ABSTRACT

Title of Thesis: The Characterization of the Oxygen Transfer Capabilities of Fermentors

Joseph Stephen Adamca, Jr., Master of Science in Chemical Engineering, 1980

Thesis directed by: Assistant Department Chairman Dr. John E. McCormick

A method of characterizing the oxygen mass transfer capabilities of fermentors was developed where volumetric oxygen mass transfer coefficients are obtained using a modified sulfite oxidation method in conjunction with on line digital data processing. Carboxymethylcellulose is used in the reaction media to simulate the viscosity of typical non-Newtonian fermentation broths. Using this method, instantaneous values of volumetric oxygen mass transfer coefficients can be obtained for various combinations of agitation and airflow rates in different fermentor configurations. This data is useful in the scale up or scale down of fermentors.

Data obtained using this method have revealed that for a given fermentor configuration, oxygen transfer capability decreases with increasing medium viscosity up to some critical value, after which further increases in

viscosity produce little change in oxygen transfer. Such data were obtained quickly and easily by this method thus demonstrating its usefulness as a tool in characterizing and comparing fermentor oxygen mass transfer capabilities. Accuracy of the data obtained is limited by the accuracy of the sensing devices and control instrumentation employed.

THE CHARACTERIZATION OF THE OXYGEN TRANSFER CAPABILITIES OF FERMENTORS

by

Joseph Stephen Adamca, Jr.

Thesis submitted to the Faculty of the Graduate School of the New Jersey Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering

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APPROVAL SHEET

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INTRODUCTION

Oxygen mass transfer capability is one of the major considerations when specifying equipment for aerobic fermentations. A properly designed fermentation process should operate at maximum productivity, which implies that the fermentor operate at cellular and metabolic levels limited only by the physical constraints of the system, usually oxygen mass transfer and occasionally specific limiting nutrients. The oxygen mass transfer capability of a fermentor can be characterized by measuring the volumetric liquid phase oxygen mass transfer coefficient, abbreviated as K_La. The determination of K_La provides a quantitative measure of the maximum oxygen transfer capability of the fermentor for a given set of fermentor conditions. The K_La for a given fermentor is dependent upon fermentor configuration (e.g. baffling), agitator speed, aeration rate, temperature, and broth characteristics such as viscosity and surface tension.

The determination of K_La values can be obtained by many techniques. A steady state oxygen balance on the fermentor gas stream will determine the oxygen transfer rate (OTR) and the simultaneous measurement of dissolved oxygen, along with assumptions regarding the flow patterns of gas in the fermentor (e.g. well-mixed or plug flow) allows calculation of K_La during the fermentation.[1]

To compare fermentors on an oxygen transfer efficiency basis, it is often desirable to evaluate the K_La without the presence of biological growth.[1] A method for determining K_La for the purpose of characterizing the oxygen mass transfer capability of a given fermentor, without the presence of biological growth is presented here. It is based on the sulfite oxidation method[2], a steady state method involving the chemical oxidation of sodium sulfite to sodium sulfate. Gas analysis, rather than titration, will be used, in the method presented, to determine the oxygen transfer rate.

A material was sought which had non-Newtonian properties similar to that of an average fermentation broth. Aqueous solutions of sodium carboxymethylcellulose (CMC) have rheological properties similar to that of an average fermentation broth. Such solutions were used also because of the complete solubility of CMC in water. Another modification to the classical sulfite oxidation method for K_La determination was the use of an on-line computer which continuously logged important fermentation variables and calculated instantaneous values of K_La and oxygen transfer rates (OTR).

This thesis describes a practical method for characterizing the oxygen transfer capabilities of fermentors, utilizing an on-line computer to obtain instantaneous values of K_La under varying conditions of aeration and agitation. Aqueous solutions of sodium carboxymethylcellulose (CMC) were used to simulate the non-Newtonian behavior exhibited by many fermentation broths.

I. REVIEW OF PAST METHODS

A general review of the various methods of measuring oxygen mass transfer coefficients was given by J. W. Richards[8], and later by Tuffile and Pinho[4]. Included in their reviews are six commonly used methods:

1) Sulfite Oxidation
2) Gassing Out Method
3) Chemical or Winkler Method
4) Biological Method
5) Dynamic Gassing Out Method
6) Oxygen Balance Method

The sulfite oxidation method, originally used by Cooper, Fernstrom, and Miller[2] is based on the catalytic oxidation of sulfite to sulfate by oxygen in the presence of copper or cobalt ions. The reaction between the dissolved oxygen and sulfite ions is rapid enough so that the rate of solution of oxygen in the liquid controls the rate of the reaction. The reaction rate is independent of sulfite ion concentration over a wide range. Cooper, Fernstrom and Miller[2] showed that the reaction could be considered to be of zero order with respect to both sulfite and sulfate concentration, and cited references indicating the reaction was exothermic and involved negligible gas film resistance. The rate of sulfite oxidation was determined iodimetrically, back-titrating with standard thiosulfate solution to a starch indicator endpoint.

The sulfite method has been generally conducted in water only. The major criticism of the results obtained by this method, is that the aqueous sulfite solution does not possess the rheological properties, mainly viscosity, of most fermentation broths.[3,4] West and Deindoerfer[5] have shown several fermentation broths to exhibit non-Newtonian behavior, penicillin broth, for example, exhibits pseudo plastic behavior. They point out that because of interlacing mycelial networks or long flexible unidimensional cell chains, mold, actinomycetic, algal, and certain bacterial cultures should impart some degree of structural rigidity to their broths. They have shown that rheological properties of fermentation broths do influence the nature of the fluid regime in fermentors, and as a consequence, are important factors when considering mass transfer. Loucaide & Mc Manamey[6] used a paper pulp suspension, in conjunction with the sulfite method, to simulate a fermentation medium, however, they observed that the pulp moves away from the rotating agitator shaft, leaving a region of clear liquid, which is not characteristic of fermentation broths. Paca & Gregr[7] used aqueous solutions of glycerol to simulate fermentation broth.

Gas analysis can also be used to determine the sulfite oxidation rate. The volumetric oxygen mass transfer liquid phase coefficient, K_La, can then be calculated from the oxygen mass balance equation generally used to describe transfer of oxygen to a respiring culture[4]:

$$\frac{dC_L}{dt} = K_La \ (C^* - C_L) - RO_2$$

where C^* = oxygen concentration in the bulk liquid at equilibrium with the partial pressure of oxygen in the contacted gas, t = time, C_L = actual concentration of oxygen in bulk liquid, and RO_2 = oxygen uptake rate of respiring culture. It is assumed that the fermentor is well-mixed so that the dissolved oxygen concentration is uniform throughout the bulk liquid. This is a reasonable assumption based on the experiments of Hanhart, Kramers, and Westerterp.[9] Assuming steady state, $\frac{dC_L}{dt} = 0$, and because the sulfite reaction rate is very rapid, C_L is considered zero. Since the rate of sulfite oxidation is used to simulate the oxygen uptake rate of the respiring culture, RO_2, K_La is then equal to RO_2/ C^* .

Tuffile and Pinho[4] have pointed out the disadvantages to this method, mainly that the oxidation of sulfite is quite complex and the mechanism poorly understood, and that aqueous sulfite solutions do not adequately simulate fermentation media in viscosity, the presence of surface-active agents, solute concentration, and the presence of the organism itself, all of which can effect K_La.

The gassing out method, used by Bartholomew, Karow, Sfat, and Wilhelm[10], is carried out in a nonrespiring fermentation medium, $RO_2 = 0$. The oxygen mass balance equation described above, is then integrated to obtain: $\ln (C^* - C_L) = -(K_La)t + \ln C^*$ K_La is then determined as the slope of a semilog plot of $C^* - C_L$ versus time, assuming C^* is constant. Using this method, the oxygen content of the liquid is first reduced to zero, usually by sparging with nitrogen, then aeration is started and C_L is measured as a function of time using either a galvanic or polarographic oxygen probe, or samples can be periodically withdrawn and measured in a polarographic cell. The disadvantages of this method are that, in order to have no respiration demand, uninoculated broth or broth which has been pasteurized or poisoned must be used, and only one K_La value can be calculated per fermentation run.

The dynamic gassing out method, used by Taguchi and Humphrey,[11] is conducted in an actively respiring medium. In it, aeration is stopped and the decrease in dissolved oxygen due to respiration is measured as a function of time to obtain the oxygen uptake rate, RO_2, from the equation $RO_2 = -\frac{dC_L}{dt}$. which applies under conditions of no aeration. Before the critical oxygen level is reached, the aeration is resumed and the increase in dissolved oxygen is measured as a function of time. The oxygen mass balance equation is rearranged to obtain the form:

$$C_L = -\left(\frac{1}{K_La}\right)\left(\frac{dC_L}{dt} + RO_2\right) + C^*$$

The term (dC_L/dt) is obtained from a plot of C_L versus time after aeration is resumed, K_La and C^* can be determined from a plot of C_L versus $(dC_L/dt + RO_2)$ as the reciprocal of the slope and the intercept. The disadvantage of the method as pointed out by Tuffile and Pinho[4] is that it assumes a rapid disengagement of air bubbles from the fermentation medium upon termination of aeration, which is not the case with highly viscous non-Newtonian media or in production scale fermentors where liquid height which the bubbles must traverse prior to disengagement is so much greater. Bandyopadhay and

Humphrey[12] give a detailed description of this method. According to Dunn and Einsele[11] the dynamic gassing out method is subject to large errors when gas phase dynamics and oxygen electrode response time are not considered. Linek, Sobotka, and Prokop[13] found that the dynamic method gives accurate values of K_La only within a limited range of conditions. Linek and Vacek[14] showed that substantial error could be introduced by neglecting the oxygen probe response during the startup period when aeration is re-initiated.

The chemical or Winkler method[15] used extensively in water treatment, can be used when water only is aerated. It requires the periodic withdrawing of samples, the oxygen level is then determined by oxidation of manganous ions, excess of which is made to liberate iodine from potassium iodide. The iodine is back-titrated with sodium thiosulfate.

The biological method employs the use of an organism such as Aerobacter aerogenes whose growth rate is controlled in a known manner by oxygen uptake. The organism must be grown in a medium that does not limit growth. The attainment of the same growth rate in different fermentors indicate equal values of K_La. The use of this method in the scale-up of fermentors is described by Lumb, Mercer, and Wilkin.[16]

The oxygen balance method uses the steady state oxygen balance equation: $RO_2 = K_L a \ (C^* - C_L)$

It requires the direct measurement of oxygen concentration in the exhaust gas and of dissolved oxygen in the actual fermentation medium. From these measurements, all terms in the above equation can be calculated. Siegell and Gaden[17] expressed the opinion that this is the best method of evaluating the oxygen transfer capabilities of fermentors because no assumptions need to be made about the effects of cells, surface active agents, and viscosity. The disadvantage in using this method to characterize the oxygen transfer capabilities of fermentors is that the actual fermentation medium, containing living cells, which is used, is difficult to reproduce exactly because a living culture in a batch fermentation is constantly changing with time. It would therefore appear that the oxygen balance method is more suitable in determining the oxygen uptake rates of specific fermentations rather than the oxygen transfer capabilities of fermentors.

Most of the above methods require the use of a steam sterilizable dissolved oxygen probe. There are two types of probes generally used, the polarographic probe and the galvanic probe. A complete description of the galvanic probe and its operating principles are given by Phillips and Johnson,[18] and Johnson, Borkowski, and Engblom,[19] with recent improvements described by Borkowski and Johnson.[20] Polarographic probes are described by Bartholomew, Karow, Sfat, and Wilhelm,[10] Steel and Brierly,[21] and Clark.[22] Tuffile and Pinho[4] have evaluated both type probes, and although the polarographic probe was found to be more accurate and sensitive, the galvanic probe was declared more rugged and dependable.

II. THEORY

The equations used for the calculations of the volumetric liquid phase oxygen mass transfer coefficient, K_La (hr.$^{-1}$) and the oxygen transfer rate, OTR or RO_2, (mmoles/l.hr.) are the following:

$K_LA = RO_2/(OXY*.02077-DO_4*.04350\ E-1)$ and

$RO_2 = AF4*273.1/297.1*(20.95-OXY)*600.0/22.40/WEIGHT$

The above equations are written in Foxboro Process Language, the language of the Fox 2/10 computer used, and can be found in the Computer Program Printout (see Figure I., underlined equations). These equations are developed below.

The instantaneous volumetric oxygen transfer or uptake rate, designated as RO_2 in the computer program printout, is determined from a steady state oxygen mass balance across the fermentor and the "broth" volume in the vessel:

$$RO_2 = \underbrace{\frac{(AF4)(0.2095)(60)}{V(0.0224)}}_{\text{oxygen in}} - \underbrace{\frac{(AF4)(\bar{C})(60)}{V(0.0224)}}_{\text{oxygen out}} = \frac{(AF4)(0.2095-\bar{C})(60)}{V(0.0224)} \qquad (1)$$

where AF4 = Fermentor aeration rate in liters/min. expressed at 0°C. and 1.0 atmosphere absolute pressure (STP).

$\overline{C}$ = Decimal or mole volumetric fraction of O_2 in fermentor exit gas, determined from the exit gas paramagnetic oxygen analyzer.

V = Volume of "broth" in vessel, in liters.

The term 0.0224 is the molar volume of an ideal gas expressed as 0.0224 liters/millimole of ideal gas at STP. The factor 60 merely converts the aeration rate from liters per minute to liters per hour. Because the fermentor used was equipped with load cells, which measured the "broth" weight in kilograms, the "broth" volume in equation (1) was replaced with the "broth" weight, designated as WEIGHT in the computer program printout, assuming the densities of the CMC solutions used was approximately that of water. The volumetric % oxygen in the exit gas, as measured by the paramagnetic oxygen analyzer, designated as OXY in the computer program printout, divided by 100 yields the decimal or mole fraction $\overline{C}$.

Substituting WEIGHT for V and OXY for $\overline{C}$ in equation (1) gives:

RO_2=(AF4)(273.1/297.1)(20.95-OXY)(600)/(22.4)(WEIGHT) (2)

which is the exact form of the equation used in the computer program printout. The factor $\frac{273.1}{297.1}$ in equation

(2) is a correction factor needed because the airflow controller output reading is defined at 24°C. (297.1°K.) and 1 atmosphere rather than 0°C. and 1 atmosphere.

The volumetric oxygen mass transfer coefficient, K_La, designated as K L A in the computer printout, is determined from an oxygen mass balance equation of the form:

$$\frac{d(VC_L)}{dt} = K_La(C_L^* - C_L)(V) - RO_2 \qquad (3)$$

accumulation rate of oxygen in liquid	rate of transfer of oxygen into liquid	oxygen uptake rate

where:

V = "broth" volume in liters

t = time, in hours

C_2 = actual concentration of oxygen in bulk liquid, in millimoles/l.

K_La = liquid phase oxygen mass transfer coefficient in $hr.^{-1}$

C_L^* = oxygen concentration in the bulk liquid at equilibrium with the partial pressure of oxygen in the contacted gas, in millimoles/l.

RO_2 = oxygen uptake rate by sulfite oxidation in millimoles O_2/l.hr.

The above equation is valid assuming the dispersed gas and liquid phases are well-mixed. Assuming further steady state conditions and constant volume, equation 3 becomes:

$$RO_2 = K_La(C_L^* - C_L) \quad (4)$$

Solving for K_La: $K_La = RO_2/(C_L^* - C_L)$ $(hr.^{-1})$ (5)

In the above equation the term C_L is usually assumed to be zero, when using the sulfite method, due to the rapid reaction rate of the sulfite oxidation reaction.[4]

In the experiments conducted, the term C_L, was often very close to zero, but the term was left in for completeness since it is present in the standard equation normally used to calculate K_La in actual biological fermentations. In equation (5) RO_2 is calculated using equation (2) and the term $(C_L^* - C_L)$ can be written as follows:

$$(C_L^* - C_L) = \left(\frac{OXY}{100}\right)\left(\frac{1253}{760}\right)\left(\frac{1.26 \text{ mmoles } O_2}{\text{liter}}\right) - \left(\frac{DO4}{100}\right)(0.2095)\left(\frac{1253}{760}\right)\left(\frac{1.26 \text{ mmoles } O_2}{\text{liter}}\right) \quad (6)$$

where OXY = the volumetric % oxygen in the exit gas, determined from the paramagnetic oxygen analyzer.

DO4 = the % of saturation of dissolved oxygen at 10.0 p.s.i.g. back pressure as measured by a Johnson - Borkowski type membrane probe.

The 1.26 factor is the solubility of pure oxygen in water at 25°C. and partial pressure of 760 mm Hg. This factor must be corrected to represent the actual conditions of the dry exit gas, as follows:

Absolute pressure in fermentor = 1277 mm Hg (10 p.s.i.g.)

Vapor pressure water @ 25°C. = 24 mm Hg

Absolute pressure of dry exit gas = 1253 mm Hg (by difference)

The correction factor is therefore $\frac{1253}{760}$

It is assumed here that the solubility of oxygen in the CMC solutions used is essentially the same as in distilled water at the same temperature. Multiplication together of the various factors in equation (6) gives the equation found in the computer program printout:

KLA = RO2/((OXY) (.02077) - (DO4) (.00435)) (7)

III. EXPERIMENTAL METHOD

A 380 liter jacketed and fully baffled stainless steel fermentor was used as the reaction vessel in all experiments conducted. (See Figure II.) The vessel was equipped with load cells, a 3 hp agitator with 3 four-bladed turbines, tachometer, torque meter, automatic vessel pressure control, automatic airflow control, automatic temperature control and a Johnson - Borkowski type membrane dissolved oxygen probe connected to a potentiometer and 0-10mv recorder.

A sample line was connected from the exhaust air line to a paramagnetic oxygen analyzer. The sample gas was first passed through a series of filters, condensers, a pressure regulator, and flowmeter before entering the analyzer to ensure that the sample was free from water vapor and any entrained liquid and was delivered at a controlled flowrate of about 2 CFH. This was necessary because of the sensitivity of paramagnetic oxygen analyzers to water vapor and flowrate. Output signals from load cells, temperature controller, vessel pressure controller, airflow controller, torque meter, tachometer, dissolved oxygen probe, and oxygen analyzer were all connected to an on line Foxboro 2/10 computer. (See Figure III.) The computer was programmed to print out these parameters as well as calculated values of volumetric oxygen uptake rates (RO_2) and volumetric oxygen mass transfer coefficients (K_La) every two minutes on a teletype. (See Figure I. for computer program printout.)

The reaction medium consisted of 230 to 250 kilograms of a solution of 100 centipoise sodium carboxymethylcellulose (CMC) in water. In order to completely dissolve the CMC in water, the mixture was heated, using steam on the jacket to 90°C, with vigorous agitation, and held at this temperature for 30 minutes, and then cooled down to 25°C. The amount of carboxymethylcellulose was varied to simulate different fermentation viscosities. Medium viscosities of approximately 1, 60, 170, 320, and 730 centipoise were obtained using carboxymethylcellulose concentrations of approximately 0, 32, 36, 48, and 60 grams/liter, respectively. All viscometer measurements were made on a Brookfield Synchro-lectric Viscometer Model LVF, using a #2 spindle at 30 r.p.m. and 25°C. for 60 seconds. The vessel temperature was controlled automatically at 25°C. and the vessel pressure was controlled automatically at 10 p.s.i.g. The dissolved oxygen electrode was calibrated by applying maximum airflow and agitation rates and adjusting the potentiometer to achieve 100% of scale on the dissolved oxygen recorder, which represents an oxygen saturation of 100%. After the calibration, the vessel was de-pressurized, and enough sodium sulfite was manually added to achieve a 0.2 M solution. The vessel was then closed and re-pressurized at 10 p.s.i.g. The desired initial agitation and aeration rates were then set and after stabilization of airflow rate, temperature, and vessel pressure, approximately 30 liters of catalyst, a .003 M solution of copper sulfate ($CuSO_4$), was transferred into the fermentor from a pressurized holding tank which was hard-piped to the fermentor.

As the sulfite reaction proceeded the Foxboro 2/10 computer printed out instantaneous values of temperature, aeration rate, back pressure, agitation speed, weight, RO_2 and K_La every 2 minutes. After steady state was achieved, about 8 to 10 minutes, either the agitation or aeration rate was changed, all other parameters remaining constant, and the effect on K_La was readily observable on the computer printout.

IV. DISCUSSION OF RESULTS AND CONCLUSIONS

The actual instantaneous values of K_La, along with instantaneous values of the oxygen transfer rate, RO_2, are tabulated in Tables I. through V. These instantaneous values were obtained from the computer printouts, examples of the actual computer printouts are found in the appendix. Results of the experiments are summarized in Table VI., showing average K_La values for different aeration rates, agitation rates, and "broth" or CMC solution viscosities. The K_La values in Table VI. are an average of three or more data points as printed out by the computer after a steady state was reached.

The data in Table VI. indicate that K_La increases with increasing aeration rates, which was expected. The data indicate that K_La increases with increasing agitation, which also was expected. K_La is observed to decrease with increasing viscosity which is also expected. A close look at the data indicates that the effect on K_La, of increasing either aeration or agitation, diminishes with increasing viscosity.

It is interesting to note that the corresponding K_La values at different aeration and agitation rates did not change appreciably when the viscosity of the CMC solution was increased from 320 centipoise to 730 centipoise, suggesting that after a critical viscosity is reached, there is no further influence of viscosity on K_La. This can be a topic for further investigation.

It is also to be noted that at low viscosities and high agitation, the sulfite reaction was so fast that the percent oxygen in the exit gas as measured by the paramagnetic oxygen analyzer, went below scale, preventing the determination of K_La with the equipment used. During the course of each experiment, despite automatic temperature control, the temperature at times increased from 25°C. to 27°C. due to the exothermic nature of the sulfite reaction, causing K_La values to slightly increase during assumed periods of steady state, but this introduced only small error in the calculated K_La values.

In view of the above results, it can be concluded that the modified sulfite oxidation method described can be a useful tool for obtaining K_La data which adequately characterize the oxygen mass transfer capability of a fermentor, when used in conjunction with a medium, such as CMC solution, which simulates the viscosity of a typical non-Newtonian fermentation broth.

To best use the method described, a material should first be found which closely simulates the rheological properties of the particular fermentation broth in question. There undoubtedly exist materials, other than carboxymethylcellulose, which closely simulate the rheological properties of typical as well as atypical fermentation broths. This, however, would be a subject of a separate study.

It is noteworthy to emphasize the important role that the on line computer plays in this method in providing instantaneous K_La values as the agitation and aeration conditions of the fermentor are varied. Instantaneous K_La values enable us to determine how long it will take for the oxygen transfer rate to change in response to a change in aeration and/or agitation. The computer also provides faster results than any other method previously employed to obtain K_La data. The simultaneous printout of other instantaneous fermentor parameters, such as temperature, back pressure, vessel weight, agitation rate, and aeration rate, along with the instantaneous K_La values, provides written evidence and assurance that these parameters were in fact controlled during the course of the experimental run.

The accuracy of the K_La values obtained are limited by how well other parameters, such as temperature, back pressure, agitation and aeration rates are controlled, as well as the accuracy of the measuring devices employed, such as the dissolved oxygen electrode, the exit gas oxygen analyzer, and the load cells. Therefore, as the accuracy of these sensing devices and control instrumentation are improved, the accuracy of the K_La values obtained by this method will be improved.

FIGURE I.

COMPUTER PROGRAM PRINTOUT

```
DEF:TASK:SULFITE2Ø4(1);
    ACT:DO4;
    ACT:OXY1;
    ACT:OXY;
    ACT:CO2;
    ACT:BP4;
    ACT:AF4;
    ACT:T4;
    ACT:TORQUE;
    ACT:WEIGHT;
    ACT:SPEED;
    LET:OGO1=Ø;
    LET:OGO2=Ø;
    LET:OGO3=Ø;
    LET:OGO4=1;
    LET:RO2=AF4*273.1/297.1*(2Ø.95-OXY)*6ØØ.Ø/22.4Ø/WEIGHT;
    LET:KLA=RO2/(OXY*.Ø2Ø77-DO4*.Ø435Ø E-1);
    PRINT(1)"SULFITE EXPERIMENT TK2Ø4

 2: PRINT(1)(1,3,Ø)"DO2="DO4," %

    LET:RO2=AF4*273.1/297.1*(2Ø.95-OXY)*6ØØ.Ø/22.4Ø/WEIGHT;
    LET:KLA=RO2/(OXY*.Ø2Ø77-DO4*.Ø435Ø E-1);
    PRINT(1)(1,4,2)"EXIT O2="OXY," %

    PRINT(1)(1,3,1)"TEMP.="T4," DEG.C.

    PRINT(1)(1,3,Ø)"AIRFLOW="AF4," SLPM

    PRINT(1)(1,3,1)"BACKPRESSURE="BP4," PSIG.

    PRINT(1)(1,3,Ø)"AGIT.SPEED="SPEED," RPM

    PRINT(1)(1,3,Ø)"TORQUE="TORQUE," IN.LBS.

    PRINT(1)(1,3,Ø)"WEIGHT="WEIGHT," KGS.

    PRINT(1)(1,3,2)"CO2="CO2," %

    PRINT(1)(1,5,2)"RO2="RO2," M-MOLES O2/L.HR.

    PRINT(1)(1,5,2)"KLA="KLA," 1/HR.


    WAIT:6Ø;
    GOTO:2;
```

FIGURE II.

TANK CONFIGURATION

Drive: 3 hp, 400 r.p.m. max. Shaft: 64" length x 1¼" diam.

Distance from bottom of shaft to bottom of tank = 3½"

Turbines (3): 9¼" diam., 4 blades, 2½" x 3$\frac{3}{8}$" x $\frac{1}{8}$"

Aeration: 600 S.L.P.M. max.

Sparger: $\frac{3}{4}$" diam. line with 5$\frac{1}{8}$" diam. ring with 32 holes, $\frac{1}{8}$" I.D. spaced ½" apart

Baffles (4): 48" x 2" x $\frac{3}{8}$", spaced 90° apart

Tank Cap.: 380 L. max.

Tank Diam.: T = 22"

Turbine Diam.: D = 9¼"

Blade Length: L = 3$\frac{3}{8}$"

Blade Width: W = 2½"

D/T = 0.42 L/D = 0.37

W/D = 0.27 L/W = 1.35

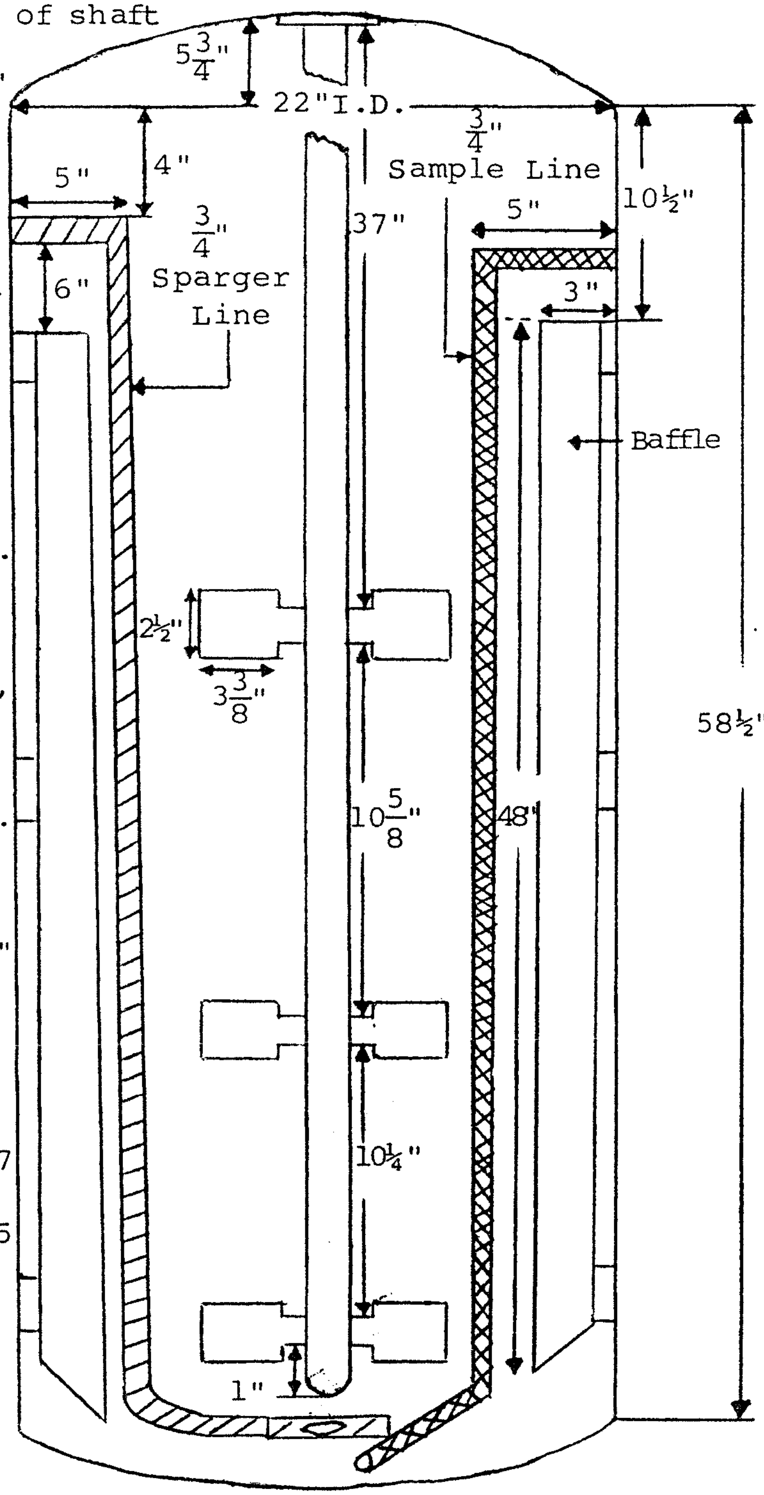

FIGURE III.

DIAGRAM OF EQUIPMENT USED

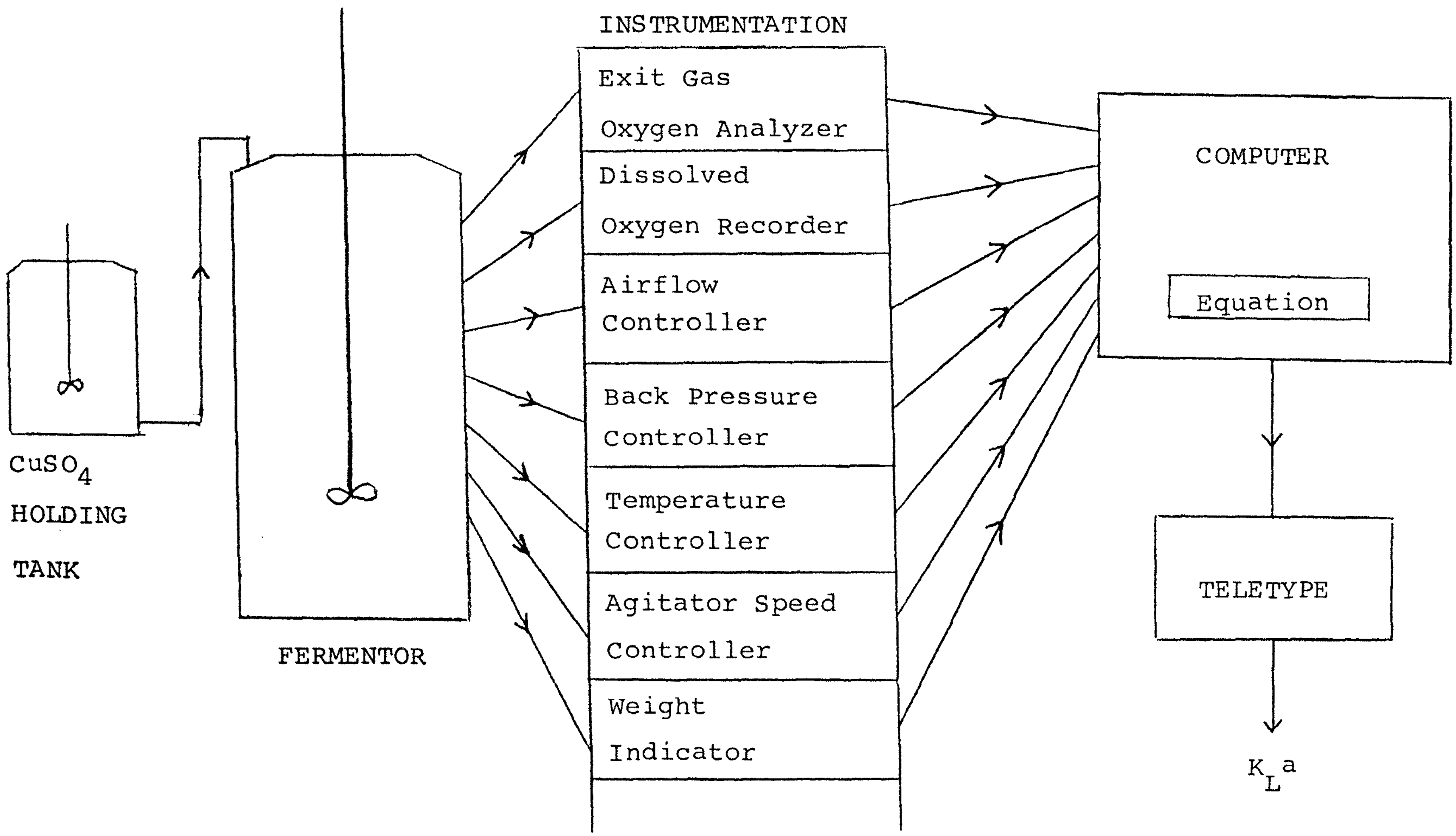

TABLE I.

INSTANTANEOUS VALUES OF K_La ($hr.^{-1}$) AND VOLUMETRIC OXYGEN TRANSFER RATES, RO_2 (mmoles/l.hr.)

VISCOSITY = 1 CP. @ 30 R.P.M. & 25°C.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
155	154	67.2	218
156	155	68.6	222
157	155	66.6	216
158	155	69.0	223
300	155	95.1	288
310	155	92.3	279
306	154	93.8	285
309	155	93.0	283
301	155	95.8	293
303	155	97.7	299
312	155	96.1	296
456	155	127	385
445	156	126	381
450	156	128	388
462	156	126	383
593	156	149	445
599	156	151	450
607	156	156	464

TABLE I.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
599	156	155	462
611	303	249	813
626	302	256	859
618	303	251	843
623	0	51.3	133
604	0	51.0	132
595	0	53.0	137
609	0	51.7	134
622	0	50.6	131
449	0	35.9	92
464	0	34.6	88
455	0	33.7	86
456	0	34.5	88
298	0	21.3	54
301	0	20.1	51
301	0	20.0	50.4
153	0	8.9	22
155	0	7.9	20
151	0	7.9	20

TABLE II.

INSTANTANEOUS VALUES OF K_La ($hr.^{-1}$) AND VOLUMETRIC OXYGEN TRANSFER RATES, RO_2, (mmoles/l.hr.)

VISCOSITY = 60 CP. @ 30 R.P.M. & 25°C.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
158	152	13.9	33.9
155	152	13.5	32.9
152	152	14.3	34.8
151	152	14.5	35.3
310	153	20.5	49.2
296	153	19.7	47.1
302	153	20.7	49.6
456	153	24.8	59.0
450	154	26.3	62.7
467	154	26.5	63.2
605	154	32.2	76.6
591	153	31.5	74.9
619	153	32.5	77.4
445	0	18.3	43.0
457	0	17.4	40.8
462	0	17.5	41.1
454	0	16.7	39.3
298	0	11.9	27.8

TABLE II.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
300	0	11.6	27.1
304	0	11.6	27.1
158	0	6.5	15.3
163	0	6.2	14.5
157	0	6.0	14.0
158	310	57.4	160
158	310	57.1	161
162	312	60.1	171
163	309	63.2	181
310	313	87.4	235
296	314	88.4	239
469	304	107	280
469	304	112	295
445	304	109	289
465	304	116	307
604	305	150	397
598	304	138	361
578	304	139	367
577	304	138	365
602	304	149	396
466	305	170	494
452	305	174	502

TABLE III.

INSTANTANEOUS VALUES OF K_La ($hr.^{-1}$) AND VOLUMETRIC OXYGEN TRANSFER RATES, RO_2, (mmoles/l.hr.)

VISCOSITY = 170 CP. @ 30 R.P.M. & 25°C

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
163	152	6.0	14.3
159	152	5.7	13.7
161	152	6.1	14.5
303	151	9.0	21.6
306	152	8.8	21.0
313	152	8.7	20.8
467	152	11.9	28.2
445	151	11.7	27.7
467	152	11.5	27.3
595	152	14.3	34.0
596	152	14.0	33.1
625	152	14.4	34.2
605	152	14.7	35.0
595	152	14.3	33.9
621	0	10.9	25.7
602	0	10.9	25.8
589	0	10.7	25.4
469	0	8.5	20.1

TABLE III.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
460	0	8.6	20.4
448	0	8.7	20.6
297	0	5.8	13.8
301	0	6.0	14.1
304	0	5.8	13.8
155	0	2.9	6.8
153	0	3.0	7.0
152	0	2.8	6.6
156	0	2.9	6.8
151	309	16.0	39.8
150	311	18.0	45.0
155	311	18.3	45.7
153	311	17.8	44.6
299	307	22.7	55.4
306	307	23.3	56.9
310	308	22.7	55.5
446	308	27.8	67.4
452	307	28.3	68.5
453	308	28.2	68.3
598	310	31.2	75.3
604	310	30.6	73.7
590	309	31.3	75.5

TABLE III.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
153	404	32.2	84.9
151	405	32.5	86.1
152	387	32.2	85.5
151	388	33.2	88.0
301	400	40.6	103
312	402	41.0	104
299	401	41.4	105
467	405	47.2	117
449	405	48.4	120
469	405	47.9	119
445	406	48.3	120
610	407	60.1	149
598	407	61.0	152
596	410	61.5	153
613	410	62.5	156
601	408	63.2	158
602	407	64.5	161
612	407	64.9	163
604	408	66.2	166
606	407	63.7	160
602	410	64.5	162

TABLE IV.

INSTANTANEOUS VALUES OF K_La ($hr.^{-1}$) AND VOLUMETRIC OXYGEN TRANSFER RATES, RO_2, (mmoles/l.hr.)

VISCOSITY = 320 CP. @ 30 R.P.M. & 25°C

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
155	150	3.5	8.8
158	150	3.5	8.6
157	150	3.5	8.7
155	149	3.5	8.7
157	310	7.9	19.5
156	309	8.1	20.5
156	309	8.3	20.6
157	309	8.2	20.4
157	309	8.5	20.9
157	409	13.8	34.5
155	410	15.0	37.5
155	412	15.4	38.4
154	411	15.6	39.1
157	0	2.3	5.6
157	0	2.2	5.3
159	0	2.2	5.3
295	0	4.2	10.0
309	0	4.1	9.7

TABLE IV.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
304	0	4.2	9.9
308	0	4.1	9.8
309	156	6.1	14.6
310	156	5.9	14.1
302	156	6.0	14.4
310	156	5.8	14.0
307	311	10.8	26.3
307	308	11.1	26.8
306	309	11.1	26.6
306	308	11.3	27.4
307	307	11.4	27.4
306	403	17.9	43.4
306	402	18.0	43.6
305	403	18.3	44.3
306	402	18.7	45.4
308	408	18.4	44.7
448	410	22.7	54.5
457	411	22.1	53.1
461	408	21.6	51.9
456	407	22.1	53.0
455	306	14.8	35.2

TABLE IV.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
451	305	14.8	35.0
465	305	14.9	35.3
455	305	15.0	35.9
450	152	8.1	19.1
453	152	8.1	19.0
453	152	8.1	19.1
455	152	8.1	19.1
462	152	8.3	19.6
447	152	8.4	19.6
454	152	8.5	19.9
461	152	8.3	19.5
458	152	8.4	19.6
448	152	8.5	20.0
452	152	8.1	19.1
451	152	8.3	19.6
455	152	8.4	19.7
459	152	8.3	19.4
464	152	8.6	20.1
448	0	6.5	15.2
447	0	6.4	15.1
450	0	6.4	14.9

TABLE IV.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
448	0	6.5	15.1
451	0	6.7	15.6
464	0	6.7	15.7
457	0	6.6	15.4
462	0	6.7	15.6
454	0	6.8	15.8
599	151	11.2	26.2
604	152	10.9	25.4
605	152	10.8	25.3
597	152	10.9	25.6
597	151	11.0	25.7
615	151	11.2	26.3
622	151	10.9	25.5
604	151	10.8	25.3
609	151	10.9	25.5
598	310	18.5	43.7
619	310	18.2	43.0
620	310	18.5	43.7
609	310	18.8	44.6
621	409	25.7	61.3
622	410	26.0	61.9

TABLE IV.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
621	411	26.5	63.0
617	411	26.6	63.2
608	411	26.8	64.0
606	412	27.2	64.8
597	0	9.5	22.1
611	0	9.2	21.4
609	0	9.2	21.4
619	0	9.2	21.4
619	0	9.0	20.9
611	0	9.1	21.3
607	0	9.4	21.9
609	0	9.1	21.3
606	0	9.5	22.1

TABLE V.

INSTANTANEOUS VALUES OF K_La ($hr.^{-1}$) AND VOLUMETRIC OXYGEN TRANSFER RATES, RO_2, (mmoles/l.hr.)

VISCOSITY = 730 CP. @ 30 R.P.M. & 25°C

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
150	153	3.98	10.5
152	152	4.01	10.5
151	151	4.07	10.7
150	152	4.13	10.9
298	152	6.78	17.8
309	152	6.63	17.4
297	152	6.19	16.2
437	152	8.77	22.9
453	152	8.74	22.8
459	152	8.62	22.5
611	152	11.0	28.6
612	152	11.0	28.8
621	152	10.9	28.4
619	0	9.9	25.7
621	0	9.7	25.3
594	0	9.9	25.7
448	0	8.2	21.4
446	0	7.6	19.8

TABLE V.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
445	0	7.9	20.6
312	0	5.5	14.3
296	0	5.6	14.5
307	0	5.7	15.0
154	0	3.0	7.9
158	0	3.0	7.9
155	0	3.0	7.9
150	306	8.3	22.2
152	307	8.2	21.8
157	306	7.8	20.9
157	306	7.6	20.1
154	304	7.5	20.1
306	309	12.0	31.7
306	308	11.8	31.0
306	308	11.5	30.3
454	309	15.8	41.6
470	309	14.9	39.1
449	308	14.6	38.3
617	308	19.0	49.9
619	309	18.6	48.7
588	309	18.4	48.1

TABLE V.

Airflow S.L.P.M.	Agitation r.p.m.	RO_2	K_La
162	387	10.5	28.1
161	389	10.8	28.8
161	389	10.9	29.3
300	420	16.9	45.1
300	415	17.0	45.1
307	404	17.2	45.6
309	406	16.9	44.9
299	397	16.4	43.6
302	401	17.1	45.3
450	404	20.1	53.1
453	406	21.2	55.9
467	404	21.0	55.2
454	407	20.1	52.9
611	408	26.3	69.0
612	408	25.3	66.5
597	408	25.1	65.7
609	408	26.2	68.8
624	409	26.4	69.2
597	411	25.8	67.5
594	410	27.2	71.0
621	409	27.4	71.5
615	410	26.2	68.5
587	413	26.6	69.5

TABLE VI.

AVERAGE VALUES OF $K_L a$ (hr.$^{-1}$) MEASURED AT DIFFERENT VISCOSITIES, AERATION AND AGITATION RATES

Agitation r.p.m.	Airflow S.L.P.M. 150	300	450	600
	Viscosity = 1 cp. @ 30 r.p.m. & 25°C			
0	21	52	88	133
150	220	289	384	455
300	*	*	*	838
400	*	*	*	*
	Viscosity = 60 cp. @ 30 r.p.m. & 25°C			
0	15	27	41	52
150	35	48	63	76
350	165	235	260	360
400	*	*	*	*
	Viscosity = 170 cp. @ 30 r.p.m. & 25°C			
0	7	14	20	26
150	14	21	28	34
300	45	55	68	75
400	86	103	120	140

TABLE VI.

Agitation r.p.m.	Airflow S.L.P.M. 150	300	450	600
	Viscosity = 320 cp. @ 30 r.p.m. & 25°C			
0	5	10	15	21
150	8.5	14	20	25
300	20	26	35	44
400	30	44	53	63
	Viscosity = 730 cp. @ 30 r.p.m. & 25°C			
0	8	15	21	25
150	11	17	23	29
300	21	31	40	49
400	29	45	54	69

* Unmeasurable % oxygen off-scale

APPENDIX

The following are selected representative portions of the actual computer printout from which the data in Table I. were obtained.

```
DO2=    9 %
EXIT O2= 17.81 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 300 SLPM
BACKPRESSURE=  9.8 PSIG.
AGIT.SPEED= 155 RPM
TORQUE=  66 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .03 %
RO2=  95.05 M-MOLES O2/L.HR.
KLA= 288.40 1/HR.
```

```
DO2=    9 %
EXIT O2= 17.83 %
TEMP.= 25.1 DEG.C.
AIRFLOW= 310 SLPM
BACKPRESSURE=  9.8 PSIG.
AGIT.SPEED= 155 RPM
TORQUE=  66 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .03 %
RO2=  92.32 M-MOLES O2/L.HR.
KLA= 278.90 1/HR.
```

```
DO2=    9 %
EXIT O2= 17.82 %
TEMP.= 25.4 DEG.C.
AIRFLOW= 306 SLPM
BACKPRESSURE=  9.8 PSIG.
AGIT.SPEED= 154 RPM
TORQUE=  67 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .03 %
RO2=  93.81 M-MOLES O2/L.HR.
KLA= 284.90 1/HR.
```

```
DO2=    9 %
EXIT O2= 17.76 %
TEMP.= 25.6 DEG.C.
AIRFLOW= 309 SLPM
BACKPRESSURE=  9.7 PSIG.
AGIT.SPEED= 155 RPM
TORQUE=  66 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .03 %
RO2=  93.00 M-MOLES O2/L.HR.
KLA= 283.20 1/HR.
```

DO2= 10 %
EXIT O2= 18.12 %
TEMP.= 25.5 DEG.C.
AIRFLOW= 456 SLPM
BACKPRESSURE= 9.9 PSIG.
AGIT.SPEED= 155 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 252 KGS.
CO2= .03 %
RO2= 126.97 M-MOLES O2/L.HR.
KLA= 384.80 1/HR.

DO2= 10 %
EXIT O2= 18.08 %
TEMP.= 25.7 DEG.C.
AIRFLOW= 445 SLPM
BACKPRESSURE= 9.8 PSIG.
AGIT.SPEED= 156 RPM
TORQUE= 64 IN.LBS.
WEIGHT= 252 KGS.
CO2= .03 %
RO2= 125.82 M-MOLES O2/L.HR.
KLA= 381.30 1/HR.

DO2= 10 %
EXIT O2= 18.08 %
TEMP.= 25.7 DEG.C.
AIRFLOW= 450 SLPM
BACKPRESSURE= 9.7 PSIG.
AGIT.SPEED= 156 RPM
TORQUE= 64 IN.LBS.
WEIGHT= 252 KGS.
CO2= .03 %
RO2= 127.81 M-MOLES O2/L.HR.
KLA= 388.40 1/HR.

DO2= 10 %
EXIT O2= 18.03 %
TEMP.= 25.6 DEG.C.
AIRFLOW= 462 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED= 156 RPM
TORQUE= 64 IN.LBS.
WEIGHT= 252 KGS.
CO2= .03 %
RO2= 126.43 M-MOLES O2/L.HR.
KLA= 382.90 1/HR.

The following are selected representative portions of the actual computer printout from which the data in Table II. were obtained.

```
DO2=    1 %
EXIT O2= 20.03 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 155 SLPM
BACKPRESSURE=  9.6 PSIG.
AGIT.SPEED= 152 RPM
TORQUE=  69 IN.LBS.
WEIGHT= 253 KGS.
CO2=  .06 %
RO2=  13.53 M-MOLES O2/L.HR.
KLA=  32.88 1/HR.

DO2=      %
EXIT O2= 19.99 %
TEMP.= 24.5 DEG.C.
AIRFLOW= 152 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED= 152 RPM
TORQUE=  68 IN.LBS.
WEIGHT= 254 KGS.
CO2=  .06 %
RO2=  14.29 M-MOLES O2/L.HR.
KLA=  34.77 1/HR.

DO2=      %
EXIT O2= 19.98 %
TEMP.= 24.3 DEG.C.
AIRFLOW= 151 SLPM
BACKPRESSURE=  9.7 PSIG.
AGIT.SPEED= 152 RPM
TORQUE=  69 IN.LBS.
WEIGHT= 254 KGS.
CO2=  .06 %
RO2=  14.52 M-MOLES O2/L.HR.
KLA=  35.28 1/HR.

DO2=      %
EXIT O2= 19.97 %
TEMP.= 24.1 DEG.C.
AIRFLOW= 216 SLPM
BACKPRESSURE= 10.3 PSIG.
AGIT.SPEED= 153 RPM
TORQUE=  68 IN.LBS.
WEIGHT= 254 KGS.
CO2=  .06 %
RO2=  14.39 M-MOLES O2/L.HR.
KLA=  34.98 1/HR.
```

```
DO2=        %
EXIT O2= 20.26 %
TEMP.= 24.1 DEG.C.
AIRFLOW= 310 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED= 153 RPM
TORQUE=  67 IN.LBS.
WEIGHT= 253 KGS.
CO2=  .07 %
RO2=  20.53 M-MOLES O2/L.HR.
KLA=  49.18 1/HR.

TYPE:DO4;.7500

DO2=        %
EXIT O2= 20.27 %
TEMP.= 24.1 DEG.C.
AIRFLOW= 296 SLPM
BACKPRESSURE=  9.6 PSIG.
AGIT.SPEED= 153 RPM
TORQUE=  66 IN.LBS.
WEIGHT= 253 KGS.
CO2=  .07 %
RO2=  19.66 M-MOLES O2/L.HR.
KLA=  47.07 1/HR.

TYPE:DO4;.7226

DO2=        %
EXIT O2= 20.26 %
TEMP.= 24.2 DEG.C.
AIRFLOW= 302 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED= 153 RPM
TORQUE=  67 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .07 %
RO2=  20.73 M-MOLES O2/L.HR.
KLA=  49.63 1/HR.
```

```
DO2=        %
EXIT O2= 20.36 %
TEMP.= 24.3 DEG.C.
AIRFLOW= 456 SLPM
BACKPRESSURE=  9.8 PSIG.
AGIT.SPEED= 153 RPM
TORQUE=  66 IN.LBS.
WEIGHT= 253 KGS.
CO2=  .07 %
RO2=  24.80 M-MOLES O2/L.HR.
KLA=  59.04 1/HR.

DO2=        %
EXIT O2= 20.36 %
TEMP.= 24.3 DEG.C.
AIRFLOW= 450 SLPM
BACKPRESSURE=  9.7 PSIG.
AGIT.SPEED= 154 RPM
TORQUE=  65 IN.LBS.
WEIGHT= 253 KGS.
CO2=  .07 %
RO2=  26.34 M-MOLES O2/L.HR.
KLA=  62.70 1/HR.

TYPE:DO4;.6484

DO2=        %
EXIT O2= 20.36 %
TEMP.= 24.4 DEG.C.
AIRFLOW= 467 SLPM
BACKPRESSURE=  9.8 PSIG.
AGIT.SPEED= 154 RPM
TORQUE=  64 IN.LBS.
WEIGHT= 253 KGS.
CO2=  .07 %
RO2=  26.52 M-MOLES O2/L.HR.
KLA=  63.21 1/HR.

DO2=        %
EXIT O2= 20.38 %
TEMP.= 24.5 DEG.C.
AIRFLOW= 605 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED= 154 RPM
TORQUE=  64 IN.LBS.
WEIGHT= 253 KGS.
CO2=  .07 %
RO2=  32.18 M-MOLES O2/L.HR.
KLA=  76.61 1/HR.
```

DO2= %
EXIT O2= 20.61 %
TEMP.= 24.7 DEG.C.
AIRFLOW= 587 SLPM
BACKPRESSURE= 9.8 PSIG.
AGIT.SPEED= 3 RPM
TORQUE= 45 IN.LBS.
WEIGHT= 253 KGS.
CO2= .07 %
RO2= 19.91 M-MOLES O2/L.HR.
KLA= 46.78 1/HR.

DO2= %
EXIT O2= 20.58 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 619 SLPM
BACKPRESSURE= 9.8 PSIG.
AGIT.SPEED= 3 RPM
TORQUE= 45 IN.LBS.
WEIGHT= 253 KGS.
CO2= .07 %
RO2= 22.19 M-MOLES O2/L.HR.
KLA= 52.23 1/HR.

DO2= %
EXIT O2= 20.57 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 619 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED= 3 RPM
TORQUE= 45 IN.LBS.
WEIGHT= 253 KGS.
CO2= .07 %
RO2= 22.28 M-MOLES O2/L.HR.
KLA= 52.43 1/HR.

DO2= %
EXIT O2= 20.56 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 600 SLPM
BACKPRESSURE= 9.6 PSIG.
AGIT.SPEED= 3 RPM
TORQUE= 45 IN.LBS.
WEIGHT= 253 KGS.
CO2= .07 %
RO2= 22.21 M-MOLES O2/L.HR.
KLA= 52.30 1/HR.

```
DO2=        %
EXIT O2= 20.54 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 445 SLPM
BACKPRESSURE=  9.7 PSIG.
AGIT.SPEED=    3 RPM
TORQUE=  45 IN.LBS.
WEIGHT= 253 KGS.
CO2=  .07 %
RO2=  18.27 M-MOLES O2/L.HR.
KLA=  43.04 1/HR.

TYPE:DO4;.3242

DO2=        %
EXIT O2= 20.56 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 457 SLPM
BACKPRESSURE=  9.8 PSIG.
AGIT.SPEED=    3 RPM
TORQUE=  45 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .07 %
RO2=  17.36 M-MOLES O2/L.HR.
KLA=  40.76 1/HR.

DO2=        %
EXIT O2= 20.55 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 462 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED=    3 RPM
TORQUE=  45 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .07 %
RO2=  17.48 M-MOLES O2/L.HR.
KLA=  41.06 1/HR.

DO2=        %
EXIT O2= 20.56 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 454 SLPM
BACKPRESSURE=  9.6 PSIG.
AGIT.SPEED=    3 RPM
TORQUE=  45 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .07 %
RO2=  16.72 M-MOLES O2/L.HR.
KLA=  39.28 1/HR.
```

The following are selected representative portions of the actual computer printout from which the data in Table III. were obtained.

```
DO2=     1  %
EXIT O2= 2Ø.61  %
TEMP.= 24.5 DEG.C.
AIRFLOW= 3Ø3 SLPM
BACKPRESSURE=   9.7 PSIG.
AGIT.SPEED= 151 RPM
TORQUE=   67  IN.LBS.
WEIGHT= 275 KGS.
CO2=   .Ø9  %
RO2=    9.Ø4 M-MOLES O2/L.HR.
KLA=  21.56 1/HR.


TYPE:DO4;1.9727


DO2=     1  %
EXIT O2= 2Ø.63  %
TEMP.= 24.6 DEG.C.
AIRFLOW= 3Ø6 SLPM
BACKPRESSURE=   9.8 PSIG.
AGIT.SPEED= 152 RPM
TORQUE=   67  IN.LBS.
WEIGHT= 275 KGS.
CO2=   .Ø9  %
RO2=    8.83 M-MOLES O2/L.HR.
KLA=  21.Ø3 1/HR.


DO2=     1  %
EXIT O2= 2Ø.63  %
TEMP.= 24.6 DEG.C.
AIRFLOW= 313 SLPM
BACKPRESSURE=   9.7 PSIG.
AGIT.SPEED= 152 RPM
TORQUE=   66  IN.LBS.
WEIGHT= 275 KGS.
CO2=   .Ø9  %
RO2=    8.72 M-MOLES O2/L.HR.
KLA=  2Ø.77 1/HR.
```

DO2= 1 %
EXIT O2= 20.66 %
TEMP.= 24.6 DEG.C.
AIRFLOW= 445 SLPM
BACKPRESSURE= 9.7 PSIG.
AGIT.SPEED= 151 RPM
TORQUE= 67 IN.LBS.
WEIGHT= 275 KGS.
CO2= .09 %
RO2= 11.65 M-MOLES O2/L.HR.
KLA= 27.69 1/HR.

DO2= 1 %
EXIT O2= 20.67 %
TEMP.= 24.7 DEG.C.
AIRFLOW= 467 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 275 KGS.
CO2= .09 %
RO2= 11.48 M-MOLES O2/L.HR.
KLA= 27.28 1/HR.

DO2= 1 %
EXIT O2= 20.68 %
TEMP.= 24.7 DEG.C.
AIRFLOW= 595 SLPM
BACKPRESSURE= 9.6 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 64 IN.LBS.
WEIGHT= 275 KGS.
CO2= .09 %
RO2= 14.30 M-MOLES O2/L.HR.
KLA= 33.95 1/HR.

DO2= 1 %
EXIT O2= 20.69 %
TEMP.= 24.7 DEG.C.
AIRFLOW= 596 SLPM
BACKPRESSURE= 9.5 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 275 KGS.
CO2= .09 %
RO2= 13.96 M-MOLES O2/L.HR.
KLA= 33.13 1/HR.

DO2= 1 %
EXIT O2= 20.68 %
TEMP.= 24.7 DEG.C.
AIRFLOW= 625 SLPM
BACKPRESSURE= 9.7 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 64 IN.LBS.
WEIGHT= 275 KGS.
CO2= .09 %
RO2= 14.39 M-MOLES O2/L.HR.
KLA= 34.16 1/HR.
DO2= 1 %
EXIT O2= 20.68 %
TEMP.= 24.7 DEG.C.
AIRFLOW= 605 SLPM
BACKPRESSURE= 9.7 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 64 IN.LBS.
WEIGHT= 275 KGS.
CO2= .09 %
RO2= 14.72 M-MOLES O2/L.HR.
KLA= 34.95 1/HR.

DO2= 1 %
EXIT O2= 20.68 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 595 SLPM
BACKPRESSURE= 9.6 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 275 KGS.
CO2= .09 %
RO2= 14.28 M-MOLES O2/L.HR.
KLA= 33.89 1/HR.

9/58/20 SPEED 2.375 RPM LOAL 50.00

DO2= 1 %
EXIT O2= 20.67 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 598 SLPM
BACKPRESSURE= 9.5 PSIG.
AGIT.SPEED= 2 RPM
TORQUE= 43 IN.LBS.
WEIGHT= 275 KGS.
CO2= .09 %
RO2= 14.42 M-MOLES O2/L.HR.
KLA= 34.22 1/HR.

DO2= 1 %
EXIT O2= 20.75 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 441 SLPM
BACKPRESSURE= 9.6 PSIG.
AGIT.SPEED= 2 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 274 KGS.
CO2= .08 %
RO2= 7.92 M-MOLES O2/L.HR.
KLA= 18.70 1/HR.

DO2= 1 %
EXIT O2= 20.74 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 469 SLPM
BACKPRESSURE= 9.8 PSIG.
AGIT.SPEED= 2 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 274 KGS.
CO2= .08 %
RO2= 8.52 M-MOLES O2/L.HR.
KLA= 20.12 1/HR.

DO2= 1 %
EXIT O2= 20.74 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 460 SLPM
BACKPRESSURE= 9.7 PSIG.
AGIT.SPEED= 1 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 274 KGS.
CO2= .09 %
RO2= 8.63 M-MOLES O2/L.HR.
KLA= 20.38 1/HR.

DO2= 1 %
EXIT O2= 20.74 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 448 SLPM
BACKPRESSURE= 9.5 PSIG.
AGIT.SPEED= 1 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 274 KGS.
CO2= .09 %
RO2= 8.70 M-MOLES O2/L.HR.
KLA= 20.57 1/HR.

```
DO2=    1 %
EXIT O2= 20.73 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 302 SLPM
BACKPRESSURE=  9.7 PSIG.
AGIT.SPEED=    1 RPM
TORQUE=  44 IN.LBS.
WEIGHT= 274 KGS.
CO2=  .08 %
RO2=    5.60 M-MOLES O2/L.HR.
KLA=  13.23 1/HR.

DO2=    1 %
EXIT O2= 20.73 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 297 SLPM
BACKPRESSURE=  9.8 PSIG.
AGIT.SPEED=    1 RPM
TORQUE=  44 IN.LBS.
WEIGHT= 274 KGS.
CO2=  .09 %
RO2=    5.84 M-MOLES O2/L.HR.
KLA=  13.80 1/HR.

DO2=    1 %
EXIT O2= 20.73 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 301 SLPM
BACKPRESSURE=  9.7 PSIG.
AGIT.SPEED=    1 RPM
TORQUE=  44 IN.LBS.
WEIGHT= 274 KGS.
CO2=  .08 %
RO2=    5.96 M-MOLES O2/L.HR.
KLA=  14.07 1/HR.

DO2=    1 %
EXIT O2= 20.73 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 304 SLPM
BACKPRESSURE=  9.9 PSIG.
AGIT.SPEED=    1 RPM
TORQUE=  44 IN.LBS.
WEIGHT= 274 KGS.
CO2=  .09 %
RO2=    5.83 M-MOLES O2/L.HR.
KLA=  13.76 1/HR.
```

The following are selected representative portions of the actual computer printout from which the data in Table IV. were obtained.

```
DO2=    2 %
EXIT O2= 20.74 %
TEMP.= 23.7 DEG.C.
AIRFLOW= 309 SLPM
BACKPRESSURE= 10.2 PSIG.
AGIT.SPEED= 156 RPM
TORQUE=  23 IN.LBS.
WEIGHT= 250 KGS.
CO2=  .05 %
RO2=   6.12 M-MOLES O2/L.HR.
KLA=  14.58 1/HR.
```

```
DO2=    2 %
EXIT O2= 20.75 %
TEMP.= 23.6 DEG.C.
AIRFLOW= 310 SLPM
BACKPRESSURE= 10.2 PSIG.
AGIT.SPEED= 156 RPM
TORQUE=  22 IN.LBS.
WEIGHT= 250 KGS.
CO2=  .05 %
RO2=   5.94 M-MOLES O2/L.HR.
KLA=  14.14 1/HR.
```

```
DO2=    3 %
EXIT O2= 20.75 %
TEMP.= 23.5 DEG.C.
AIRFLOW= 302 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 156 RPM
TORQUE=  23 IN.LBS.
WEIGHT= 250 KGS.
CO2=  .06 %
RO2=   6.00 M-MOLES O2/L.HR.
KLA=  14.38 1/HR.
```

```
DO2=    3 %
EXIT O2= 20.75 %
TEMP.= 23.5 DEG.C.
AIRFLOW= 310 SLPM
BACKPRESSURE= 10.2 PSIG.
AGIT.SPEED= 156 RPM
TORQUE=  23 IN.LBS.
WEIGHT= 250 KGS.
CO2=  .06 %
RO2=   5.83 M-MOLES O2/L.HR.
KLA=  13.98 1/HR.
```

DO2= 2 %
EXIT O2= 20.58 %
TEMP.= 23.7 DEG.C.
AIRFLOW= 307 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 308 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 250 KGS.
CO2= .05 %
RO2= 11.13 M-MOLES O2/L.HR.
KLA= 26.85 1/HR.

DO2= 2 %
EXIT O2= 20.58 %
TEMP.= 23.8 DEG.C.
AIRFLOW= 306 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 309 RPM
TORQUE= 62 IN.LBS.
WEIGHT= 250 KGS.
CO2= .05 %
RO2= 11.05 M-MOLES O2/L.HR.
KLA= 26.56 1/HR.

DO2= 3 %
EXIT O2= 20.57 %
TEMP.= 23.8 DEG.C.
AIRFLOW= 306 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 308 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 250 KGS.
CO2= .05 %
RO2= 11.31 M-MOLES O2/L.HR.
KLA= 27.43 1/HR.

DO2= 2 %
EXIT O2= 20.57 %
TEMP.= 23.9 DEG.C.
AIRFLOW= 307 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 307 RPM
TORQUE= 68 IN.LBS.
WEIGHT= 250 KGS.
CO2= .05 %
RO2= 11.37 M-MOLES O2/L.HR.
KLA= 27.37 1/HR.

DO2= 2 %
EXIT O2= 20.35 %
TEMP.= 24.7 DEG.C.
AIRFLOW= 306 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 402 RPM
TORQUE= 105 IN.LBS.
WEIGHT= 250 KGS.
CO2= .04 %
RO2= 17.98 M-MOLES O2/L.HR.
KLA= 43.59 1/HR.

DO2= 2 %
EXIT O2= 20.34 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 305 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 403 RPM
TORQUE= 113 IN.LBS.
WEIGHT= 250 KGS.
CO2= .05 %
RO2= 18.30 M-MOLES O2/L.HR.
KLA= 44.29 1/HR.

DO2= 2 %
EXIT O2= 20.33 %
TEMP.= 25.1 DEG.C.
AIRFLOW= 306 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 402 RPM
TORQUE= 106 IN.LBS.
WEIGHT= 250 KGS.
CO2= .04 %
RO2= 18.72 M-MOLES O2/L.HR.
KLA= 45.43 1/HR.

DO2= 2 %
EXIT O2= 20.33 %
TEMP.= 25.3 DEG.C.
AIRFLOW= 308 SLPM
BACKPRESSURE= 10.2 PSIG.
AGIT.SPEED= 408 RPM
TORQUE= 105 IN.LBS.
WEIGHT= 250 KGS.
CO2= .04 %
RO2= 18.44 M-MOLES O2/L.HR.
KLA= 44.66 1/HR.

DO2= 1 %
EXIT O2= 20.44 %
TEMP.= 25.6 DEG.C.
AIRFLOW= 448 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 410 RPM
TORQUE= 92 IN.LBS.
WEIGHT= 250 KGS.
CO2= .05 %
RO2= 22.69 M-MOLES O2/L.HR.
KLA= 54.53 1/HR.

DO2= 1 %
EXIT O2= 20.45 %
TEMP.= 25.8 DEG.C.
AIRFLOW= 457 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 411 RPM
TORQUE= 95 IN.LBS.
WEIGHT= 250 KGS.
CO2= .05 %
RO2= 22.10 M-MOLES O2/L.HR.
KLA= 53.06 1/HR.

DO2= 1 %
EXIT O2= 20.45 %
TEMP.= 25.8 DEG.C.
AIRFLOW= 461 SLPM
BACKPRESSURE= 10.2 PSIG.
AGIT.SPEED= 408 RPM
TORQUE= 94 IN.LBS.
WEIGHT= 250 KGS.
CO2= .05 %
RO2= 21.62 M-MOLES O2/L.HR.
KLA= 51.85 1/HR.

DO2= 1 %
EXIT O2= 20.46 %
TEMP.= 25.5 DEG.C.
AIRFLOW= 456 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 407 RPM
TORQUE= 88 IN.LBS.
WEIGHT= 250 KGS.
CO2= .05 %
RO2= 22.11 M-MOLES O2/L.HR.
KLA= 53.02 1/HR.

```
DO2=    1 %
EXIT O2= 20.62 %
TEMP.= 24.7 DEG.C.
AIRFLOW= 455 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 306 RPM
TORQUE=   57 IN.LBS.
WEIGHT= 250 KGS.
CO2=   .05 %
RO2=   14.83 M-MOLES O2/L.HR.
KLA=   35.23 1/HR.

DO2=    1 %
EXIT O2= 20.62 %
TEMP.= 24.3 DEG.C.
AIRFLOW= 451 SLPM
BACKPRESSURE= 10.1 PSIG.
AGIT.SPEED= 305 RPM
TORQUE=   57 IN.LBS.
WEIGHT= 250 KGS.
CO2=   .05 %
RO2=   14.76 M-MOLES O2/L.HR.
KLA=   35.03 1/HR.

DO2=    1 %
EXIT O2= 20.61 %
TEMP.= 24.1 DEG.C.
AIRFLOW= 465 SLPM
BACKPRESSURE= 10.2 PSIG.
AGIT.SPEED= 305 RPM
TORQUE=   58 IN.LBS.
WEIGHT= 250 KGS.
CO2=   .05 %
RO2=   14.85 M-MOLES O2/L.HR.
KLA=   35.34 1/HR.

DO2=    2 %
EXIT O2= 20.62 %
TEMP.= 24.1 DEG.C.
AIRFLOW= 455 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED= 305 RPM
TORQUE=   56 IN.LBS.
WEIGHT= 250 KGS.
CO2=   .05 %
RO2=   15.04 M-MOLES O2/L.HR.
KLA=   35.89 1/HR.
```

The following are selected representative portions of the actual computer printout from which the data in Table V. were obtained.

```
DO2=  11 %
EXIT O2= 20.68 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 150 SLPM
BACKPRESSURE=  9.6 PSIG.
AGIT.SPEED= 153 RPM
TORQUE=  65 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .08 %
RO2=   3.98 M-MOLES O2/L.HR.
KLA=  10.48 1/HR.

DO2=  11 %
EXIT O2= 20.67 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 152 SLPM
BACKPRESSURE=  9.7 PSIG.
AGIT.SPEED= 152 RPM
TORQUE=  65 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .08 %
RO2=   4.01 M-MOLES O2/L.HR.
KLA=  10.54 1/HR.

DO2=  11 %
EXIT O2= 20.67 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 151 SLPM
BACKPRESSURE=  9.6 PSIG.
AGIT.SPEED= 151 RPM
TORQUE=  65 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .08 %
RO2=   4.07 M-MOLES O2/L.HR.
KLA=  10.71 1/HR.

DO2=  11 %
EXIT O2= 20.67 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 150 SLPM
BACKPRESSURE=  9.6 PSIG.
AGIT.SPEED= 152 RPM
TORQUE=  65 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .08 %
RO2=   4.13 M-MOLES O2/L.HR.
KLA=  10.87 1/HR.
```

DO2= 11 %
EXIT O2= 2Ø.75 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 437 SLPM
BACKPRESSURE= 1Ø.Ø PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 252 KGS.
CO2= .Ø9 %
RO2= 8.77 M-MOLES O2/L.HR.
KLA= 22.92 1/HR.

DO2= 11 %
EXIT O2= 2Ø.75 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 453 SLPM
BACKPRESSURE= 9.8 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 251 KGS.
CO2= .Ø8 %
RO2= 8.74 M-MOLES O2/L.HR.
KLA= 22.84 1/HR.

DO2= 11 %
EXIT O2= 2Ø.76 %
TEMP.= 24.9 DEG.C.
AIRFLOW= 459 SLPM
BACKPRESSURE= 9.7 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 252 KGS.
CO2= .Ø8 %
RO2= 8.62 M-MOLES O2/L.HR.
KLA= 22.51 1/HR.

DO2= 11 %
EXIT O2= 2Ø.76 %
TEMP.= 24.8 DEG.C.
AIRFLOW= 611 SLPM
BACKPRESSURE= 1Ø.Ø PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 252 KGS.
CO2= .Ø8 %
RO2= 1Ø.96 M-MOLES O2/L.HR.
KLA= 28.63 1/HR.

DO2= 11 %
EXIT O2= 20.76 %
TEMP.= 24.7 DEG.C.
AIRFLOW= 612 SLPM
BACKPRESSURE= 9.8 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 251 KGS.
CO2= .08 %
RO2= 11.03 M-MOLES O2/L.HR.
KLA= 28.80 1/HR.

DO2= 11 %
EXIT O2= 20.76 %
TEMP.= 24.6 DEG.C.
AIRFLOW= 621 SLPM
BACKPRESSURE= 10.0 PSIG.
AGIT.SPEED= 152 RPM
TORQUE= 65 IN.LBS.
WEIGHT= 251 KGS.
CO2= .08 %
RO2= 10.89 M-MOLES O2/L.HR.
KLA= 28.43 1/HR.

9/58/45 SPEED 3.000 RPM LOAL 50.00

DO2= 11 %
EXIT O2= 20.78 %
TEMP.= 24.4 DEG.C.
AIRFLOW= 619 SLPM
BACKPRESSURE= 9.9 PSIG.
AGIT.SPEED= 3 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 253 KGS.
CO2= .08 %
RO2= 9.86 M-MOLES O2/L.HR.
KLA= 25.71 1/HR.

DO2= 11 %
EXIT O2= 20.78 %
TEMP.= 24.4 DEG.C.
AIRFLOW= 621 SLPM
BACKPRESSURE= 9.6 PSIG.
AGIT.SPEED= 3 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 252 KGS.
CO2= .08 %
RO2= 9.69 M-MOLES O2/L.HR.
KLA= 25.27 1/HR.

DO2= 11 %
EXIT O2= 20.78 %
TEMP.= 24.3 DEG.C.
AIRFLOW= 594 SLPM
BACKPRESSURE= 9.7 PSIG.
AGIT.SPEED= 3 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 251 KGS.
CO2= .08 %
RO2= 9.87 M-MOLES O2/L.HR.
KLA= 25.73 1/HR.

DO2= 10 %
EXIT O2= 20.76 %
TEMP.= 24.3 DEG.C.
AIRFLOW= 448 SLPM
BACKPRESSURE= 9.2 PSIG.
AGIT.SPEED= 3 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 250 KGS.
CO2= .08 %
RO2= 8.20 M-MOLES O2/L.HR.
KLA= 21.38 1/HR.

DO2= 10 %
EXIT O2= 20.78 %
TEMP.= 24.2 DEG.C.
AIRFLOW= 446 SLPM
BACKPRESSURE= 9.5 PSIG.
AGIT.SPEED= 3 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 251 KGS.
CO2= .08 %
RO2= 7.61 M-MOLES O2/L.HR.
KLA= 19.84 1/HR.

DO2= 10 %
EXIT O2= 20.77 %
TEMP.= 24.2 DEG.C.
AIRFLOW= 445 SLPM
BACKPRESSURE= 9.5 PSIG.
AGIT.SPEED= 2 RPM
TORQUE= 44 IN.LBS.
WEIGHT= 251 KGS.
CO2= .08 %
RO2= 7.92 M-MOLES O2/L.HR.
KLA= 20.65 1/HR.

```
DO2=   1Ø %
EXIT O2= 2Ø.74 %
TEMP.= 24.1 DEG.C.
AIRFLOW= 162 SLPM
BACKPRESSURE=  8.3 PSIG.
AGIT.SPEED=    3 RPM
TORQUE=  44 IN.LBS.
WEIGHT= 251 KGS.
CO2=  .Ø8 %
RO2=    3.17 M-MOLES O2/L.HR.
KLA=    8.27 1/HR.
```

```
DO2=   1Ø %
EXIT O2= 2Ø.75 %
TEMP.= 24.1 DEG.C.
AIRFLOW= 154 SLPM
BACKPRESSURE=  9.7 PSIG.
AGIT.SPEED=    3 RPM
TORQUE=  44 IN.LBS.
WEIGHT= 252 KGS.
CO2=  .Ø8 %
RO2=    3.Ø3 M-MOLES O2/L.HR.
KLA=    7.89 1/HR.
```

```
DO2=   1Ø %
EXIT O2= 2Ø.74 %
TEMP.= 24.1 DEG.C.
AIRFLOW= 158 SLPM
BACKPRESSURE=  9.8 PSIG.
AGIT.SPEED=    2 RPM
TORQUE=  44 IN.LBS.
WEIGHT= 251 KGS.
CO2=  .Ø8 %
RO2=    3.Ø5 M-MOLES O2/L.HR.
KLA=    7.92 1/HR.
```

```
DO2=   1Ø %
EXIT O2= 2Ø.74 %
TEMP.= 24.1 DEG.C.
AIRFLOW= 155 SLPM
BACKPRESSURE=  9.6 PSIG.
AGIT.SPEED=    3 RPM
TORQUE=  44 IN.LBS.
WEIGHT= 251 KGS.
CO2=  .Ø8 %
RO2=    3.Ø3 M-MOLES O2/L.HR.
KLA=    7.89 1/HR.
```

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