

Headspace BOD (HBOD): A Rapid and Practical Alternative to the Conventional BOD Test

Bruce Logan, Booki Min, Dave Kohler

The Pennsylvania State University

Jason Brown

University Area Joint Authority WWTP

(email: blogan@psu.edu; www.engr.psu.edu/ce/enve/logan.htm)

Biochemical Oxygen Demand (BOD) test

- Developed in 1870
- Dilution test to protect river water quality
- The 5-day time arbitrarily chosen (based on the time for the Thames River in England to flow from London to the ocean)
- Large imprecision ($\pm 20\%$)
- Accuracy impossible to verify

Why replace a BOD test ?

- Labor intensive
- Requires 5 days to obtain results
- Lacks accuracy, precision and automation present in most modern laboratory procedures
- Does not takes advantages of advances in laboratory equipment since 1900 (except for using a DO probe)



Why replace a BOD test?... continued

- The FUTURE is online respirometry...
- But... online tests don't always match BOD values-- because they are different tests!
- But... many WWTPs cannot afford expensive online systems
- And... you can't have online respirometers everywhere in the plant

The HBOD test can be used today-- it is easy, fast and compares well to BOD₅ and bCOD tests

Contents

- **Introduction** : Review HBOD test procedure
- **Objectives** : Use the HBOD probe, HBOD tests at 2 wastewater treatment plants
- **Method** : How to run an HBOD test
- **Results**
- **Conclusions**

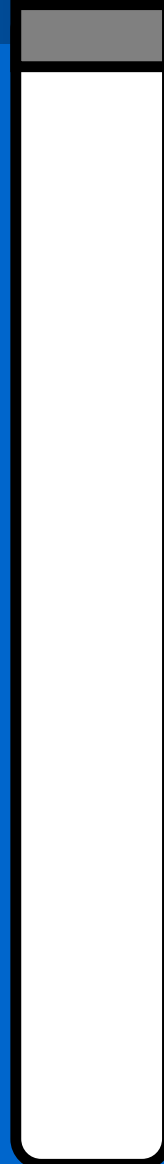
INTRODUCTION



- Respirometric BOD (RBOD) test procedures are now included in *Standard Methods* as a proposed method.
- RBOD tests are routinely used in Europe.
- The Headspace BOD (HBOD) test was developed in 1993 (Logan and Wagenseller; *Water Env. Res.*)
- HBOD – a respirometric test (non-dilution RBOD).
- The HBOD test reaches the same value as a BOD_5 test in just 2 or 3 days.

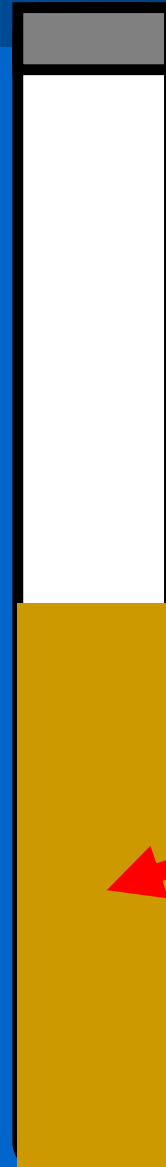
HBOD Test:

HBOD
Tube



HBOD Test:

HBOD
Tube



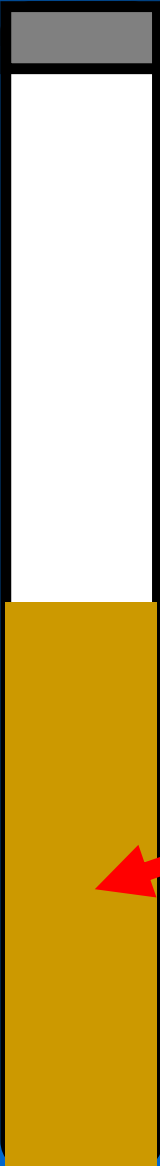
14 ml
(WW)

HBOD Test:

HBOD
Tube

WW: 8 mg/L of DO

14 ml
(WW)

A vertical diagram of an HBOD tube. The tube is divided into two sections: a white upper section and a brown lower section. A red arrow points from the text '14 ml (WW)' to the brown section. The tube is capped with a grey stopper at the top.

HBOD Test:

**HBOD
Tube**

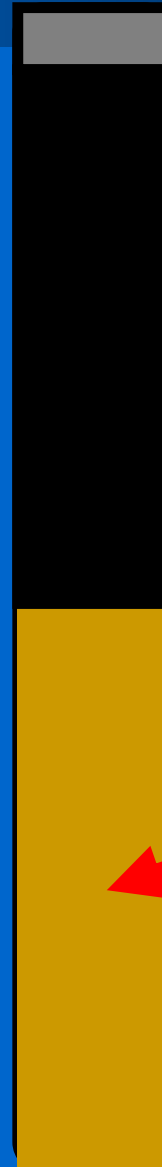
Start: 8 mg/L of DO

Finish: 1 mg/L of DO

**Maximum
HBOD=7 mg/L**

If no air is used
in the HBOD
test, it is just like
a BOD test

**14 ml
(WW)**



HBOD Test:

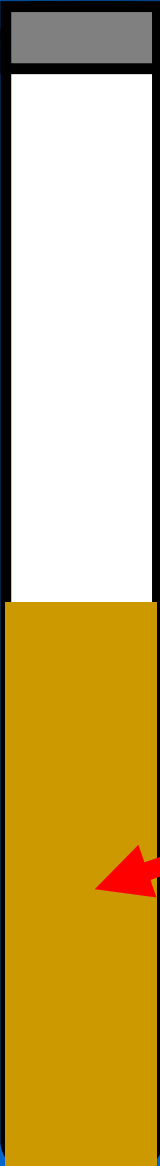
HBOD Tube

Air serves as a fixed
“reservoir of DO”

Air O₂ concentration
changes with DO

WW: 8 mg/L of DO

14 ml
(WW)

A vertical tube representing an HBOD tube. The top portion is white, representing air, and the bottom portion is brown, representing wastewater (WW). A red arrow points from the text '14 ml (WW)' to the brown section of the tube.

HBOD Test:

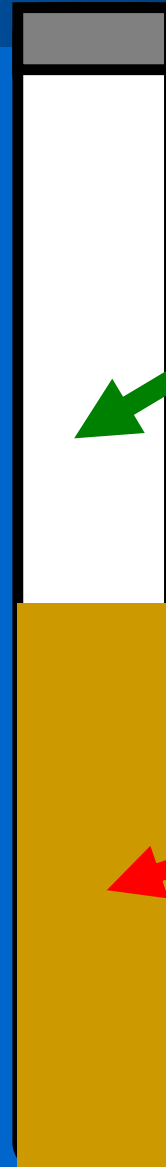
HBOD
Tube

Air: 400 mg/L of “DO”

WW: 8 mg/L of DO

14 ml
(air)

14 ml
(WW)



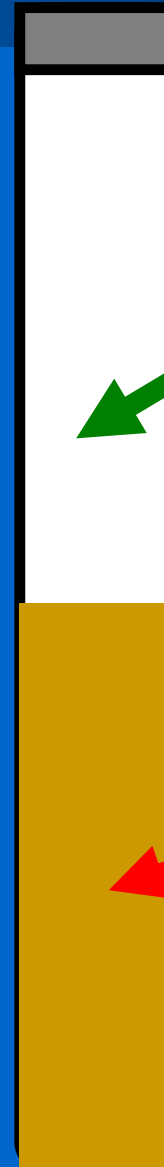
HBOD Test: **START**

Air: 400 mg/L of “DO”

WW: 8 mg/L of DO

HBOD=0 mg/L

HBOD
Tube



14 ml
(air)

14 ml
(WW)

HBOD Test: FINISH

HBOD
Tube

WW: 4 mg/L of DO

HBOD=204 mg/L

O₂ in WW is
now reduced
to $\frac{1}{2}$ original
value



HBOD Test: **FINISH**

Air: 200 mg/L of “DO”

WW: 4 mg/L of DO

HBOD=204 mg/L

HBOD
Tube



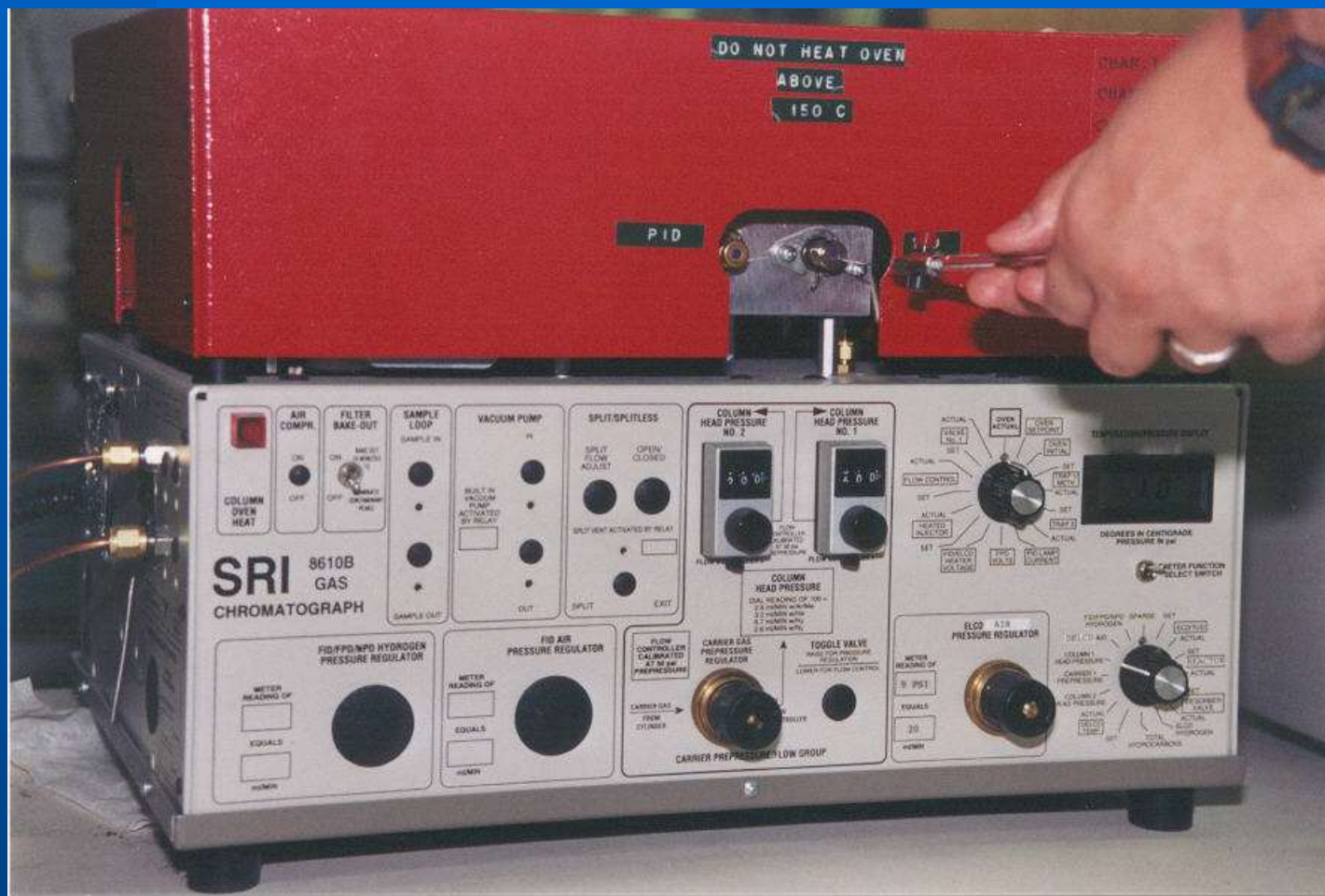
O₂ is air
must also be
 $\frac{1}{2}$ of its
starting
value

O₂ in WW is
now reduced
to $\frac{1}{2}$ original
value

Limitations of the HBOD Test?

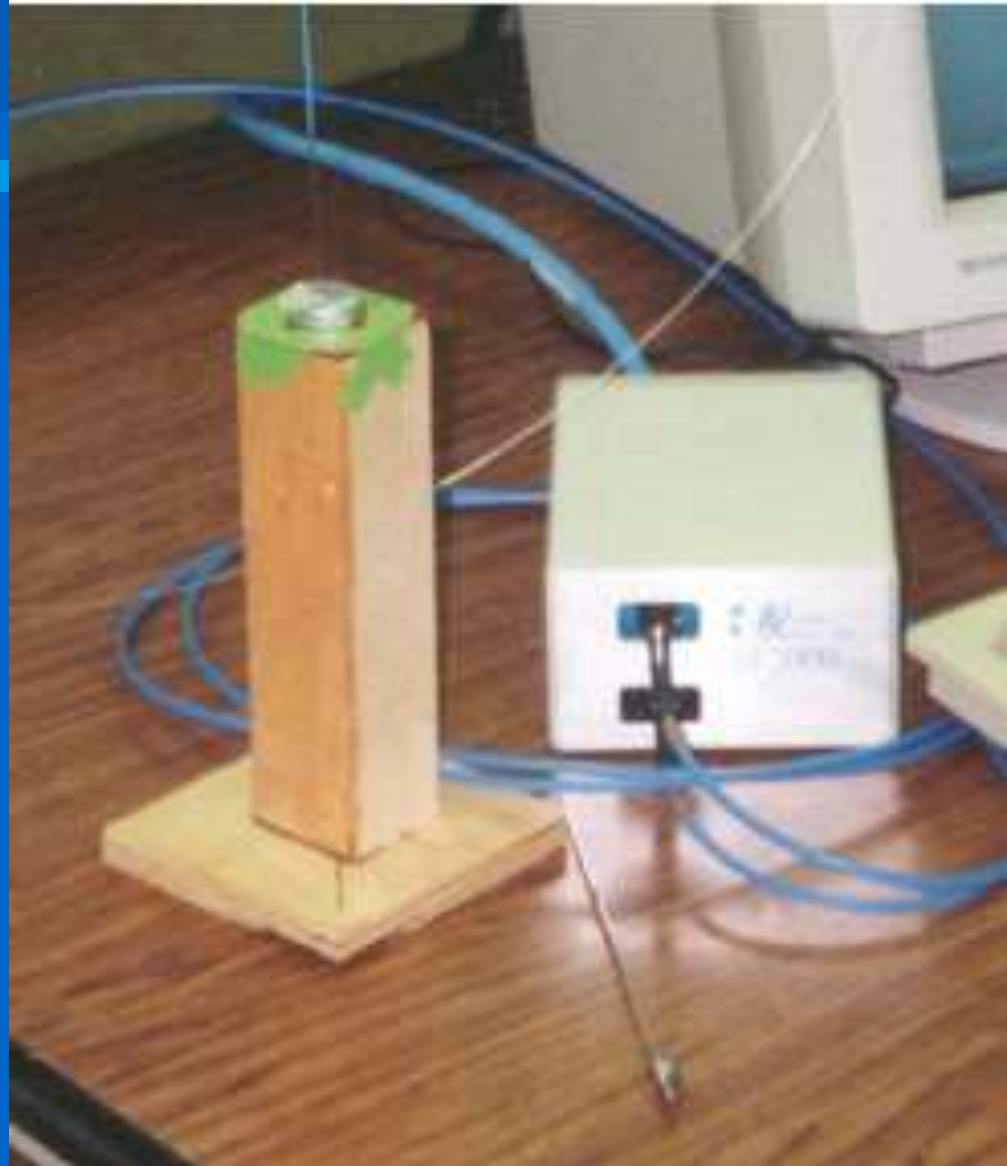
- **Yes:** Needed a gas chromatograph to measure oxygen in the headspace (GC-HBOD test)
- **No!** Have modified procedures to use a new HBOD probe to provide instantaneous oxygen concentrations.

GC: cost about \$6,000

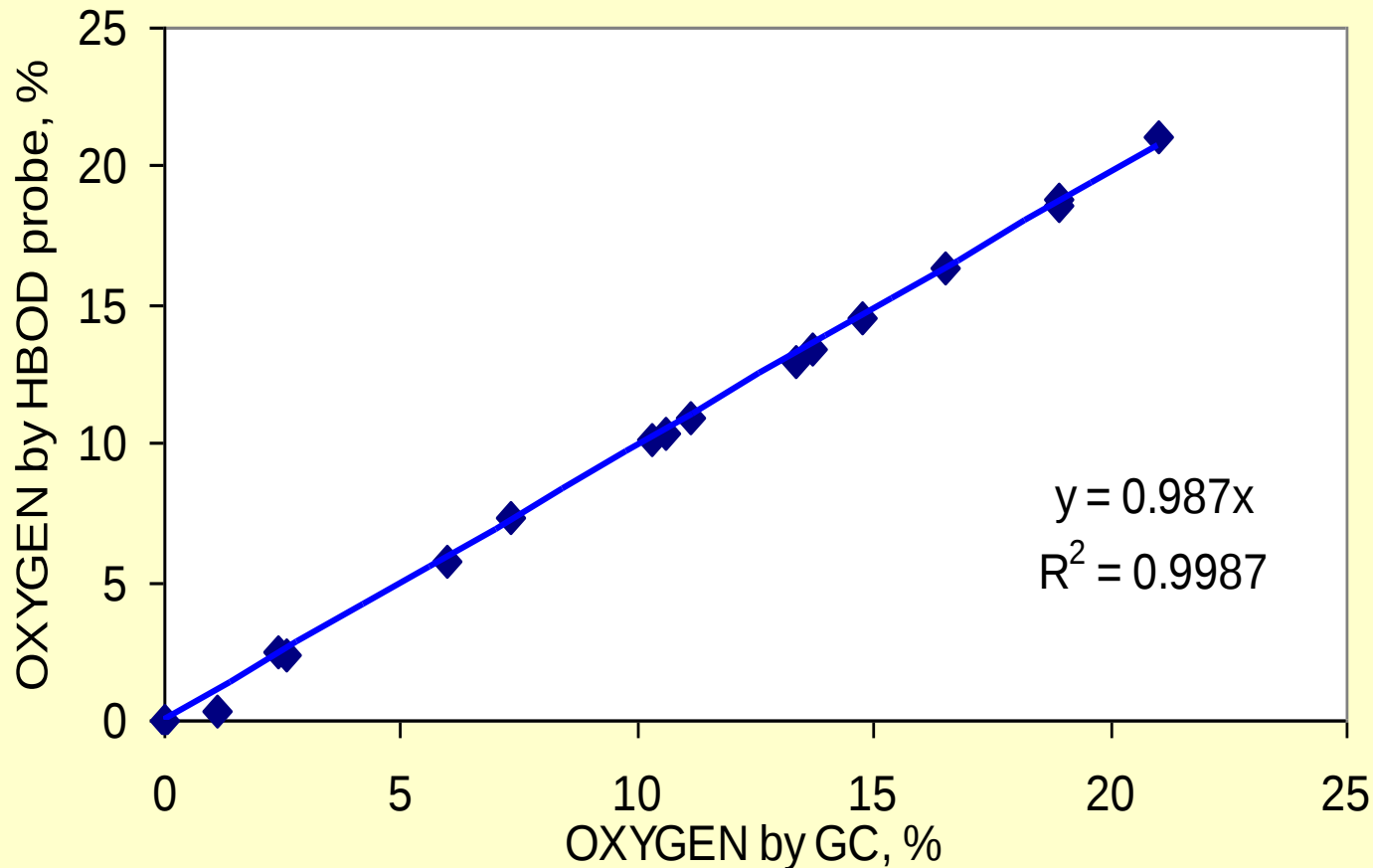


HBOD Probe: \$1,000

System: \$4,000)



The HBOD probe and GC provide identical results.



OBJECTIVES

- Demonstrate that the **HBOD probe** can be used to measure the concentration of oxygen in HBOD tubes.
- Show that the HBOD test provides more **precise estimates** of biochemical oxygen demand than the BOD test.
- Present data that show the oxygen demand is exerted faster in an HBOD test (2 or 3 days) versus the 5-day **BOD** test

METHODS:

How to run an HBOD test...

1. **Dispense** the wastewater into the HBOD tube (with using 5 mL digital dispensette) and seal this tube using a rubber stopper and an aluminum crimp top.
2. **Incubate** tubes in the dark on a shaker table
3. **Measure** the concentration of oxygen in headspace in tubes with using an HBOD probe on a completion day of incubation
4. **Calculate** the HBOD values using an HBOD equation.

STEP 1: Dispense



A digital dispensette is used to put wastewater in HBOD tubes

Only 2 sample volumes cover a wide range of HBOD values

Sample Volume (mL) in 28 mL HBOD tube	HBOD Range (mg/L)
23	7 – 50
10	51 – 364

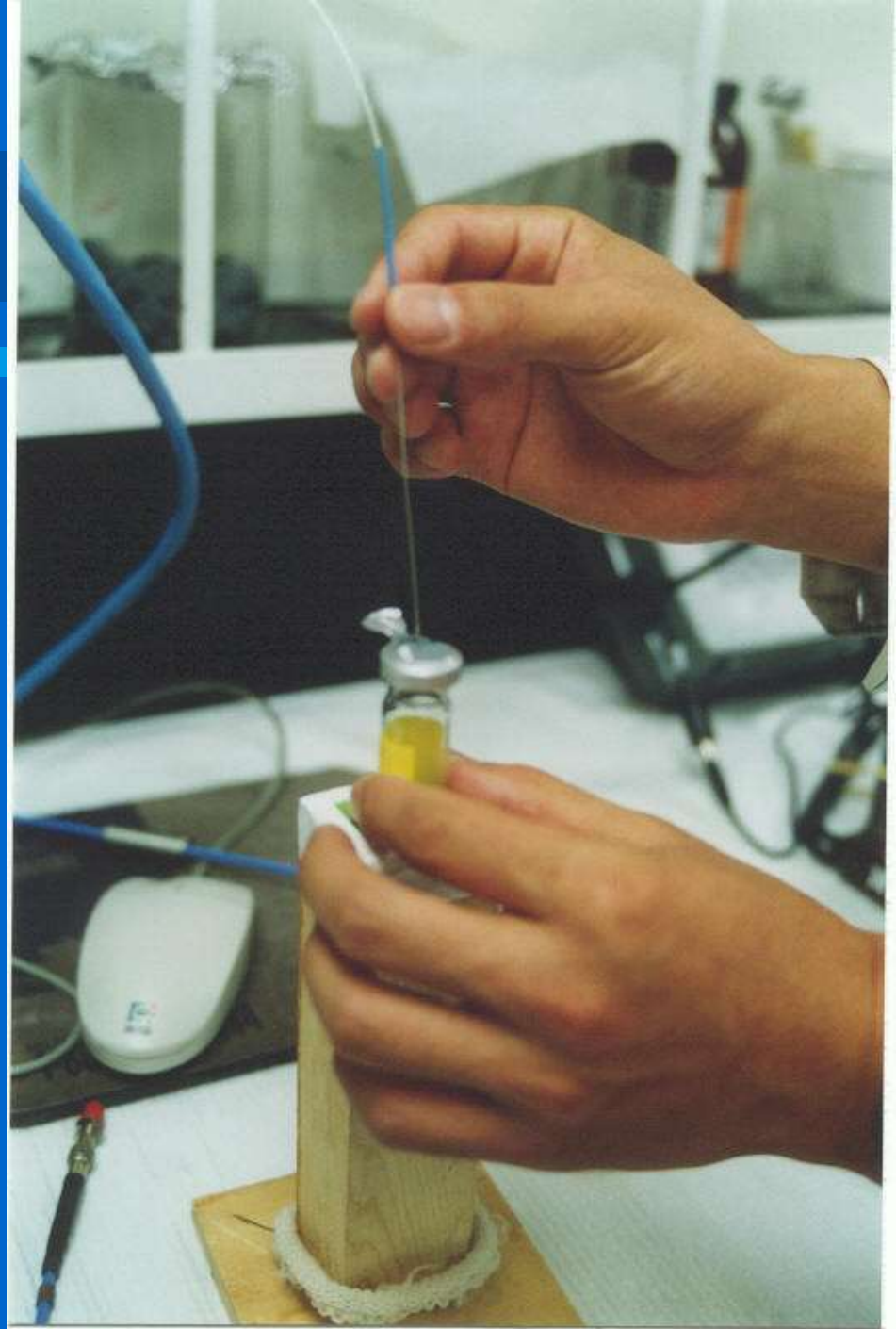
STEP 2 : Incubate



A box and a shaker are used for incubation

Step 3 : Measure

The HBOD probe
is inserted into
the tube...





... and the O_2 concentration read from the computer in just a few seconds.

STEP 4: Calculate

$$HBOD_n = (P_o - 0.01p_{o,w} r_o) \left(1 - \frac{O_n}{O_{0,n}} \right) \left[\frac{107.2}{(T_o + 273.15)} \left(\frac{V_T}{V_l} - 1 \right) + \frac{DO}{760 - p_{o,w}} \right]$$

HBOD_n = Headspace BOD on day n [mg/L].

O_{0,n} & O_n = Oxygen in sample on day 0 and n analyzed on day n [%].

V_T & V_l = Volumes of tube. T=total, l= liquid used in tube [mL].

DO = Saturation dissolved oxygen concentration in water at 760 mmHg [mg/L] (from table)

Air data: **p_{o,w}** = water vapor pressure (from table)

r = relative humidity; **T_o** = air temperature (From monitor)

Laboratory data is obtained from a digital barometer



HBOD calculations can be done using an Excel Spreadsheet

HBOD Calculation Sheet

Barometer information

Temperature of air on day 0 from temperature gauge	To (°C)	23
Air Pressure on day 0 recorded from barometer	Po (in Hg)	28.82
Relative humidity of lab air on day 0 read from relative humidity gauge	ro (%)	26

Tabulated information

Vapor pressure of water in air on day 0 (From sheet VapPress).	po,w (mm Hg)	21.07
Dissolved oxygen concentration in water at 1atm at To (From sheet DO-sat)	DO (mg/L)	8.58

Instrument/sample information

Total volume of empty HBOD tube	VT (mL)	28	
Liquid volume of wastewater sample put into HBOD tube	VL (mL)	10	
Oxygen concentration of sample on day n	O2 reading 1	tube 1 (%)	12.76
	O2 reading 2	tube 2 (%)	12.71
	O2 reading 3	tube 3 (%)	12.49
	O2 Average	An (% O2)	12.65
Oxygen conentration of empty tube from day 0	An,o (% O2)	20.9	

HBOD (mg/L) 190 +/- 2

Spreadsheet available at:
www.engr.psu.edu/ce/enve/hbod/hbod.htm

Predicting the BOD₅

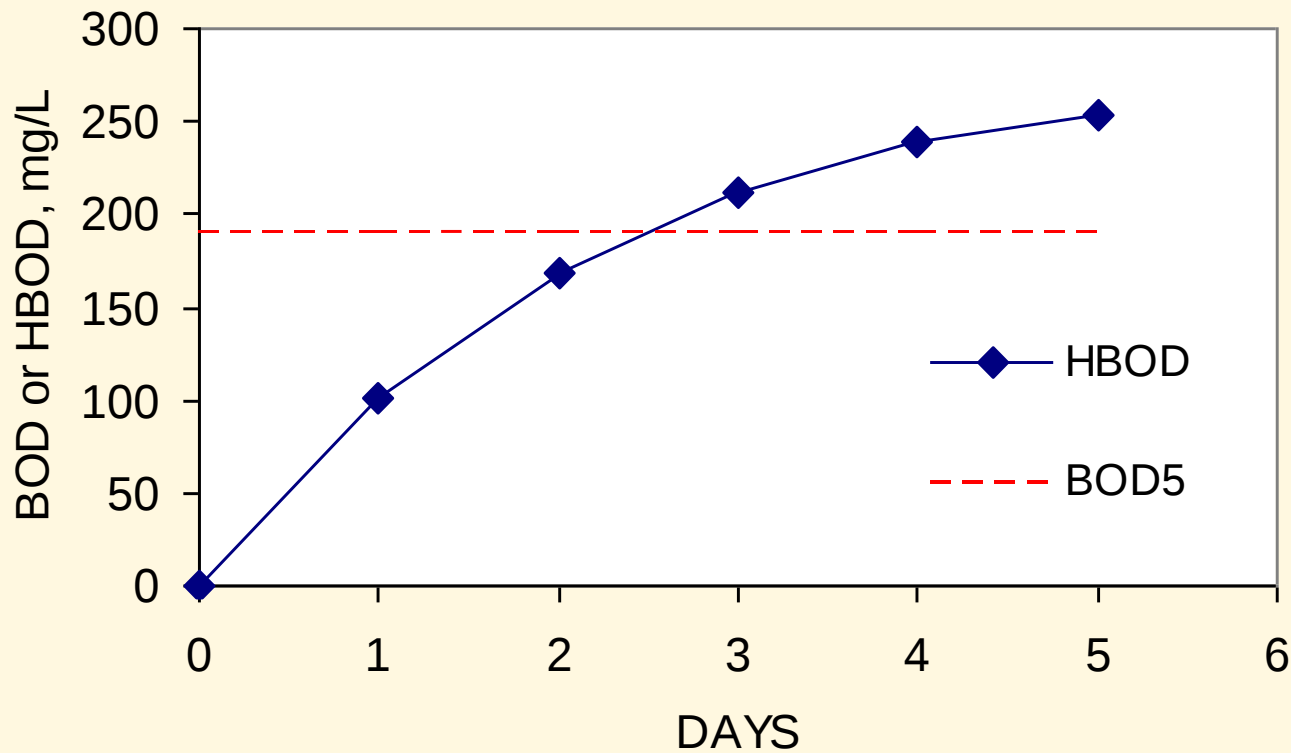
$$\text{BOD}_5 = C_n \times \text{HBOD}_n$$

C_n = Constant dependent on specific WWTP
and day of HBOD

n = day (typically day 2 or 3)

RESULTS

RESULT: The BOD_5 is reached in only 2-3 days in the HBOD test



Primary clarifier effluent, Penn State University WWTP

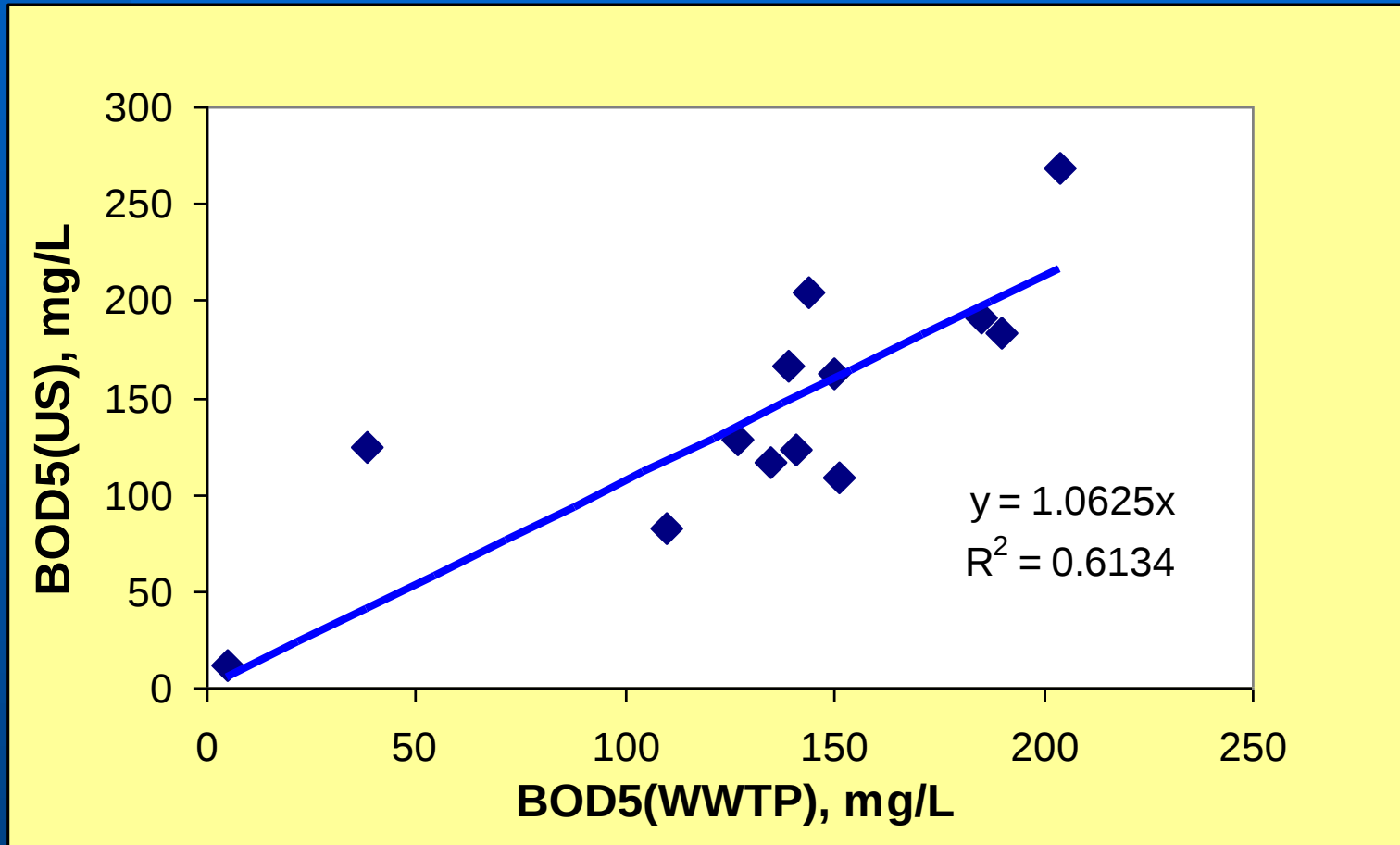
Precision of HBOD and BOD tests

- $\text{BOD}_5 = 191 \pm 29 \text{ mg/L}$
- $\text{HBOD}_2 = 168 \pm 12 \text{ mg/L}$
- $\text{HBOD}_3 = 212 \pm 2 \text{ mg/L}$
- The smaller $\pm\text{SD}$ demonstrates the greater precision of the HBOD test

Penn State University WWTP

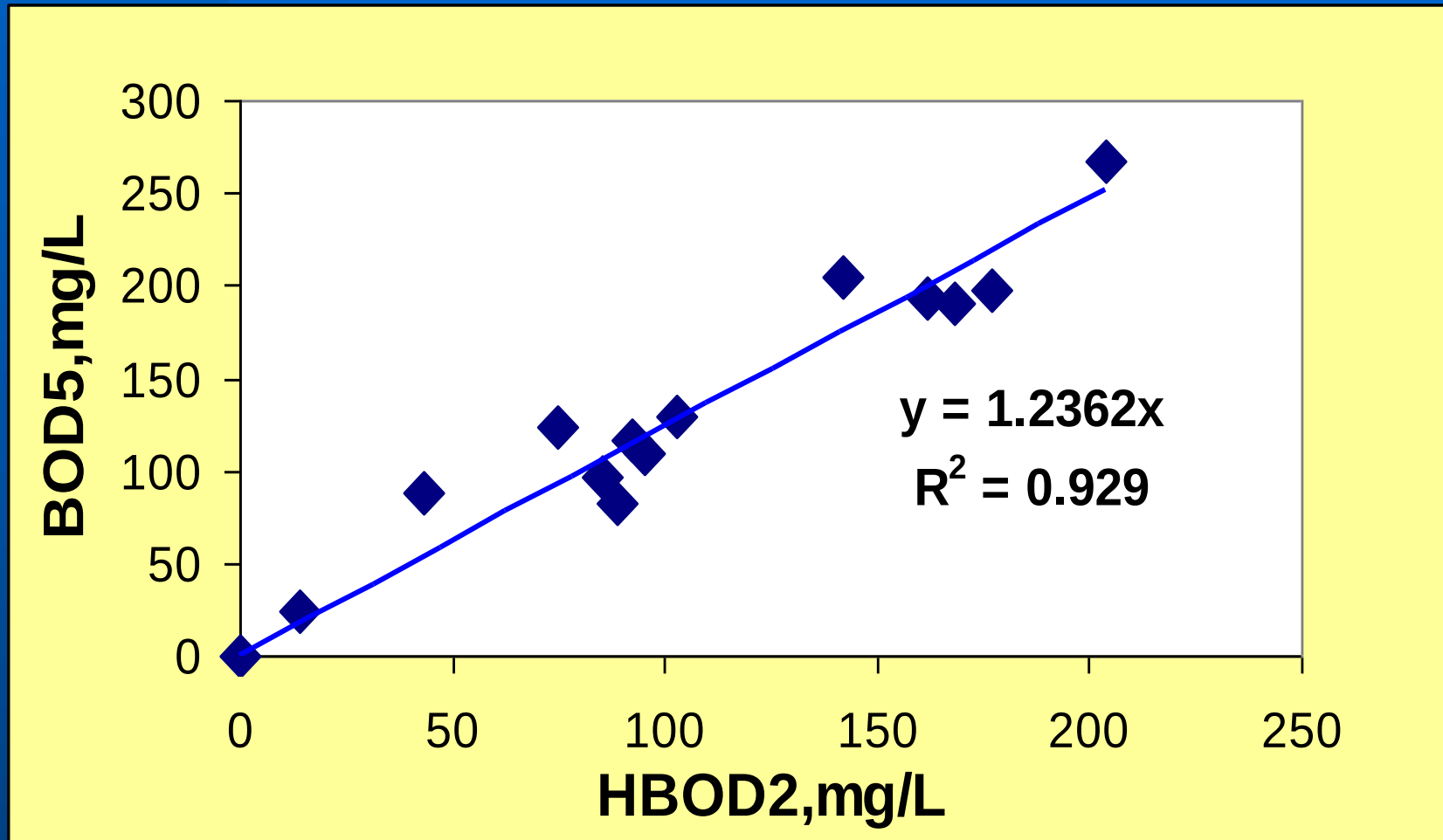
How well do BOD₅ tests compare?

WWTP vs PSU



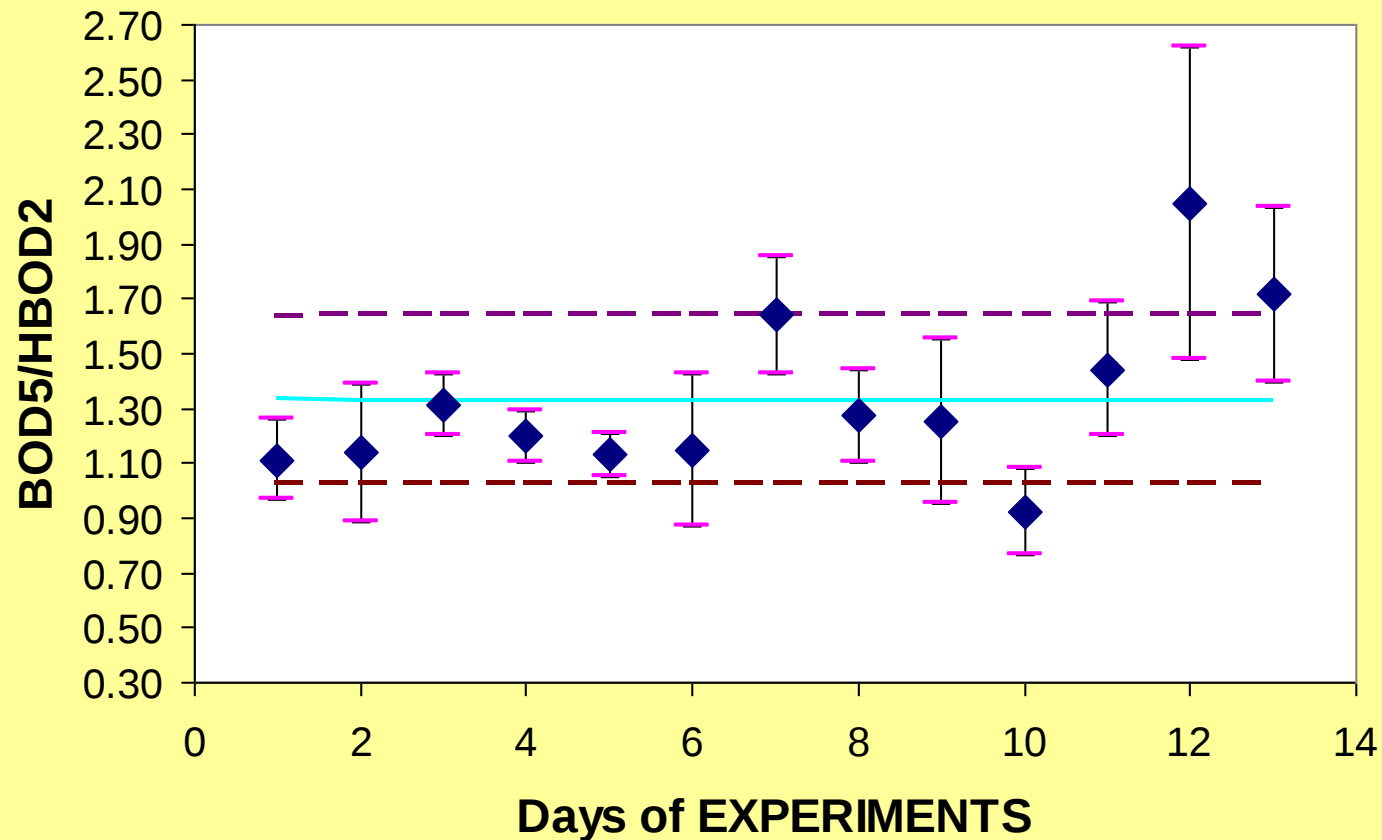
Penn State University WWTP

2-Day Test: $BOD_5 = 1.24 \times HBOD_2$



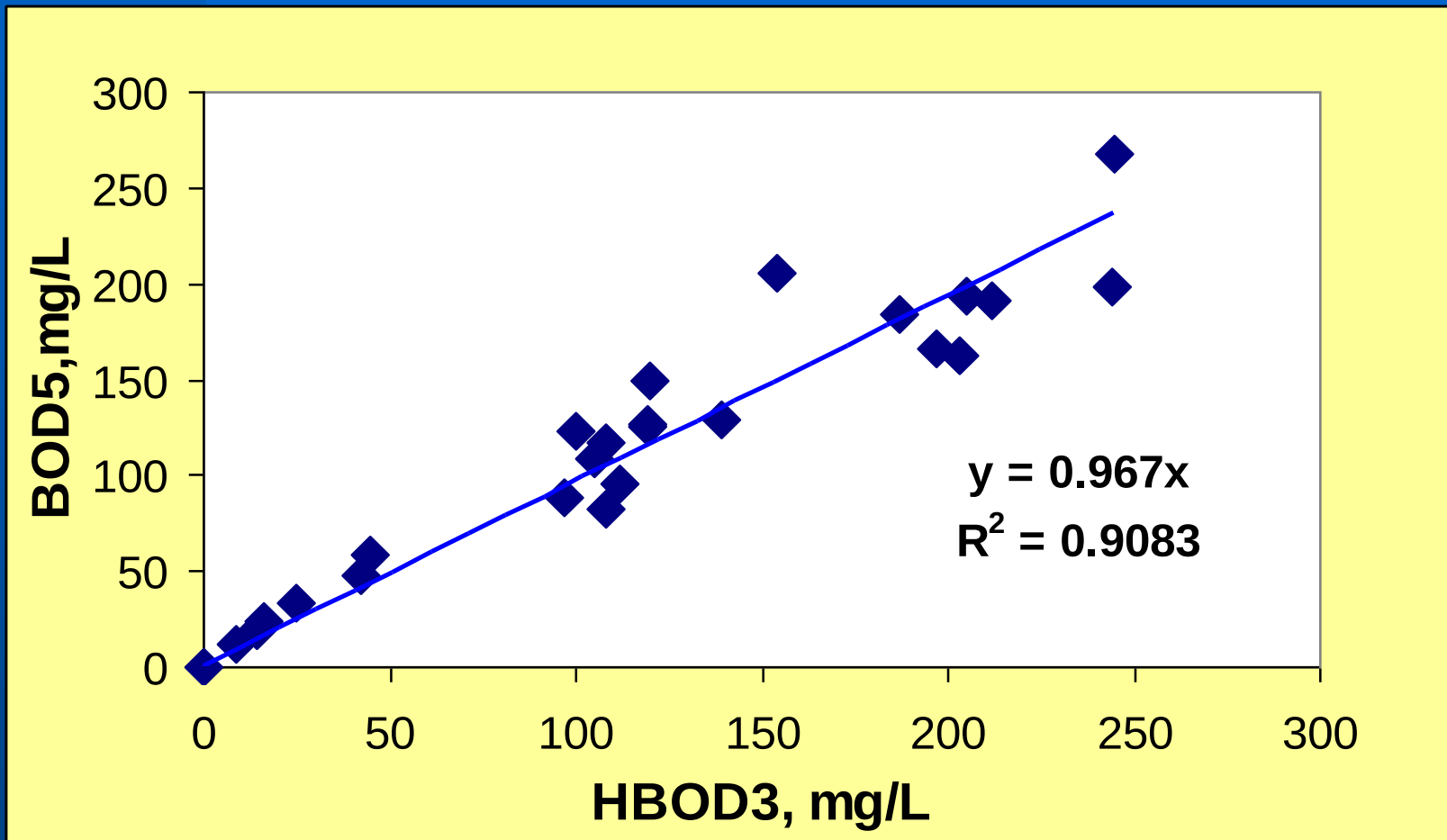
Penn State University WWTP

2-Day Test: $\text{BOD}_5 = 1.33 \times \text{HBOD}_2$



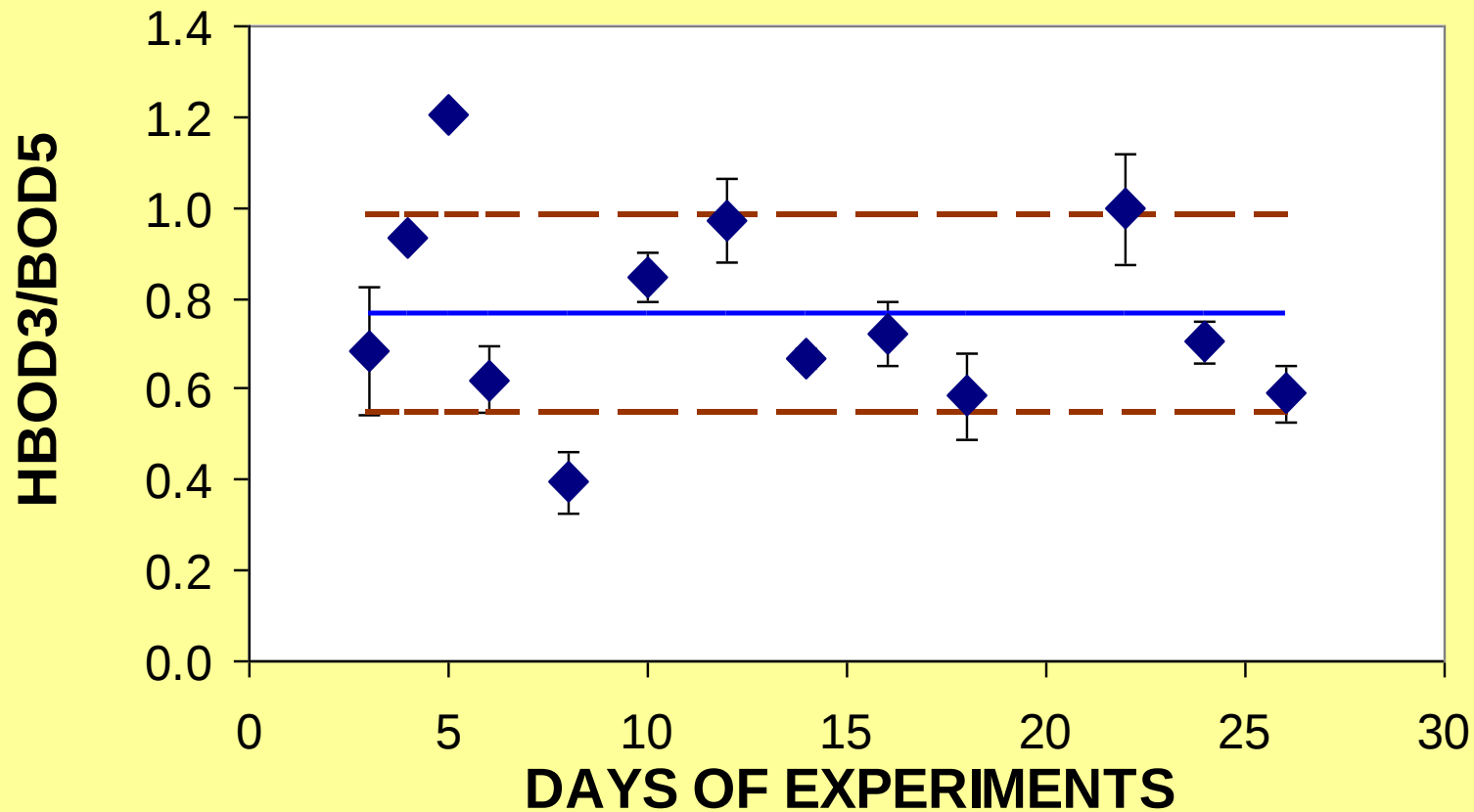
Penn State University WWTP

3-Day Test: $BOD_5 = 0.97 \times HBOD_3$



UAJA WWTP

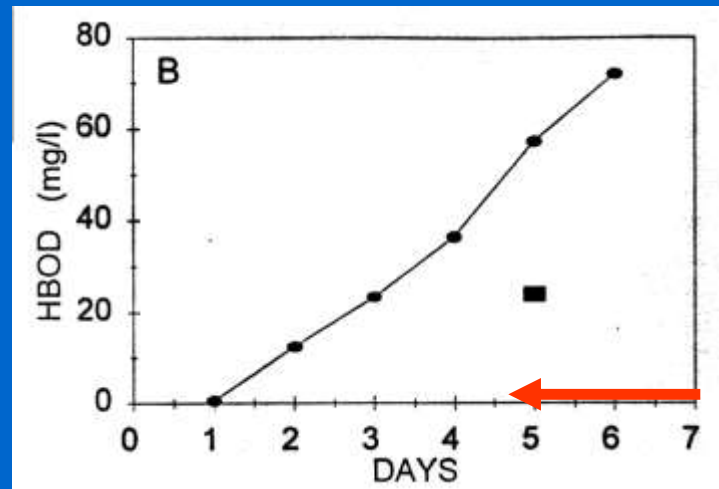
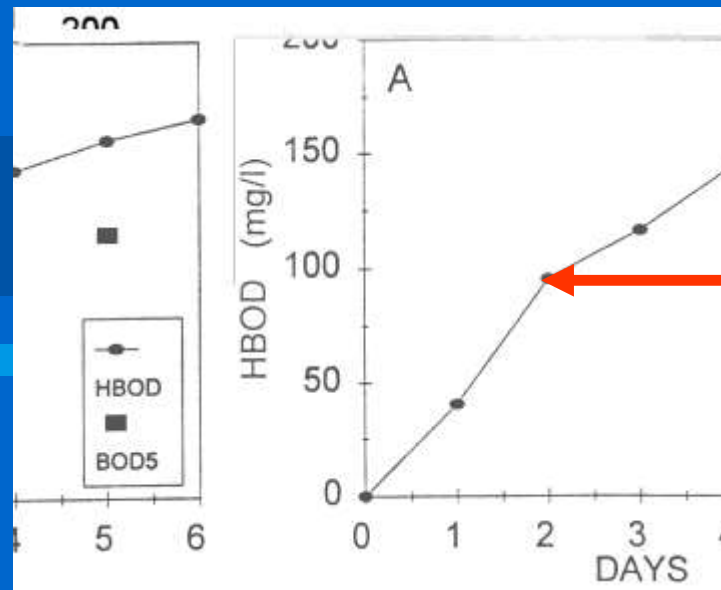
3-Day Test: $BOD_5 = 1.3 \times HBOD_3$



HBOD Tests: Arizona

Ina Rd.
Wastewater
Treatment Plant
(Tucson, Arizona)

From: Logan & Patnaik (1998)
Wat. Env. Res.

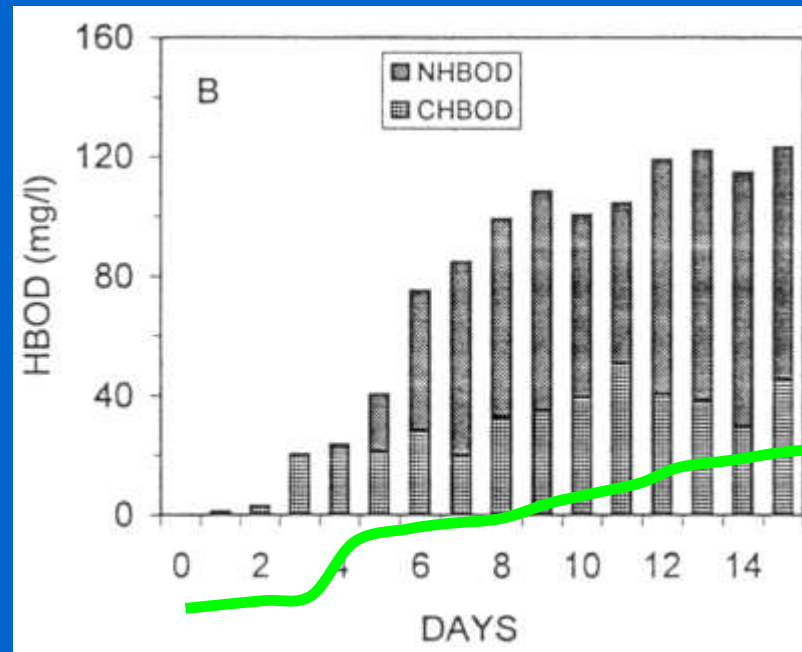
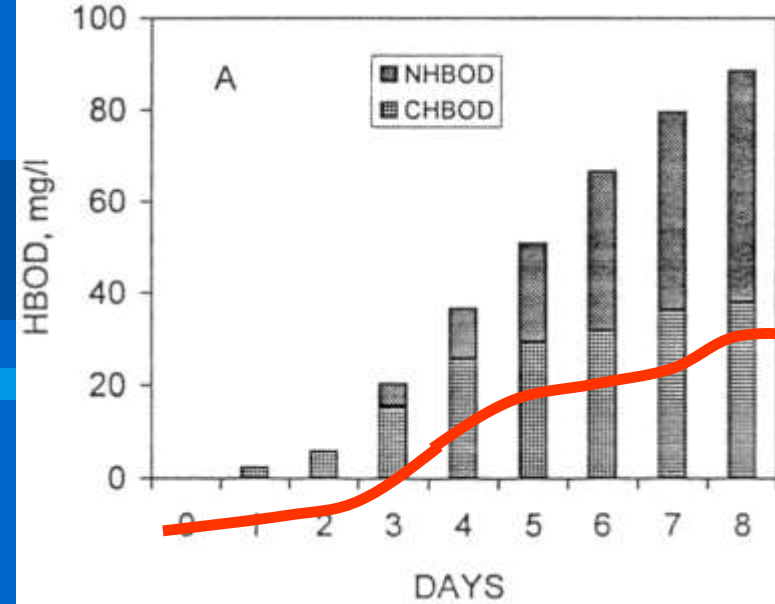


Nitrification

Trickling Filter

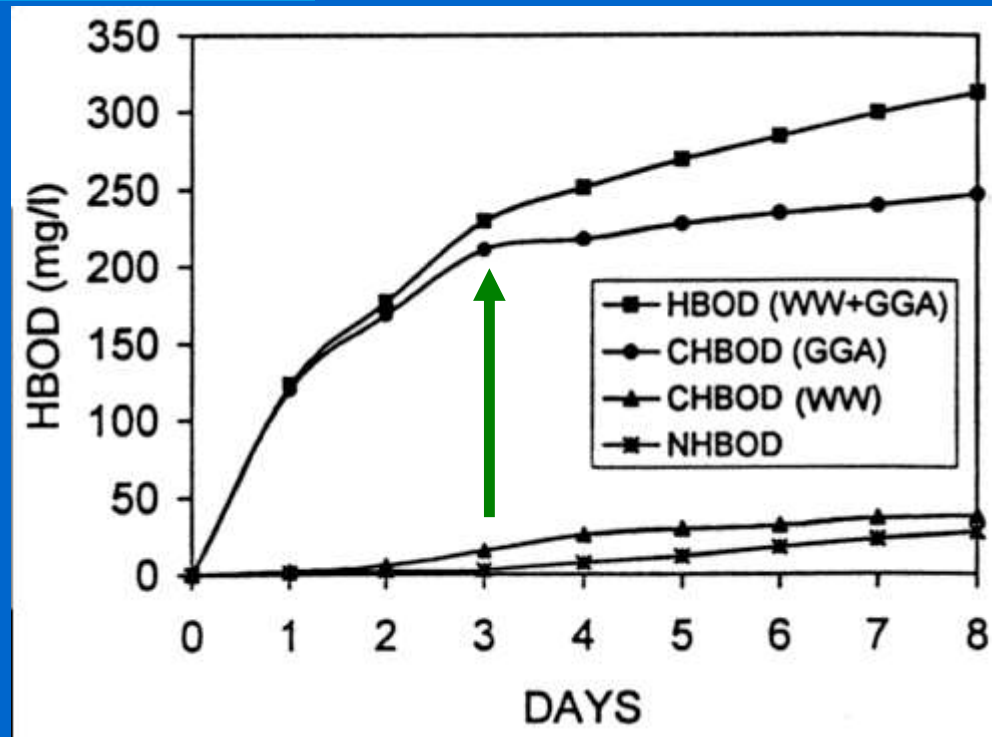
(Roger Rd.
Wastewater
Treatment Plant,
Tucson, Arizona)

From: Logan & Patnaik (1998)
Wat. Env. Res.



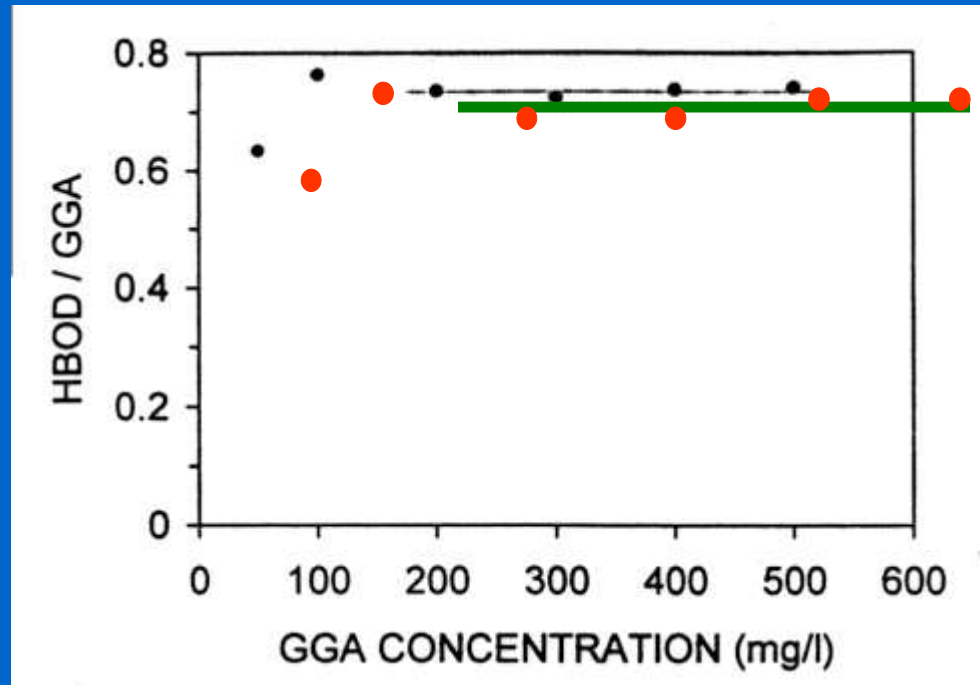
Calibration: Glucose-Glutamic acid (GGA) test

300 mg/L
GGA
produces a
HBOD₃ of
200 mg/L



Calibration: Glucose-Glutamic acid (GGA) test

The HBOD₅ to
GGA ratio is
is constant



Summary of advantages of the HBOD₃ test compared to the BOD₅ test

Wastewater
samples do not
need to be diluted
(although they can be).



Fewer HBOD tubes are necessary than BOD bottles

Sample Volume (mL) in 28 mL HBOD tube	HBOD Range (mg/L)
23	7 – 50
10	51 – 364

Sample Volume (mL) in 300 mL BOD bottle	BOD range (mg/L)
90	7 – 27
22	27 – 110
6	100 – 405

2 HBOD tubes cover the same range as 3 BOD bottles

HBOD tubes are smaller
than BOD bottles



O_2 analysis takes only a few seconds per bottle...

... and the probe does not contact the wastewater, so that it is highly resistant to fouling.



CONCLUSIONS

- The HBOD probe allows an HBOD test to be run very simply and quickly.
- HBOD results are obtained in just 2 or 3 days that are comparable to BOD₅ values.
- HBOD results are more precise BOD₅ results.
- The HBOD test can be used in the wastewater treatment plants in order to evaluate biological treatment processes.

Acknowledgments

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- David Smith at the UAJA plant.
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- Most experiments were conducted in the Kappe Laboratories at Penn State University