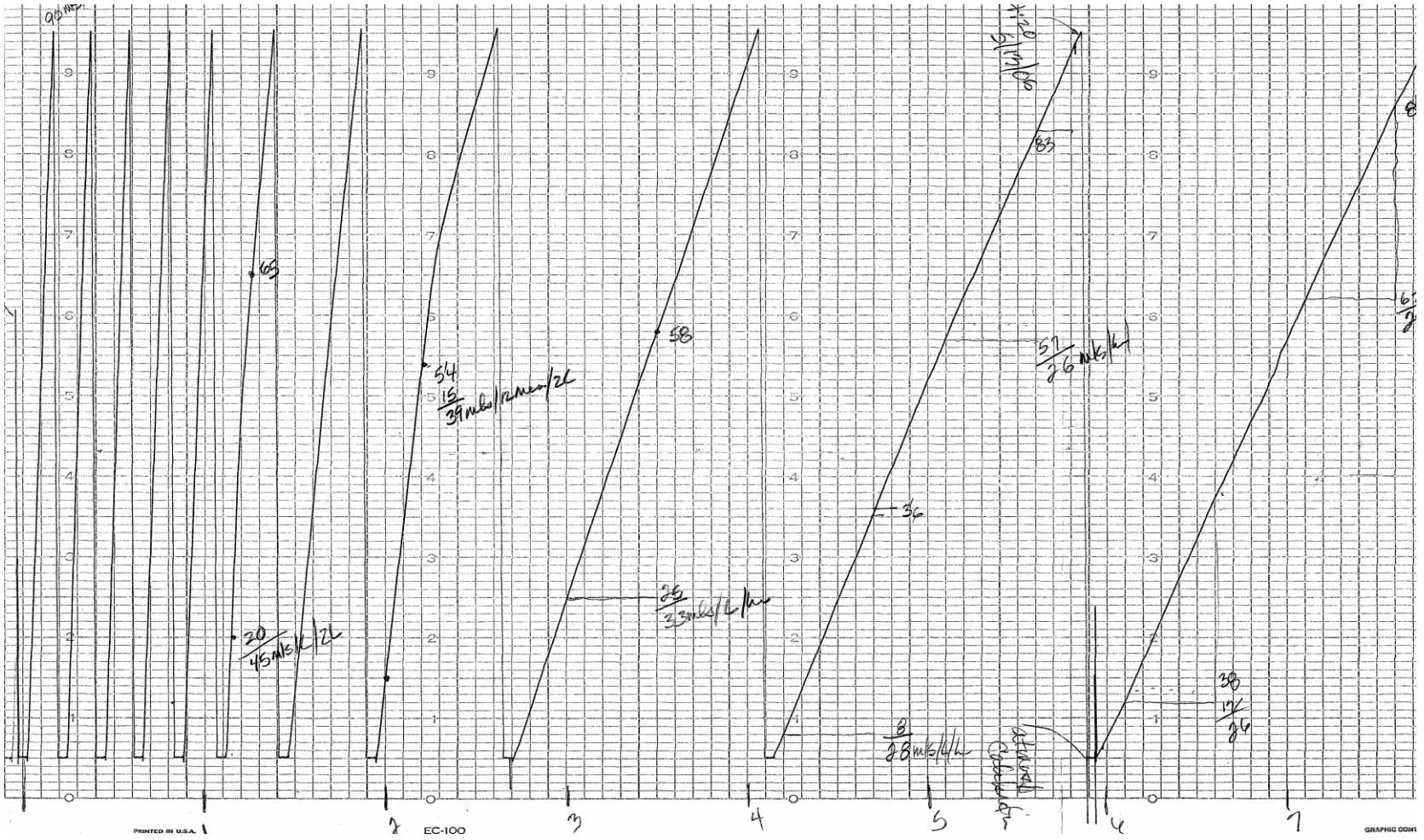
# Terre Haute, IN:  Domestic Only



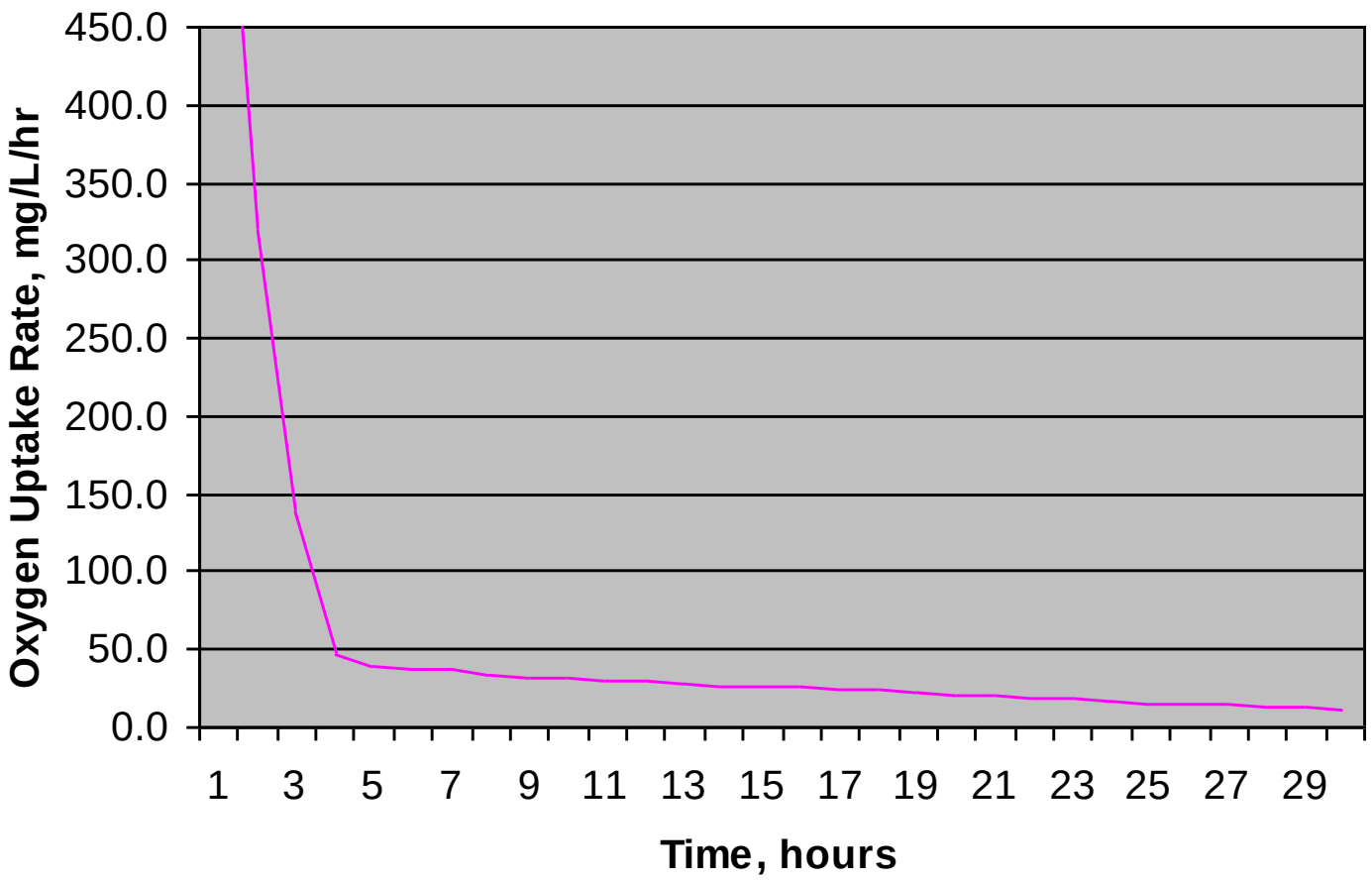
# Terre Haute, IN: Splenda Process Discharge



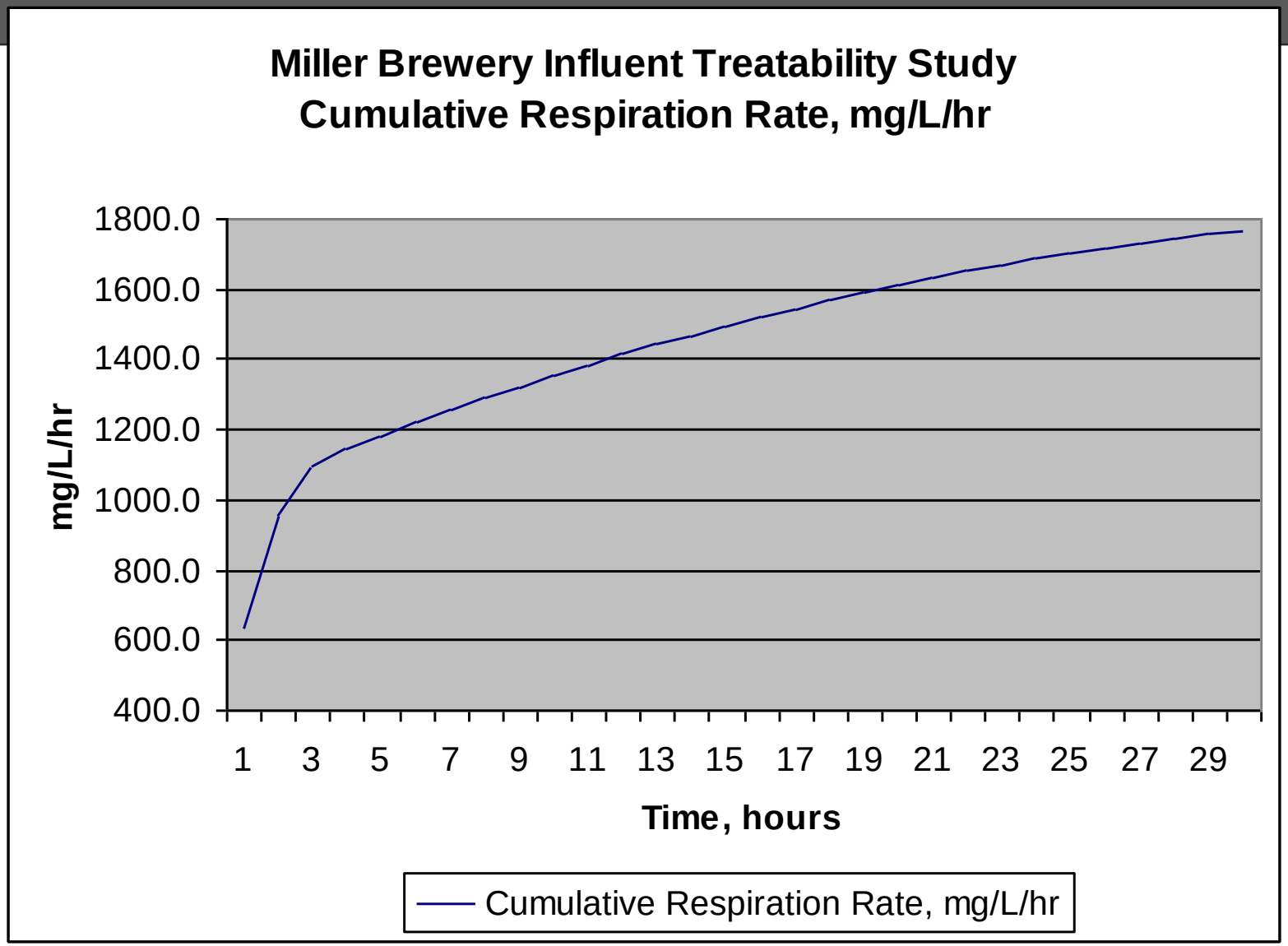
# Miller Brewery, Trenton, OH: Process Discharge



# Miller Brewery Influent Respirometry



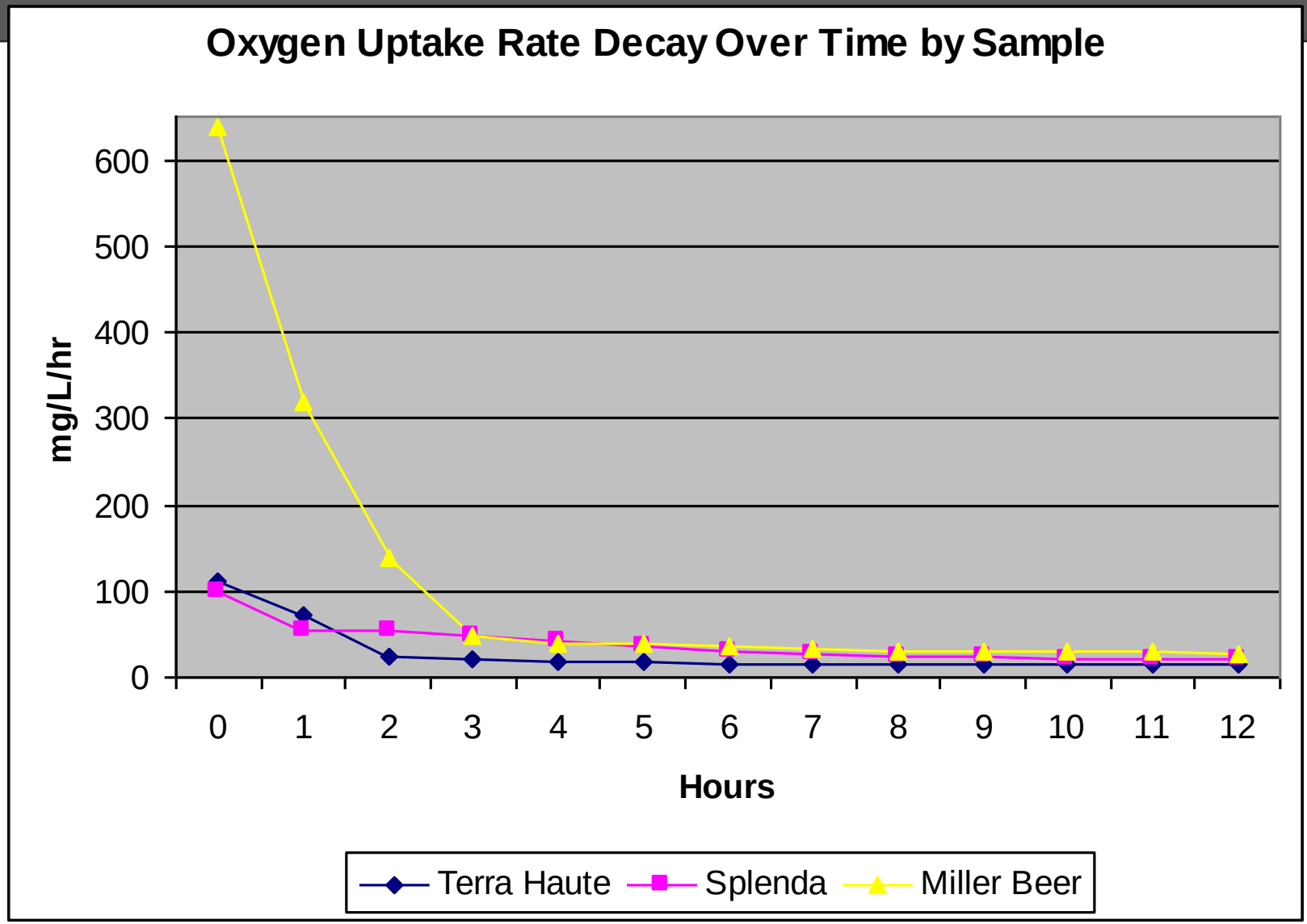
# Miller Brewery Influent Respirometry



# Oxygen Uptake Rate Decay

| Oxygen Demand and Decay Rate Comparisons | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Initial Rate | 1 Hour | 2 hour | 4 hour | 6 hours | 12 hour | Treatment |
| | mg/L/hr | mg/L/hr | mg/L/hr | mg/L/hr | mg/L/hr | mg/L/hr | Time, hrs. |
| Terre Haute | 110 | 72 | 23 | 18 | 16 | 16 | 1.6 |
| Splenda | 99 | 54 | 53 | 41 | 31 | 20 | 8.5 |
| Miller Beer | 639 | 319 | 139 | 40 | 37 | 28 | 2.5 |

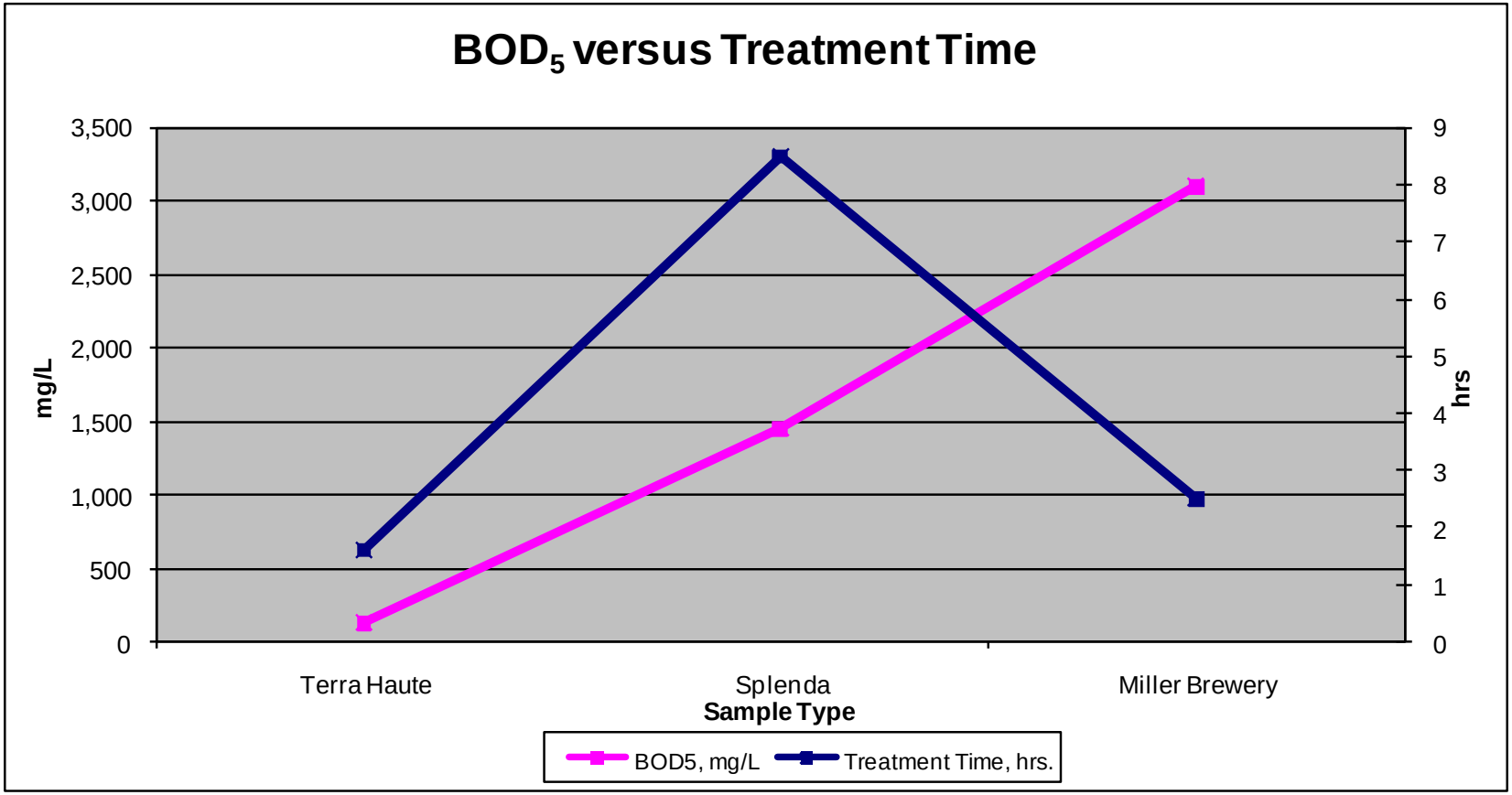
# Oxygen Uptake Rate Decay



# Treatability versus $BOD_5$

- $TBOD_5$ analysis of the influent can be misleading:
  1. Terre Haute Wastewater - $TBOD_5$ 127 mg/L (primary effluent) with 1.6 hours treatment time
  2. Splenda Process Wastewater - $TBOD_5$ 1,450 mg/L with 8.5 hours treatment time. At approximately the same MLSS concentration, 10 times the wastewater strength resulted in 5 times the treatment time.
  3. Miller Brewery wastewater – $TBOD_5$ 3,100 mg/L with 2.5 hours treatment time. At 24 times the wastewater strength, the treatment time only increased 156% or 1.6 times.

# Treatment Time versus $BOD_5$



# Questions????