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REGION III
ANNAPOLIS FIELD OFFICE

Statistical Analysis
of
Dissolved Oxygen Sampling
Procedures Employed by the
Annapolis Field Office

TECHNICAL PAPER [illegible]

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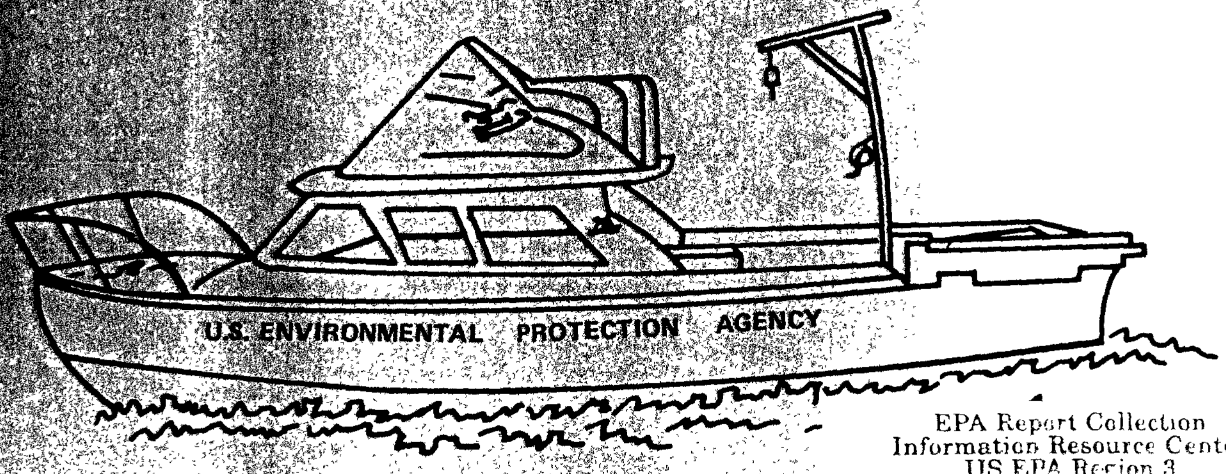
WORKING FOR A BETTER ENVIRONMENT



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I. INTRODUCTION

The Annapolis Field Office began using pumps to obtain dissolved oxygen samples during water quality surveys in 1967. Testing of results obtained at the time indicated that the pumps were sufficiently accurate for use in the surveys. Furthermore, tests on submersible pumps reported in the literature supported this conclusion.[1] Two types of pumps have been used by AFO crews to sample for dissolved oxygen: the Rule Master 1300 (submersible, push) and the Teel 1P580 (mounted, pull).

During the August 1975 Delaware Intensive Survey, the AFO loaned the Philadelphia Water Department a Rule Master high speed pump. Following this survey, the Water Department performed a series of tests comparing DO samples from the Rule Master pump and DO samples by an APHA sampler.[2] These tests indicated that their pumped samples had been significantly aerated at DO levels between 1 and 6 mg/l (corresponding to DO deficits between 2 and 7 mg/l). It was not determined whether the aeration resulted from improper use of the pump. Common errors include failure to completely clear the pump hose before filling the DO bottle, failure to adequately restrict the flow from the high speed pump hose thus allowing splashing in the DO bottle, and failure to allow water in the DO bottle to overflow 2-3 volumes before capping. It was recommended that AFO review its sampling procedure and conduct a similar study.

The mention of trade names or commercial products in this report is for illustration pruposes and does not constitute endorsement or recommendation by the U. S. Environmental Protection Agency.

II. THEORETICAL CONSIDERATIONS

First, the potential sources of extraneous oxygen in the pumps were considered. For a submerged pump, such as the Rule Master, aeration could result from (1) transient air initially caught in the pump and hose, (2) splashing of the sample stream in the DO bottle, or (3) air leaks in the hose. The first problem should be eliminated by clearing the lines by pumping through at least three gallons of water before taking a sample. The second problem should be eliminated by crimping the hose to reduce the velocity of the stream, by inserting the hose well into the DO bottle, and by allowing the DO bottle to overflow three volumes before removing the hose and capping. The third problem should be eliminated by regular inspections of the hose. All of these problems, then, should be controllable.

For a surface mounted pump, such as the Teel, the same potential problems and solutions are applicable. In addition, however, is the potential introduction of air through the pump itself during operation. This could result from a loose casing and/or extra strain on the pump caused by excessive crimping of the hose (by restricting the flow of water through the apparatus, the volume displacement pump could pull air through the casing). This problem should be minimized with careful, experienced handling and periodic inspections of the pump.

If aeration is occurring due to faulty pumps or handling techniques, the amount of dissolved oxygen added to the sample should be proportional to the partial pressure gradient in the gas phase and the concentration gradient in the liquid phase. [3] This is similar to reaeration in streams described by the following equation:

$$\frac{dC}{dt} = K_L \frac{A}{V} (C_s - C)$$

where

K_L = the interfacial oxygen transfer coefficient

A = surface area through which transfer occurs

V = volume of the sample

C_s = saturation value of DO

C = concentration of DO in the sample

The oxygen transfer coefficient itself is a function of the diffusivity of oxygen in water D_L and the rate of surface renewal r, itself a function of flow regime:

$$K_L = \sqrt{D_L\ r}$$

The terms describing the gas phase and air-water interface are usually lumped in a volumetric coefficient K_a, which is a weak function of temperature:

$$K_{aT} = K_{a20}\ \Theta^{T-20}$$

where $\Theta = 1.025$ (1.016 - 1.040).

Thus, for a constant temperature,

$$\frac{dC}{dt} = K_a (C_s - C),$$

and, over a small period of contact time,

$$\Delta\ DOD = K_a \times DOD \times \Delta t,$$

where DOD is the DO deficit of the water being sampled, $C_s - C$. Assuming a constant volumetric oxygen transfer rate K_a and contact time t, then the dissolved oxygen deficit of the sample DOD_s should be related to the deficit of the water by

$$DOD_s = DOD\ (1 - K_a \Delta t).$$

As one consequence of this relationship, a linear regression of DOD_s versus DOD should give an intercept of 0 and a slope less than or equal to 1.0. Because K_a is a positive exponential function of temperature, DOD_s versus DOD should yield progressively smaller slopes at higher temperatures. Variations in pump operation would probably mask this effect in experimental situations, however, allowing the grouping of data taken throughout a moderate temperate range.

III. EXPERIMENTAL PROCEDURE

The subsequent steps were followed during all experiments reported in this paper.

1. A plastic 75 gallon drum was filled with tap water.
2. Oxygen was monitored with a YSI submergible probe, YSI 5419, and a model 51 A YSI meter. The YSI equipment had been previously calibrated using the azide modification of the Winkler dissolved oxygen method, APHA 1975, pp. 143-448[4].
3. An A. H. Thomas 8590-H20 stirrer was employed to maintain an adequate current for the YSI probe and to minimize a dissolved oxygen gradient. Homogeneinty of this system was established in a preliminary experiment in which 24 samples were siphoned from the drum and assayed (Appendix A).
4. Prepurified nitrogen and/or oxygen was bubbled through the drum using a gas dispersion tube, Kimax 28630, until the desired D.O. was obtained.
5. Stirring was maintained and the temperature was recorded.
6. The Rule Master 1300 or the Teel 1P580 pump line was placed in the drum and three gallons of water were pumped out to free the lines of entrapped air.
7. The delivery hose of the pump was crimped to restrict the flow from the pump until splashing was minimized.
8. The hose was placed at the bottom of a 300cc BOD type bottle. Twelve bottles were over filled with approximately three times their volume. This was

achieved by filling the bottles over an empty plastic bucket of predetermined volume.

9. The pump was stopped and twelve replicate bottles were siphoned from the tank using tygon tubing (1/4" O.D.). Over-filling was not deemed necessary since the flow was very slight and no splashing was observed.

10. All bottles were capped after being filled and immediately "fixed" as outlined in APHA 1975, p. 443.

11. All samples were immediately assayed using a Fisher Model 41 Auto Titralyzer. Fisher P-340, 0.025 N Potassium Biodate was used as the primary standard and twenty duplicate biodate standards were used to establish the precision of this instrument, (Appendix A).

RESULTS AND DISCUSSION

Prior to experimentation with the pumps, the precision of both the analytical method and of the siphoning procedure was determined. Twenty replicates of 0.025N Potassium biodate standards were run on a Fisher Titralyzer, giving a variance of 0.0025 $(mg/l)^2$DO (S = .05 mg/l). Twenty-four replicate samples were siphoned from the tank, giving a variance of 0.0049 $(mg/l)^2$DO (S = .07 mg/l). Thus the variance added by siphoning alone was approximately twice the variance due to the analytical procedure. Assuming perfect accuracy in sampling and analysis, 95 of 100 siphoned samples should lie within $\pm$ 0.12 mg/l from the correct value. Both the analytical procedure and the siphoning technique were considered precise enough to proceed with the experiments.

Nine experiments at DO levels ranging from 1.1 - 5.6 mg/l (DOD from 4.5 - 9.1 mg/l) were run by an AFO chemist, to compare the samples collected by the Rule Master pump with those obtained by siphoning. Nine similar experiments were performed with the Teel pump at DO levels from 1.0 - 5.0 mg/l (DOD from 4.1 - 8.8 mg/l). [To check the sensitivity to technique involved in sampling, the following pump operators were tested: A field technician and an AFO chemist not experienced in the operation of the pump; and an experienced field technician.] Twelve replicates from the pump and the siphon were analyzed during each experiment. Variances were tested for homogeneity using the F-test at the α = .01 level. Means were tested for equality using the one-tailed student's t-test for unpaired data at the α = .01 level.

TABLE 1

Summary of Experiments

Instrument Operator	Number of Replicates	Siphon DO (mg/l)	Temp (° C)	Siphon DOD (mg/l)	Pump DOD (mg/l)	Homogeneous Variance (α = .01)	Equal Means (α = .01)	Prob of not det 0.1 mg/l dif.(β) (α = .01)
Rule Master	12/12	5.6	15	4.5	4.5	√	√	.07
operated	12/12	5.6	15	4.5	4.5	√	√	.07
by lab	11/12	4.5	16	5.4	5.0	x[1]	--	--
chemist	12/12	3.3	15	6.8	6.7	√	√	.11
	12/12	3.1	15	7.0	6.9	√	√	.17
	12/12	2.6	15	7.5	7.5	√	x	.05
	12/12	2.3	16	7.6	7.6	√	√	0
	12/12	1.1	15	9.0	9.0	√	√	.31
	12/11	1.2	14	9.1	9.0	√	x	.12
Tot or Avg.	12/12					8	6	.11
Teel	12/12	3.1	16	6.8	5.7	x	--	--
operated	12/12	2.7	16	7.2	7.1	x	--	--
by lab chemist	12/12	1.0	16	8.9	8.8	x	--	--
Tot or Avg.	12/12					0	--	--
Teel operated	12/12	5.0	17	4.7	4.1	x	--	--
by inexper.	12/12	3.1	11	7.9	7.1	x	--	--
field tech.	12/12	1.6	17	8.1	7.7	x	--	--
	12/12	1.8	11	9.2	8.2	x	--	--
Tot or Avg.	12/12					0	--	--
Teel operated	12/12	1.9	16	8.0	8.1	√	√	.36
by exper.	12/12	1.7	16	8.2	8.2	√	√	.07
field tech.								
Tot or Avg.	12/12					2	2	.21

[1] In this first experiment performed, the pump line was not sufficiently cleared before sampling.

The probability of not detecting a mean difference of 0.1 mg/l (the β-error) was computed from the sample size, pooled standard deviation, and the α level (.01). Data from each experiment are listed in Appendix A, and a summary is provided in Table 1.

Of the nine experiments on the Rule Master pump operated by a laboratory chemist, all but the first passed the test for homogeneous variances. In the first experiment, the pump line was not sufficiently cleared before sampling, and aeration of the samples occurred due to residual air in the pump and hose. In subsequent experiments at least 3 gallons of water were pumped through the hose before collecting samples. Subject to adequate clearing of the hose, the Rule Master pump is a sufficiently precise sampling instrument.

Eight experiments with the Rule Master pump and the siphon were tested for equality of means. Although two experiments did result in statistically significant differences, the average differences were all less than 0.1 mg/l. The probability of not detecting a 0.1 mg/l difference in means averaged 11%. A linear regression between pumped D.O. deficits (DOD_p) and siphoned deficits (DOD_s) gave a slope of .991, an intercept of 0.063 mg/l DOD_p and a correlation coefficient exceeding 0.999. It is concluded that, with adequate handling, the Rule Master pump is a sufficiently accurate sampling instrument.

Of the nine experiments on the Teel pump, seven were operated by inexperienced operators, and none of these seven experiments passed the test for homogeneous variances. In two of these experiments, the average differences between pump and siphon were 0.08 and 0.11 mg/l, respectively giving marginally unacceptable accuracies. Generally, however, the Teel pump with inexperienced operators is neither a sufficiently precise nor sufficiently accurate sampling instrument.

The two experiments on the Teel pump with an experienced operator passed both the test for homogeneous variances and the test for equal means. Average differences between pump and siphon were 0.0 and 0.03 mg/l, respectively. In the latter experiment, both the precision and the accuracy of the pump seemed to exceed that of the siphon. The Teel pump with an experienced operator, then, can be both a sufficiently precise and sufficiently accurate sampling instrument.

CONCLUSIONS

1. The Rule Master pump is sufficiently precise and accurate to use for sampling D.O. at deficits as high as 9 mg/l (this covers all D.O. concentrations at temperatures exceeding 20°C, and down to 1 mg/l D.O. at 15°C).
2. The Teel pump can be operated by experienced personnel in a manner sufficiently precise and accurate to use for sampling D.O. at deficits as high as 8 mg/l.
3. The Teel pump operated by inexperienced personnel can result in imprecise and inaccurate D.O. measurements.
4. The Rule Master pump is preferable to the Teel pump because it is less sensitive to variations in operating procedures.

REFERENCES

1. Whaley, R. C., "A Submersible Sampling Pump," Limnology and Ocenography, Vol. 3, No. 4, October, 1958.
2. Blair, D. D., "Statistical Analysis of Two Dissolved Oxygen Sampling Procedures", Technical Report prepared by the Philadelphia Water Department, December 10, 1975.
3. O'Connor, D. J. et al, "Mathematical Modelling of Natural Systems," notes for a course given in May, 1975.
4. Standard Methods for the Examination of Water and Wastewater, 14th Edition, American Public Health Association, Inc., 1975.

APPENDIX A

EXPERIMENTAL DATA AND STATISTICS

Preliminary Experiment: Uniform D.O.

Twenty-four D.O. bottles were siphoned from the tank and assayed via the Azide-Modification of the Winkler Method, APHA 1975 pp. 443-448. The following D.O. concentrations (ppm) were obtained:

4.3	4.2
4.3	4.2
4.2	4.1
4.2	4.1
4.1	4.1
4.3	4.1
4.2	4.2
4.1	4.1
4.2	4.1
4.2	4.2
4.2	4.1
4.1	4.1

N = 24
S = 0.07

Preliminary Experiment: Precision of Fisher Auto Titralyzer

Twenty duplicate standards were prepared using: 10 ml of 0.025 N Potassium biodate, 284 ml of distilled water; 2 ml of conc. H_2SO_4; 2 ml of APHA* Manganese sulfate; and 2 ml of APHA* Alkali-iodide-Azide reagent. These standards were titrated using the Fisher model 41 titralyzer and the following concentrations (ppm) were obtained:

4.9	5.0
5.0	5.1
5.0	5.0
5.0	5.0
5.0	5.0
5.0	5.0
5.0	4.9
5.0	5.0
5.0	4.9
5.0	4.9

with N = 20 and S = 0.05

* APHA 1975, p. 443

Experiment 1

Dissolved Oxygen Range 4.3 - 5.6 mg/l Chemist 2/23

Temperature 16°C

Rule Master Pump	Siphon
4.7	4.5
5.6	4.5
5.0	4.5
4.9	4.3
5.0	4.5
4.7	4.4
4.7	4.4
4.7	4.5
4.8	4.4
4.8	4.5
4.7	4.5
	4.4
$n_1=11$	$n_2=12$
$\overline{X_1}=4.873$	$\overline{X_2}=4.467$
$S_1^2=.0722$	$S_2^2=.00455$

$H_0: \sigma_1^2 = \sigma_2^2$ $\alpha = .01$ $F\alpha = 4.23$

F = 15.8641 Reject - Variances are not homogeneous

$\overline{X_1} - \overline{X_2} = 4.87 - 4.47 = 0.40$

Comments:

Pump line not completely cleared before running experiment (only 1 gal water

running experiment (only 1 gal water was pumped prior to experiment)

Experiment 2

Dissolved Oxygen Range 2.5 - 2.7 mg/l Chemist 3/17

Temperature 15°C

Rule Master Pump	Siphon
2.6	2.6
2.6	2.5
2.7	2.5
2.7	2.5
2.6	2.6
2.6	2.5
2.6	2.6
2.5	2.6
2.6	2.6
2.6	2.5
2.6	2.6
2.6	2.5

$n_2 = 12$ $n_1 = 12$

$\overline{X}_2 = 2.608$ $\overline{X}_1 = 2.55$

$S_2^2 = .00265$ $S_1^2 = .00273$

$H_0: \sigma_1^2 = \sigma_2^2$ $\alpha = .01$ $F_\alpha = 4.47$

$F = \frac{S_1^2}{S_2^2} = 1.0292$ Accept - variances are homogeneous

$H_0 = \mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.508$

$T = 2.7529$

Reject - there is a significant difference between means

$\overline{X}_1 - \overline{X}_2 = 2.61 - 2.55 - 0.06$

$$d^* = \frac{\delta}{\sigma} \frac{1}{\sqrt{n_1 + n_2 - 1}} \sqrt{\frac{n_1 n_2}{n_1 + n_2}}$$, where δ = the mean difference to be detected = 0.1 mg/l

$d^* = .9848$ $\beta = .05$

Experiment 3

Dissolved Oxygen Range 1.1 - 1.4 mg/l Chemist 3/17

Temperature 14^{o}C

Rule Master Pump	Siphon
1.2	1.2
1.3	1.2
1.3	1.1
1.3	1.1
1.3	1.1
1.2	1.3
1.4	1.3
1.3	1.2
1.3	1.2
1.2	1.2
1.3	1.2
1.3	
$n_2 = 12$	$n_1 = 11$
$\overline{X}_2 = 1.2833$	$\overline{X}_1 = 1.1909$
$S_2^2 = .00334$	$S_1^2 = .00491$

$H_o: \sigma_1{}^2 = \sigma_2{}^2$ $\alpha = .01$ $F\alpha = 4.23$

$F = 1.4714$ Accept - variance are homogeneous

$H_o: \mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.518$

$T = 3.4643$

Reject - there is a significant difference in means

$\overline{X}_1 - \overline{X}_2 = 1.28-1.19 = 0.09$

$d^* = .7993$ $\beta = .12$

Experiment 4

Dissolved Oxygen Range 5.5 - 5.7 mg/l Chemist 4/2

Temperature 15°C

Rule Master Pump	Siphon
5.6	5.5
5.5	5.7
5.6	5.6
5.6	5.6
5.6	5.6
5.6	5.6
5.7	5.6
5.7	5.7
5.7	5.6
5.6	5.6
5.5	5.6
5.6	5.6
$n_1 = 12$	$n_2 = 12$
$\overline{X}_1 = 5.6083$	$\overline{X}_2 = 5.6083$
$S_1^2 = .00447$	$S_2^2 = .00265$

H_0: $\sigma_1^2 = \sigma_2^2$ $\alpha = .01$ $F\alpha = 4.47$

F = 1.6849 Accept - variance are homogeneous

H_0: $\mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.508$

T = 0 Accept - no significant difference in means

$\overline{X}_1 - \overline{X}_2 = 5.61 - 5.61 = 0$

d* = .8561 $\beta = .07$

Experiment 5

Dissolved Oxygen Range 5.5 - 5.7 mg/l   Chemist 4/2

Temperature 15°C

Rule Master Pump	Siphon
5.6	5.7
5.6	5.6
5.6	5.6
5.6	5.6
5.6	5.6
5.6	5.6
5.7	5.7
5.6	5.6
5.7	5.5
5.6	5.6
5.5	5.6
5.7	5.5
$n_2 = 12$	$n_1 = 12$
$\overline{X}_2 = 5.6167$	$\overline{X}_1 = 5.6$
$S_2^2 = .00333$	$S_1^2 = .00364$

$H_0: \sigma_1^2 = \sigma_2^2$ $\alpha = .01$ $F\alpha = 4.47$

$F = 1.9309$ Accept - variance are homogeneous

$H_0: \mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.508$

$T = .6934$ Accept - no significant difference in means

$\overline{X}_1 - \overline{X}_2 = 5.62 - 5.60 = .02$

$d^* = .8658$ $\beta = .07$

Experiment 6

Dissolved Oxygen Range 2.2 - 2.4 mg/l   Chemist 4/2

Temperature 16°C

Rule Master Pump	Siphon
2.3	2.3
2.3	2.3
2.3	2.2
2.4	2.3
2.3	2.2
2.3	2.3
2.3	2.3
2.3	2.3
2.3	2.3
2.3	2.3
2.3	2.3
2.3	2.3
$n_2 = 12$	$n_1 = 12$
$\overline{X}_2 = 2.3083$	$\overline{X}_1 = 2.2833$
$S_2^2 = .000833$	$S_1^2 = .00152$

H_0: $\sigma_1{}^2 = \sigma_2{}^2$ $\alpha = .01$ $F\alpha = 4.47$

F = 1.8182   Accept - variances are homogeneous

H_0: $\mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.508$

T = 1.7868   Accept - no significant difference in means

$\overline{X}_1 - \overline{X}_2 = 2.31 - 2.28 = .03$

$d^* = 1.4905$ $\beta = 0$

Experiment 7

Dissolved Oxygen Range 0.9 - 1.2 mg/l Chemist 4/2

Temperature 15.5°C

Rule Master Pump	Siphon
1.0	1.1
1.1	1.0
1.1	1.0
1.1	1.2
1.1	1.1
1.0	1.2
1.0	1.0
1.1	1.1
1.1	1.0
1.0	1.2
1.1	0.9
1.2	1.0
$n_2 = 12$	$n_1 = 12$
$\overline{X}_2 = 1.075$	$\overline{X}_1 = 1.0667$
$S_2^2 = .00386$	$S_1^2 = .0097$

$H_o: \sigma_1{}^2 = \sigma_2{}^2$ $\alpha = .01$ $F\alpha = 4.47$

$F = 2.5098$ Accept - variances are homogeneous

$H_o: \mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.508$

$T = .2479$ Accept - no significant difference in means

$\overline{X}_1 - \overline{X}_2 = 1.08 - 1.07 = .01$

$d^* = .6203$ $\beta = .31$

Experiment 8

Dissolved Oxygen Range 3.0 - 3.2 mg/l Chemist 1/4

Temperature 15^{o}C

Rule Master Pump	Siphon
3.0	3.1
3.2	3.2
3.1	3.1
3.1	3.1
3.2	3.2
3.2	3.1
3.1	3.1
3.2	3.0
3.2	3.1
3.2	3.2
3.2	3.2
3.2	3.0
$n_2 = 12$	$n_1 = 12$
$\overline{X}_2 = 3.1583$	$\overline{X}_1 = 3.1167$
$S_2^2 = .00447$	$S_1^2 = .00515$

H_0: ${\sigma_1}^2 = {\sigma_2}^2$ $\alpha = .01$ $F\alpha = 4.47$

$F = 1.1525$ Accept - variances are homogeneous

H_0: $\mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.508$

$T = 1.4685$ Accept - no significant difference in means

$\overline{X}_1 - \overline{X}_2 = 3.16 - 3.12 = .04$

$d^* = .736$ $\beta = .17$

Experiment 9

Dissolved Oxygen Range 3.2 - 3.4 mg/l   Chemist 4/4

Temperature 15°C

Rule Master Pump	Siphon
3.3	3.3
3.3	3.2
3.4	3.3
3.4	3.3
3.5	3.4
3.4	3.4
3.3	3.3
3.3	3.3
3.4	3.4
3.4	3.3
3.4	3.4
3.4	3.4
$n_2 = 12$	$n_1 = 12$
$\overline{X}_2 = 3.375$	$\overline{X}_1 = 3.3333$
$S_2^2 = .00386$	$S_1^2 = .00424$

$H_0: \sigma_1{}^2 = \sigma_2{}^2$ $\alpha = .01$ $F\alpha = 4.47$

$F = 1.0984$ Accept - variances are homogeneous

$H_0: \mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.508$

$T = 1.6041$ Accept - no significant difference in means

$\overline{X}_1 - \overline{X}_2 = 3.38 - 3.33 = .05$

$d^* = .8026$ $\beta = .11$

Experiment 10

Dissolved Oxygen Range 3.1 - 3.2 mg/l Chemist 3/26

Temperature 16°C

Teel Pump	Siphon
4.9	3.2
5.3	3.1
4.5	3.2
4.5	3.1
5.9	3.1
5.1	3.1
3.2	3.1
3.3	3.1
3.3	3.2
3.7	3.2
3.2	3.1
3.7	3.1

$n_1 = 12$ $n_2 = 12$

$\overline{X}_1 = 4.2167$ $\overline{X}_2 = 3.1333$

$S_1^2 = .8815$ $S_2^2 = .00242$

$H_0: \sigma_1{}^2 = \sigma_2{}^2$ $\alpha = .01$ $F\alpha = 4.47$

F = 364.2562 Reject - variances are not homogeneous

$\overline{X}_1 - \overline{X}_2 = 4.22 - 3.13 = 1.09$

Experiment 11

Dissolved Oxygen Range 2.6 - 2.8 mg/l   Chemist 3/26

Temperature 16^{o}C

Teel Pump	Siphon
2.7	2.7
2.6	2.8
2.7	2.7
2.7	2.7
2.6	2.7
2.6	2.7
2.7	2.8
2.7	2.6
2.8	2.7
2.7	2.7
3.3	2.7
3.3	2.6

$n_1 = 12$ $n_2 = 12$

$\overline{X}_1 = 2.7833$ $\overline{X}_2 = 2.7$

$S_1^2 = .0615$ $S_2^2 = .00364$

$H_0: \sigma_1^2 = \sigma_2^2$ $\alpha = .01$ $F\alpha = 4.47$

$F = 16.8956$ Reject - variances are not homogeneous

$\overline{X}_1 - \overline{X}_2 = 2.78 - 2.70 = 0.08$

Experiment 12

Dissolved Oxygen Range 0.9 - 1.2 mg/l Chemist 3/26

Temperature 16^{o}C

Peel Pump	Siphon
1.1	1.0
1.1	1.2
1.0	1.2
1.0	1.0
1.0	0.9
1.1	1.0
1.9	1.0
1.2	1.1
1.0	1.0
1.0	0.9
1.0	1.0
1.3	1.0
$n_1 = 12$	$n_2 = 12$
$\overline{X}_1 = 1.1417$	$\overline{X}_2 = 1.025$
$S_1^2 = .06629$	$S_2^2 = .00932$

$H_0: \sigma_1{}^2 = \sigma_2{}^2$ $\alpha = .01$ $F\alpha = 4.47$

$F = 7.1127$ Reject - variances are not homogeneous

$\overline{X}_1 - \overline{X}_2 = 1.14 - 1.03 = 0.11$

Experiment 13

Dissolved Oxygen Range 4.9 - 5.1 mgl   Inexperienced Field Technician 4/1

Temperature 17°C

Teel Pump	Siphon
4.9	5.0
6.1	5.0
8.3	5.1
7.1	5.0
5.5	5.0
5.0	4.9
5.0	5.1
5.0	5.0
4.9	5.0
4.9	5.0
4.9	5.0
5.0	5.0
$n_1 = 12$	$n_2 = 12$
$\overline{X}_1 = 5.55$	$\overline{X}_2 = 5.0083$
$S_1^2 = 1.1973$	$S_2^2 = .00265$

$H_o: \sigma_1^2 = \sigma_2^2$ $\alpha = .01$ $F\alpha = 4.47$

$F = 451.8113$ Reject - variances are not homogeneous

$\overline{X}_1 - \overline{X}_2 = 5.55 - 5.01 = 0.54$

Experiment 14

Dissolved Oxygen Range 3.0 - 3.3 mg/l   Inexperienced Field Technician 4/1

Temperature 11°C

Teel Pump	Siphon
4.9	3.2
4.8	3.2
4.2	3.0
3.5	3.1
3.7	3.2
3.8	3.3
4.1	3.0
3.4	3.0
3.7	3.3
3.4	3.0
3.3	3.0
3.5	3.0
$n_1 = 12$	$n_2 = 12$
$\overline{X}_1 = 3.8583$	$\overline{X}_2 = 3.1083$
$S_1^2 = .2899$	$S_2^2 = .0154$

$H_0: \sigma_1{}^2 = \sigma_2{}^2$ $\alpha = .01$ $F\alpha = 4.47$

F = 18.8247   Reject - variances are not homogeneous

$\overline{X}_1 - \overline{X}_2 = 3.85 - 3.11 = 0.74$

Experiment 15

Dissolved Oxygen Range 1.8 - 1.9 mg/l   Inexperienced Field Technician 4/1

Temperature 11°C

Teel Pump	Siphon
3.7	1.9
2.8	1.9
2.6	1.8
1.9	1.8
1.8	1.9
1.9	1.9
1.8	1.8
1.8	1.8
2.6	1.8
1.9	1.8
1.8	1.9
1.8	
$n_1 = 12$	$n_2 = 12$
$\overline{X}_1 = 2.2$	$\overline{X}_2 = 1.8455$
$S_1^2 = .3636$	$S_2^2 = .00273$

$H_0: \sigma_1^2 = \sigma_2^2$ $\alpha = .01$ $F\alpha = 4.4$

$F = 133.2$ Reject - variances are not homogeneous

$\overline{X}_1 - \overline{X}_2 = 2.20 - 1.85 = 0.35$

Experiment 16

Dissolved Oxygen Range 1.5 - 1.7 mg/l   Inexperienced Field Technician 4/1

Temperature 17.5°C

Teel Pump	Siphon
5.4	1.5
4.6	1.5
4.2	1.6
1.7	1.7
1.9	1.5
1.6	1.5
2.3	1.5
2.2	1.6
2.2	1.6
1.6	1.6
1.6	1.7
2.0	1.6

$n_1 = 12$ $n_2 = 12$

$\overline{X}_1 = 2.6083$ $\overline{X}_2 = 1.575$

$S_1^2 = 1.7699$ $S_2^2 = .00568$

$H_0: \sigma_1{}^2 = \sigma_2{}^2$ $\alpha = .01$ $F\alpha = 4.47$

$F = 311.5024$ Reject - variances are not homogeneous

$\overline{X}_1 - \overline{X}_2 = 2.61 - 1.58 = 1.03$

Experiment 17

Dissolved Oxygen Range 1.6 - 1.8 mg/l   Experienced Field Technician 4/2

Temperature 16.5°C

Teel Pump	Siphon
1.6	1.7
1.8	1.6
1.8	1.7
1.7	1.7
1.7	1.8
1.6	1.7
1.7	1.7
1.8	1.7
1.7	1.7
1.7	1.8
1.7	1.7
1.7	1.7

$n_1 = 12$ $n_2 = 12$

$\overline{X}_1 = 1.7083$ $\overline{X}_2 = 1.7083$

$S_1^2 = .00447$ $S_2^2 = .00265$

$H_0: \sigma_1^2 = \sigma_2^2$ $\alpha = .01$ $F\alpha = 4.47$

$F = 1.6858$ Accept - variances are homogeneous

$H_0: \mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.508$

$T = 0$ no significant difference

$\overline{X}_1 - \overline{X}_2 = 1.71 - 1.71 = 0$

$d^* = .856$ $\beta = .07$

Experiment 18

Dissolved Oxygen Range 1.8 - 1.9 mg/l Experienced Field Technician 4/2

Temperature

Teel Pump	Siphon
2.0	1.9
2.0	1.8
1.9	1.8
1.8	1.9
1.8	1.8
1.7	1.8
1.9	1.9
1.9	1.9
1.8	1.9
1.7	1.9
1.8	1.8
1.7	1.9

$n_1 = 12$ $n_2 = 12$

$\overline{X}_1 = 1.8333$ $\overline{X}_2 = 1.8583$

$S_1^2 = .0115$ $S_2^2 = .00265$

$H_0: \sigma_1{}^2 = \sigma_2{}^2$ $\alpha = .01$ $F\alpha = 4.47$

F = 4.3396 Accept - variances are homogeneous

$H_0: \mu_1 - \mu_2 = 0$ $\alpha = .01$ $T\alpha = 2.508$

T = .728 Accept - no significant difference in means

$X_1 - X_2 = 1.83 - 1.86 = 0.03$

$d^* = .607$ $\beta = .36$