IRRADIATION OF SEWAGE

by

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ABSTRACT

Frankhouser, Enoch D., University of Arizona, January 1964

"Irradiation of Sewage"

Thesis Advisor: Dr. Roy G. Post

An analysis was made of the effects of ionizing radiation on sewage components. The principal data determined experimentally were the oxygen uptake (metabolism) that resulted from feeding irradiated and unirradiated food to samples of activated sludge taken from a sewage treatment plant. The radiation dose and the type of food were varied.

A protein and a synthetic detergent, two components of domestic sewage, were irradiated with an electron beam in doses from 1.1×10^4 rads to 3.9×10^7 rads. As the dosage increased the protein material tended to polymerize and become more difficult for the activated sludge to digest. The detergent, however, tended to degrade as the dosage increased, and was more easily assimilated by the activated sludge.

ACKNOWLEDGMENT

The author wishes to express his gratitude for the guidance of Dr. Roy G. Post in the subtleties of experimental investigation and the subsequent preparation of this thesis. The voluntary support rendered by Professor Quentin M. Mees and Mr. William C. Pisano of the Civil Engineering Department is gratefully acknowledged, and also the kind assistance of Mr. E. J. Trueblood from the Tucson Sewage Treatment Plant.

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CHAPTER 1

INTRODUCTION

1.1 General

1.1.1 There are three major applications of radioactivity which may play an important part in sewage and waste treatment facilities. These are the treatment of radioactive wastes, the use of radiotracers to track operational conditions at a given time or place in the sewage treatment cycle, and the irradiation of sewage to render it more responsive to standard treatment methods, and thereby increase the capacity of existing treatment facilities. As far as this latter application is concerned, a rather comprehensive study of the effects of ionizing radiation on the rate of sedimentation of sewage was undertaken by Unidynamics Division, Universal Match Corporation. The first of their reports[1] indicates that sedimentation may decrease (65,000 R) or increase (350,000 R) depending on the radiation dosage. This report also contains an excellent bibliography on the subject. Some study has also been given to the sterilization of sewage by irradiation,[2] and in this case a portion of the work done on irradiation of food supplies may also be applicable. However, no work has been discovered that directly pertains to the chemical degradation of raw sewage by irradiation so that increased bacterial digestion may take place within the treatment plant. This, then, is the general topic for the following thesis.

1.1.2 The experimental work will be exploratory in nature, and, hence, more qualitative than quantitative in many instances. The first major undertaking will be to reduce the many variables to a level consistent with the time and equipment available.

1.1.3 An aerobic waste treatment system (which requires the addition of oxygen for operation) is the most suitable for investigation because the aerobic systems (as opposed to anerobic) are the primary systems for waste treatment in the United States and include activated sludge, trickling filters, and oxidation ponds. The activated sludge process is the most desirable process to study, because of ease of sample acquisition and the high specific activity of the microorganisms in each sample.

1.1.4 The activated sludge is to be fed with specially prepared foods (irradiated and unirradiated) which are representative of certain nutrients found in raw sewage; except that the concentration should be increased several orders of magnitude for ease of measurement. The oxygen uptake (metabolism) of the activated sludge can then be measured with a Warburg apparatus as an indication of the rate of digestion of the food supply. Raw sewage will not be utilized as a food supply, because it is desired to observe the effects of radiation on several isolated food types (particularly synthetic detergents) without interference caused by the numerous nutrients found in raw sewage. The low concentration of organic material in raw sewage also presents additional measurement difficulties.

1.1.5 The oxygen uptake of each sample of activated sludge that is mixed with a particular nutrient will be observed from six to twelve hours--the time is based on the assumption that the "holding time" in a municipal secondary treatment facility would not exceed this period.

1.1.6 Some mention should be made of how the sewage-digesting microorganisms live and die in their activated sludge environment, and why a measurement of their oxygen consumption is indicative of their activity. Activated sludge consists primarily of bacteria, fungi, protozoa, and rotifers, but the bacteria is the group of microorganisms that primarily concern us, for they are responsible for the stabilization of the organic matter and for the floc formation, without which, there would be no activated sludge.

1.1.7 Activated sludge is formed by aerating a biologically degradable waste for a period of time until a large mass of settleable solids form. These solids are active masses of microorganisms and are designated as activated sludge. As shown in Figure 1.1 the raw sewage from the primary sedimentation tanks enters the aeration tank after being mixed with a portion of the waste activated sludge which is returned as seed.

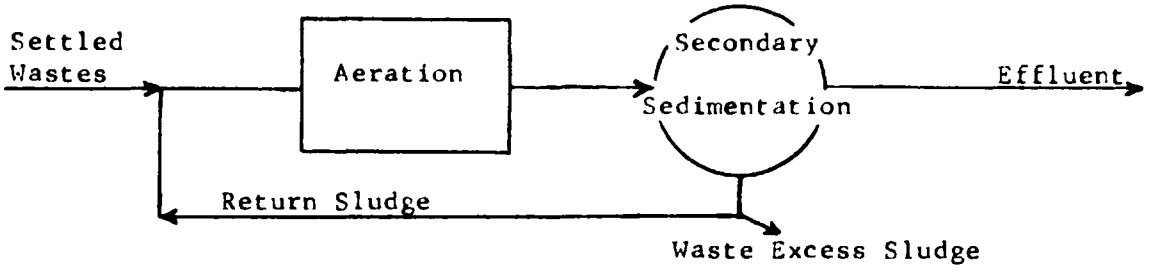

FIGURE 1.1 DIAGRAM OF CONVENTIONAL ACTIVATED SLUDGE SYSTEM (McKINNEY)

During the aeration and mixing process the microorganisms aerobically stabilize the organic matter and flow into the secondary sedimentation tank. Here the activated sludge settles out and produces a clear effluent.

1.1.8 Activated sludge will not necessarily form, however, simply because food and oxygen are available for the microorganisms. The growth pattern of the microorgamisms is shown in Figure 1.2 and consists of three phases. During the log growth phase there is an excess of food surrounding the microorganisms and the organic matter in the wastes is removed at the maximum rate. The energy level is sufficiently high to keep all the microorganisms completely dispersed, and no flocculation will occur, and hence, no activated sludge will form. As the energy content of the system decreases (as in the declining growth phase where food is no longer in excess) more and more bacteria lack the energy to overcome the forces of attraction between the cells once they have collided in the aeration tank. More and more cells stick together and soon a small floc particle has formed--the beginning of activated sludge.

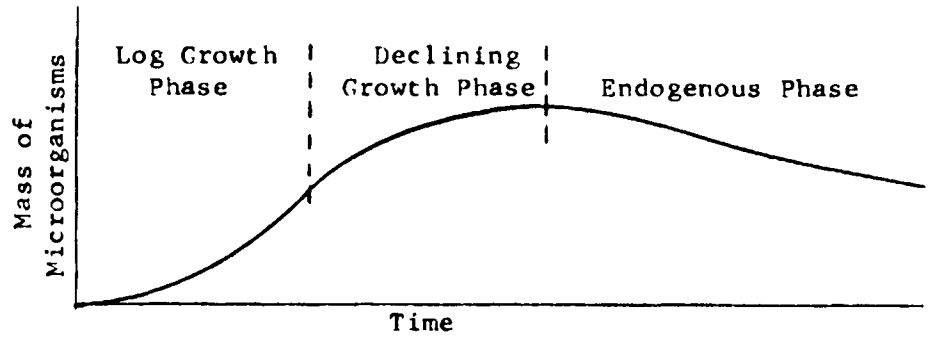

FIGURE 1.2 GROWTH PATTERN BASED ON MASS OF MICROORGANISMS (McKINNEY)

1.1.9 In the aeration tank discussed previously, oxygen was added to the organic matter in the waste water, and the microorganisms stabilized the organic matter by oxidation. These bacteria do not oxidize by the direct addition of oxygen, however, but by a system of hydrogen removal and carbon oxidation. The end products, therefore, are primarily carbon dioxide and water, since the hydrogen readily combines with the free dissolved oxygen in the aeration tank. The Warburg respirometer[3, 4] is a convenient instrument for measuring the uptake of oxygen by utilizing manometric techniques. This device will be discussed further in section 2.2.

1.2 Statement of the Problem

1.2.1 The main object of this thesis is to determine if high energy radiation (in this case, electrons) might assist the work of the microorganisms through pre-degradation of certain selected components of raw sewage that provide food for the activated sludge. With certain of the large, or long chain, molecules decomposed, the bacteria might then more easily oxidize the less complex molecules.

CHAPTER 2

EXPERIMENTAL INVESTIGATION

2.1 General

2.1.1 In the selection of a source of radiation the choice lay between a 1.2 Mev electron accelerator, a Cobalt-60 source, and a 100,000 watt TRICA reactor. The accelerator was chosen because of the capability of varying the electron beam current and beam voltage, as well as avoiding the problem of creating residual nuclear activity through neutron activation in the nuclear reactor. Neutron activation may quite possibly cause the production of radioactive wastes which would require additional disposal action.

2.1.2 The electron accelerator was used to produce the beam of particles necessary for irradiation of several common ingredients found in domestic sewage. The ingredients (beef extract, and a synthetic detergent) were irradiated, and along with a non-irradiated control sample, were fed to samples of activated sludge taken from the local municipal sewage treatment works. The consumption of oxygen by the activated sludge was measured in a Warburg apparatus[3] as an indication of the rate of food consumption by the bacteria in the activated sludge. In this way the effect of radiation on the food could be observed by comparing the ease of consumption of an irradiated and unirradiated food by activated sludge bacteria.

2.1.3 Radiation has a strong cumulative effect on organic liquids, because the reverse reaction is very slow, and, therefore, successive effects should be observed simply by increasing the radiation dose. However, one of the anomalies of nuclear radiation is that as the dose is increased, organic liquids may cease to be degraded and begin to polymerize (i.e. create larger, more complex molecules). Again, different organic compounds react differently to the same radiation dose. Aliphatic organic compounds are known,[5] for example, to be more readily affected by radiation than aromatic organic compounds (those with benzene rings). This was the primary factor in dictating the choice of experimental foods. The beef extract (high protein content) is an aliphatic; the detergent (alkyl benzene sulfonate) is an aromatic.

2.1.4 If certain of the irradiated foods do polymerize, a process such as dialysis[6] provides at least a qualitative check on the degree of polymerization. In this process the more complex molecules are separated from the less complex ones by use of a semipermeable membrane. If only the more complex molecules are then fed to activated sludge, they should behave similarly to a polymerized food of the same kind.

2.2 Apparatus

2.2.1 The experimental arrangement as shown in Figure 2.1 and Figure 2.2 was used to irradiate the nutrients that were subsequently fed to the activated sludge.

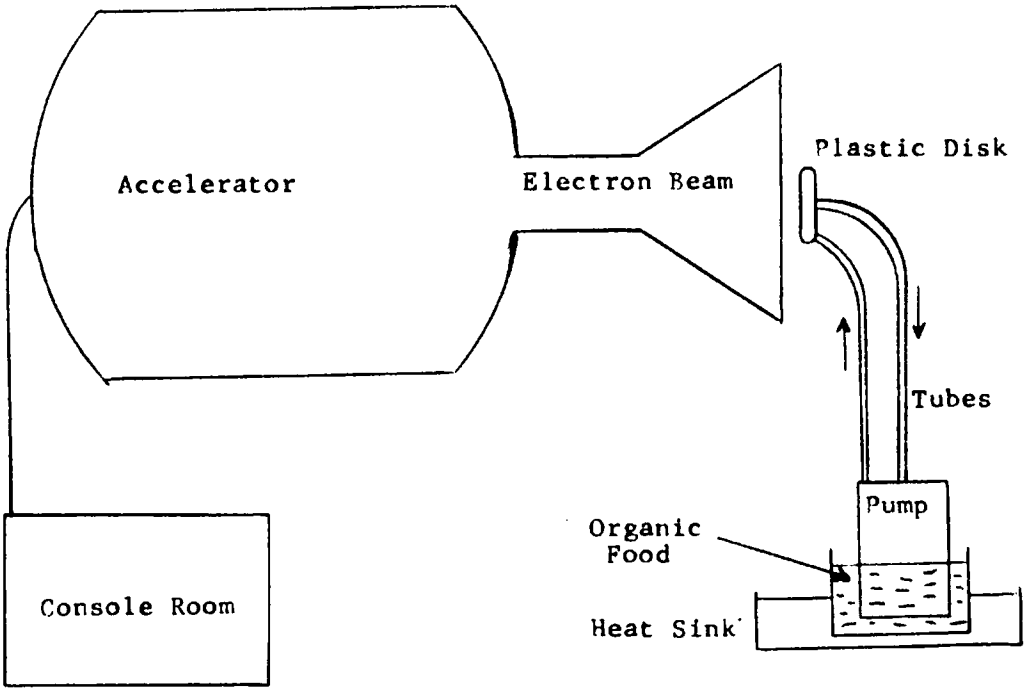

FIGURE 2.1 DIAGRAM OF IRRADIATION FACILITY

2.2.2 The accelerator produced an electron beam that was variable between 5 and 500 microamps beam current, and between 0.3 and 1.1 Mev beam voltage, and approximately 3 cm in diameter. It must be noted that an operation at high beam current and low beam voltage is not stable on this particular machine. A variable speed recirculating pump was used to pass the organic liquid at approximately 60 cm^3 per second in front of the accelerator window. In order to provide better cooling at the higher dose levels the pump and reservoir were placed in a circulating cold water heat sink. In order to take

FIGURE 2.2 ARRANGEMENT IN ACCELERATOR TARGET ROOM

full advantage of the electron beam (approximately 3 cm diameter) a hollow plastic disk (3.5 cm diameter) was prepared with inlet and outlet tubes to place squarely in the beam, 2 cm from the accelerator window. This plastic disk had one open side which was covered with .005 cm aluminum foil and faced toward the electron beam. After leaving the titanium window, the electron beam penetrated 2 cm of air, 0.005 cm aluminum, and into 0.7 cm of organic liquid.

2.2.3 The device used to measure the oxygen uptake by the activated sludge sample was a Warburg constant volume respirometer, which consists of a highly controlled ($\pm 0.0028^{o}C$) constant temperature bath, sample flasks, and a manometric pressure reading device. The respirometer is based on the principle that at constant temperature and constant gas volume any changes in the amount of gas can be measured by changes in its pressure. The experimental arrangement is shown in Figures 2.3 and 2.4. The sample was contained in a flask attached to

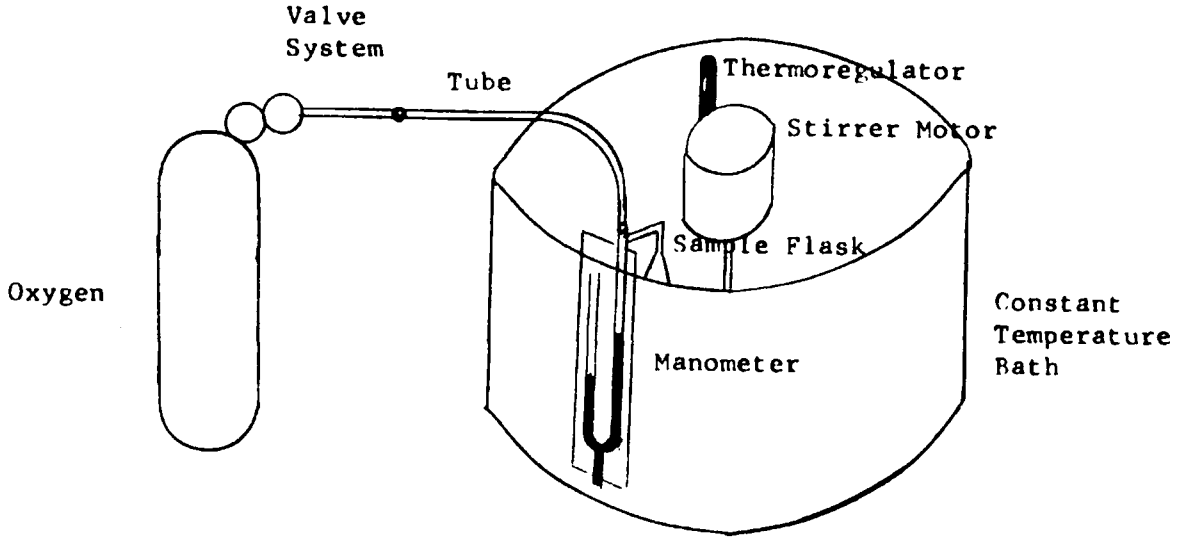

FIGURE 2.3 DIAGRAM OF WARBURG APPARATUS

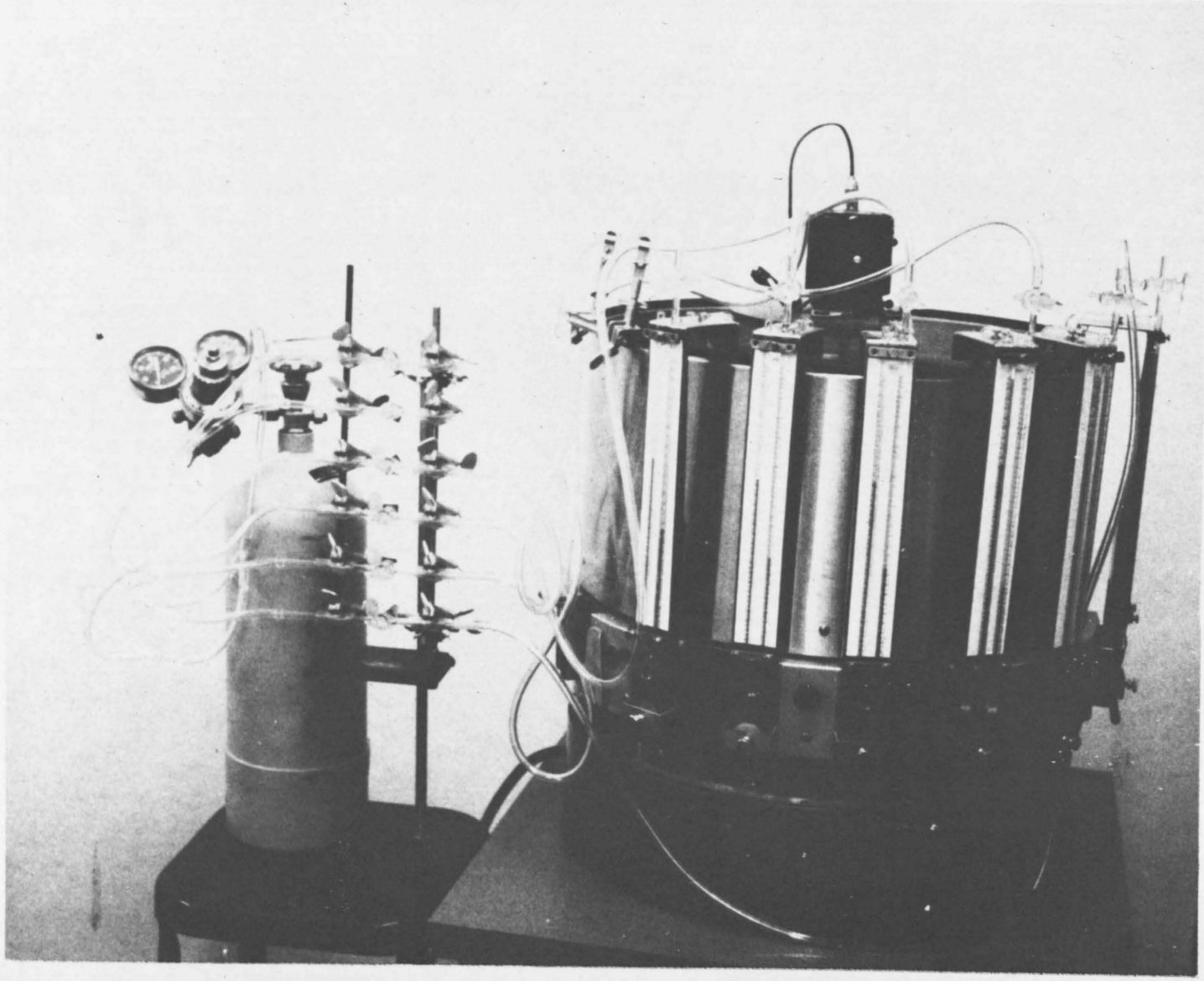

FIGURE 2.4 ARRANGEMENT FOR MEASURING OXYGEN UPTAKE WITH WARBURG RESPIROMETER

a manometer, and this whole assembly (Figure 2.5) was mounted on a shaking device in order to increase the transfer of oxygen to the liquid sample. Provision was made by use of stopcocks on both manometer and flask to purge the atmosphere above the liquid sample with oxygen.

2.2.4 The flask (125 ml) is attached to the leg of the manometer that is closed after the oxygen purge is completed, and the manometer is subsequently adjusted to keep a constant gas volume over the sample. The water bath keeps the temperature of the oxygen and liquid constant, so that the quantity of oxygen transferred to the liquid is measured by a change in gas pressure. This change is read in the open leg of the manometer, if the closed leg is adjusted each time to a constant volume reference point (such as 150 mm on the manometer scale) before a reading is recorded. As derived by Umbriet[4] the amount of gas exchanged equals the change in gas pressure times the flask constant (k) where $k = \frac{V_g \frac{273}{T} + V_f \alpha}{Po}$ (See Appendix A).

2.2.5 The foregoing calculations are valid if only one gas is changed; however, since the microorganisms in the activated sludge will produce carbon dioxide, it is necessary to remove this gas in order to compute only the oxygen uptake. The carbon dioxide is absorbed by a 1.0 ml solution of 10 per cent KOH that is placed in the center well of the flask. In order to increase the area of absorption for carbon dioxide, a piece of filter paper was accordion folded and placed in the center well (Figure 2.5).

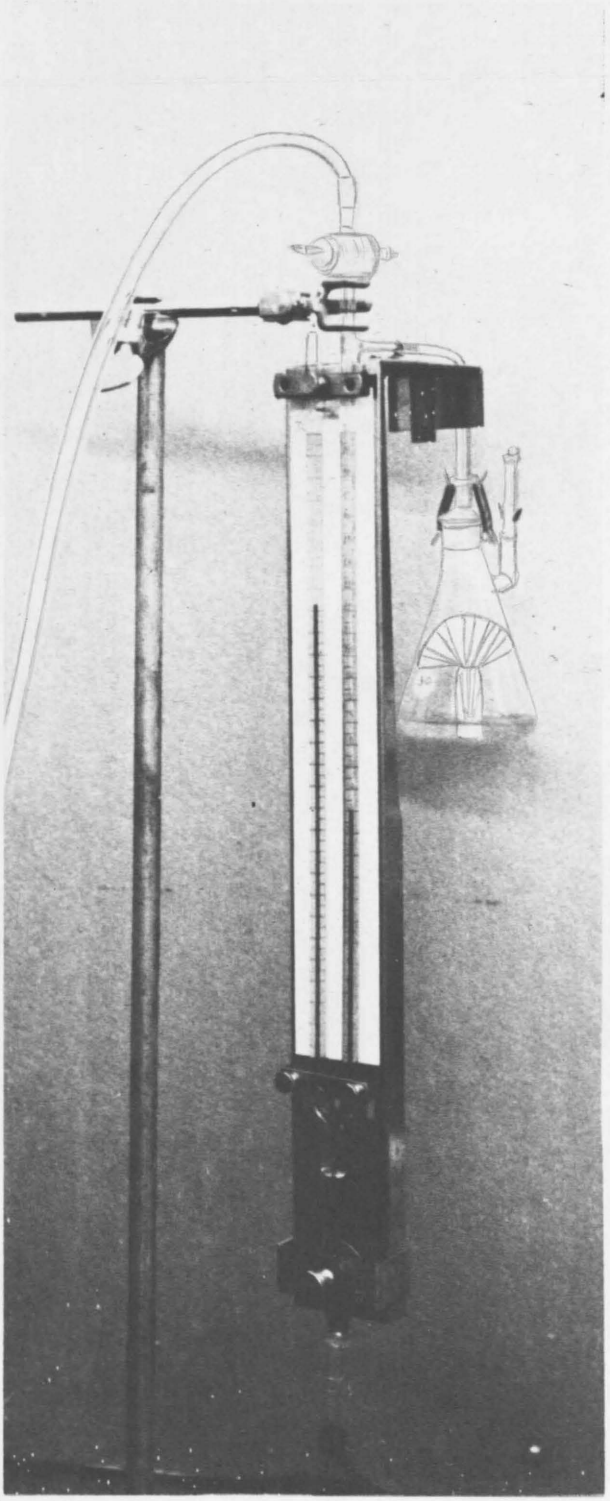

FIGURE 2.5 WARBURG MANOMETER-FLASK ASSEMBLY

2.3 Procedure

2.3.1 Following is an outline of the experimental procedure which will be discussed in greater detail in subsequent paragraphs:

(1) Calibrate Warburg apparatus

(2) Determine most desirable operating conditions for the Warburg apparatus

  (a) Activated sludge dilution

  (b) Selection of food (type and dilution)

  (c) Temperature of bath

(3) Irradiate food

(4) Prepare and feed activated sludge samples in Warburg apparatus

(5) Purge Warburg flasks with oxygen

(6) Measure oxygen consumption by activated sludge for 6 hours.

(7) Remove Warburg flasks and clean equipment

(8) Repeat steps (3) through (7) above for different irradiation conditions and food supplies.

(9) Prepare dialyzed food and compare with irradiated foods in steps (4) through (7)

2.3.2 As an initial step the volume of each Warburg manometer flask assembly was determined using the "water method" of McKinney.[3] This was a prerequisite for determining each flask constant (k).

2.3.3 Before commencing any radiation studies, it was necessary to obtain a qualitative idea of the effects of various operating conditions such as temperature, dilution, and feeding techniques on oxygen consumption. With the constant temperature bath set at 20°C, three dilutions of activated sludge were prepared (1/1, 1/10 and 1/100) from a single large sample obtained at the Tucson Municipal Sewage Treatment Plant. Since the characteristics of activated sludge may change materially between sample acquisitions, the only comparisons attempted were based on those data observed during a single experimental run. Samples of undiluted activated sludge were chosen, because they provided changes in oxygen uptake easily detected at 20-minute intervals. All samples for a single experimental run were taken from the same large master sample which was continuously stirred to keep the sludge as uniform as possible.

2.3.4 During these preliminary runs a "thermobarometer" was prepared which consisted simply of a standard Warburg manometer-flask assembly containing only water. The manometer changes on the thermobarometer responded only to changes in bath temperature and atmospheric pressure, and were used to correct the data taken on the other manometer-flask assemblies.

2.3.5 The protein food finally selected was a nutrient broth recommended in Pavlovich,[7] and consisted of the following:

5 gms Beef extract

10 gms Peptone

5 gms NaCl

1000 ml Distilled and boiled water

2.3.6 The pH of this food preparation was measured with a Beckman pH meter and was found to lie between 6.5 and 6.6. Microorganisms are extremely sensitive to pH variations, and different types of populations are predominant at different pH values. Values greater than 10 and less than 4 are toxic to nearly all bacteria, however.

2.3.7 The synthetic detergent selected was a Standard Alkyl Benzene Sulfonate Solution (ABS) consisting of the following:

ABS	54.8%
$Na_2 SO_4$	40.3%
Free Oil	.5%
Na OH	1.3%
$Na_2 CO_3$	.7%
H_2O	2.4%

2.3.8 The first trials were made using a solution of ABS (0.01 milligram per milliliter) which is comparable to the approximately 14 ppm of detergent found in domestic sewage. This concentration was too low to produce any significant results within the period of measurement, so the concentration was increased to 3 milligrams per milliliter which provided satisfactory results. Although the pH of the ABS solution was 11, the activated sludge substrate had sufficient buffering power to reduce the pH to approximately 8, when the ABS was added.

2.3.9 The constant temperature bath was raised from 20°C to 30°C to observe the effect on oxygen uptake. During the period of measurement there was no significant change in oxygen consumption, but operation of the constant temperature bath at 30°C required less cooling and thereby reduced the fluctuations in the manometer levels caused by the refrigeration cycle.

2.3.10 The food was irradiated with an electron beam (Figure 2.1) while holding the beam voltage constant (0.7 Mev) and varying the beam intensity for each different food sample. To determine the best placement for the irradiation sample, the exact location of the beam was checked by inspecting the color change after irradiation in a polyvinylchloride strip placed in front of the accelerator window. The food to be irradiated was pumped past the accelerator window with a recirculating pump for the time required to obtain the desired dosage.

2.3.11 If more than one dosage was desired in a certain type food, the pump was stopped after the first irradiation period, and the first sample was withdrawn, after which the remaining food was irradiated a second time. This procedure was repeated until the required number of food samples was irradiated. By using this method of eliminating many variables, the second and subsequent food samples were assured of receiving a larger dose than the preceding food sample even if exact dosages could not be established.

2.3.12 Although not generally associated with sewage treatment problems, cleanliness was essential to avoid misleading results for

two major reasons. No microorganisms or spores must remain in the glassware from the previous runs that would promote an uneven growth during the period of measurement. The same was true of any residue that might remain from previously inserted food.

2.3.13 The following cleaning procedure was applied to Warburg flasks, pipettes, and other glassware containing sewage or food:

(1) Rinse several times with tap water

(2) Dip and rinse with chloroform to remove grease (dries without residue)

(3) Rinse with tap water

(4) Pour cleaning solution* into glassware and let stand for 5 minutes

(5) Rinse with tap water

(6) Rinse four times with distilled water

(7) Bake in 105°C oven for 24 hours

2.3.14 After the Warburg flasks were cleaned, 1 ml of 10 per cent KOH was placed carefully in the center well with a hypodermic needle. Next, 20 ml of activated sludge from a continuously stirred master sample were placed in the bottom of the flask, and then 2 ml of the desired food were added. An accordion-folded piece of filter paper was inserted into the center well to provide more area for

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*35 grams of potassium dichromate in 100 ml distilled water. Make up to 1 liter with sulfuric acid.

absorption of CO_2 by the KOH, and the flasks were then joined to their respective manometers.

2.3.15 The flasks were purged with oxygen for 5 minutes, and then allowed 15 minutes to come to temperature equilibrium with the constant temperature bath. The manometer fluid was adjusted to the 150 mm index and all flasks closed. At the end of 20 minutes, or some other suitable time period, the closed leg of the manometer was adjusted to the 150 mm index and the open leg read. The oxygen consumption was measured in this manner for approximately 6 hours.

2.3.16 At the end of the run the flasks were cleaned (paragraph 2.3.13), and the above procedure was repeated with different food and sludge samples.

2.3.17 The final procedure is concerned with the dialysis process which was used to assist in determining the polymerization characteristics of certain food. The food to be dialyzed was placed in a tube-shaped semipermeable membrane that had been tested previously for leaks with distilled water. The food-filled tube was tied off and placed in a beaker of distilled water. The distilled water was changed 4 times in a 24-hour period, after which a sample of the food remaining in the membrane was fed to the activated sludge in the manner previously stated.

CHAPTER 3

DISCUSSION OF RESULTS

3.1 The first experimental runs had a two-fold purpose: to observe the effect that irradiated food would have on the rate of metabolism by activated sludge samples, and to observe the degree of precision with which the experimental conditions could be reproduced. In regard to the latter, the data from each pair of similar Warburg samples as shown in Figures 3.1 are reproducible within less than 10 per cent. Figure 3.2 represents the same type of experimental run (but with ten times the irradiation) and supports the findings in Figure 4.1 Both figures also show the wide difference in the rate of digestion or irradiated versus unirradiated protein-type food by the activated sludge. Not only is the irradiated food less digestible than the unirradiated food, but digestion decreases consistently with increased radiation dosage.

3.2 These results indicated that perhaps polymerization was occurring in the protein-type food, so a further comparison of the previous foods was made with an unirradiated food sample from which the less complex molecules had been removed by dialysis (See Figures 3.3, 3.4). Again the food with the highest dosage contributed least to the oxygen uptake, but the more highly irradiated foods also approached the curve representing the non-dialyzed, complex molecules,

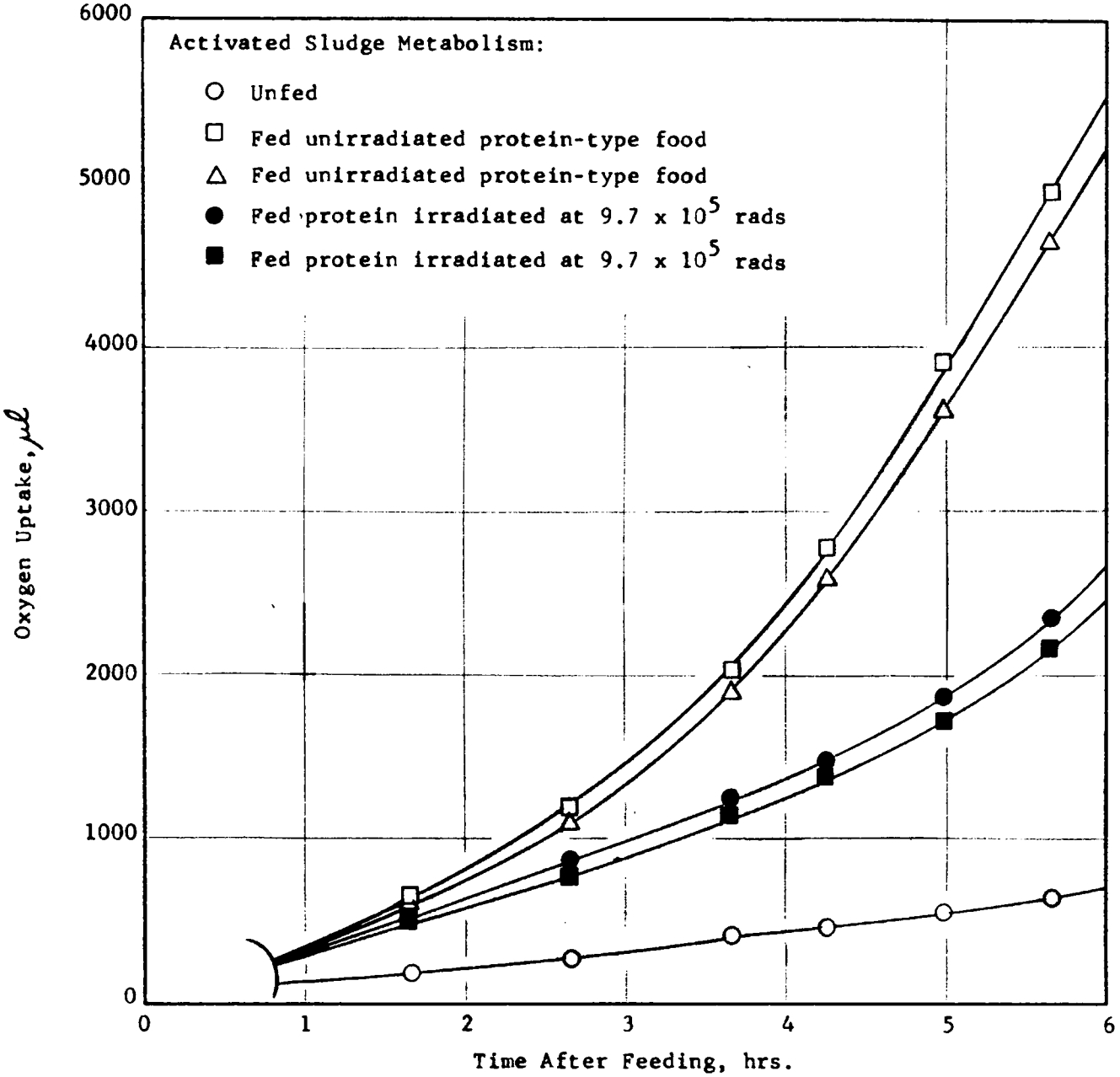

FIGURE 3.1 RATE OF METABOLISM DURING DIGESTION OF PROTEIN-TYPE FOOD

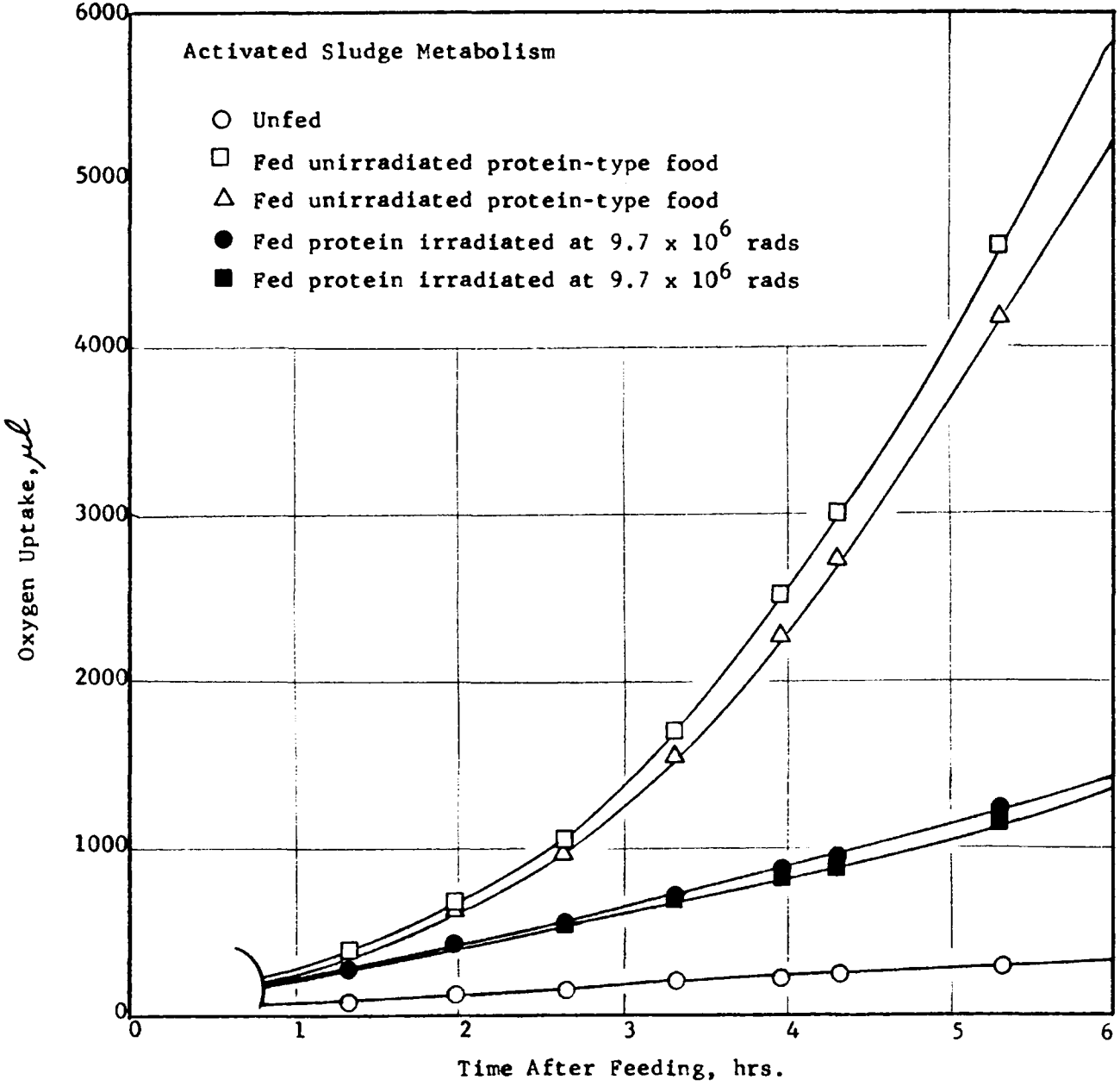

FIGURE 3.2 RATE OF METABOLISM DURING DIGESTION OF PROTEIN-TYPE FOOD

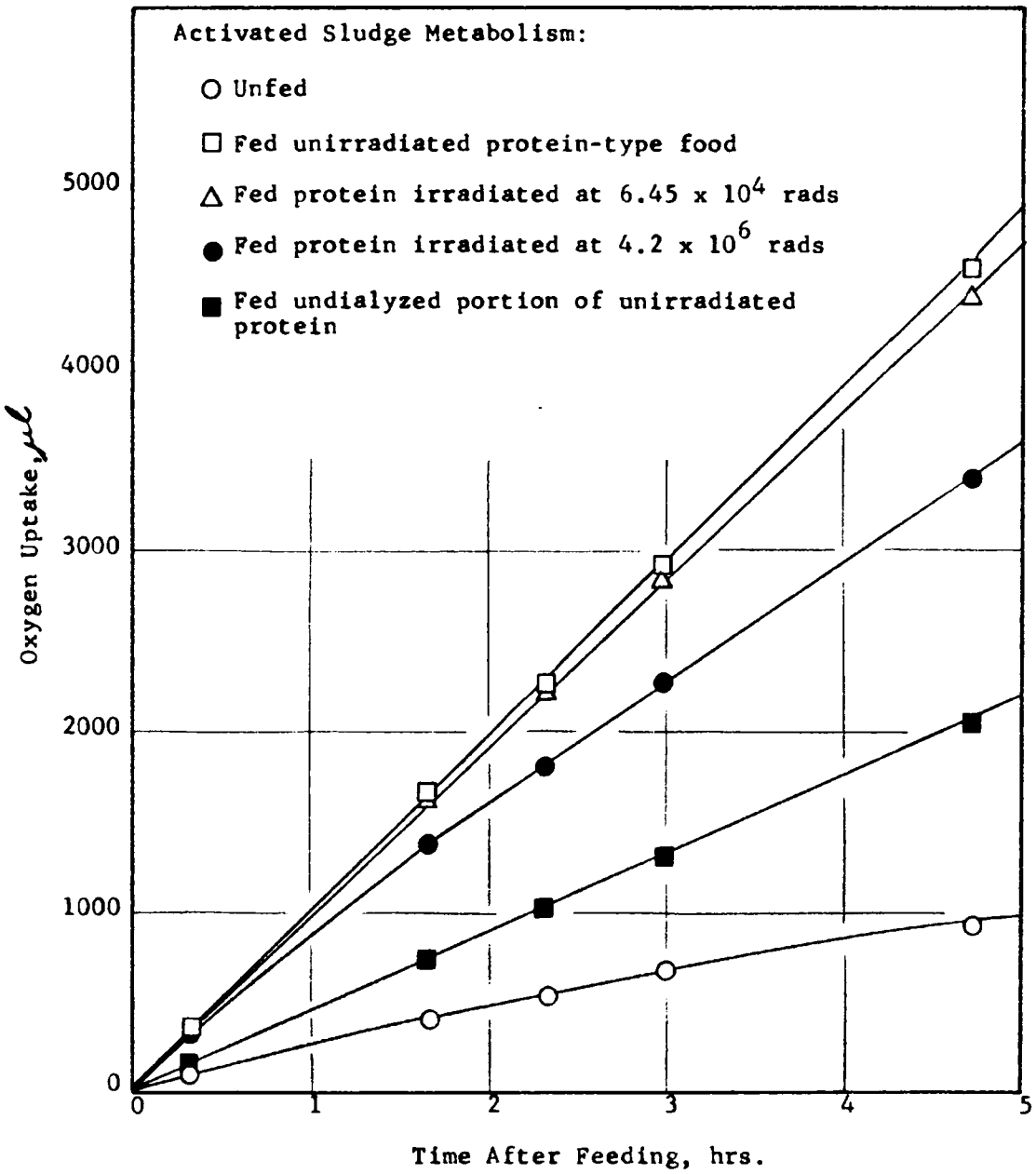

FIGURE 3.3 RATE OF METABOLISM DURING DIGESTION OF PROTEIN-TYPE FOOD

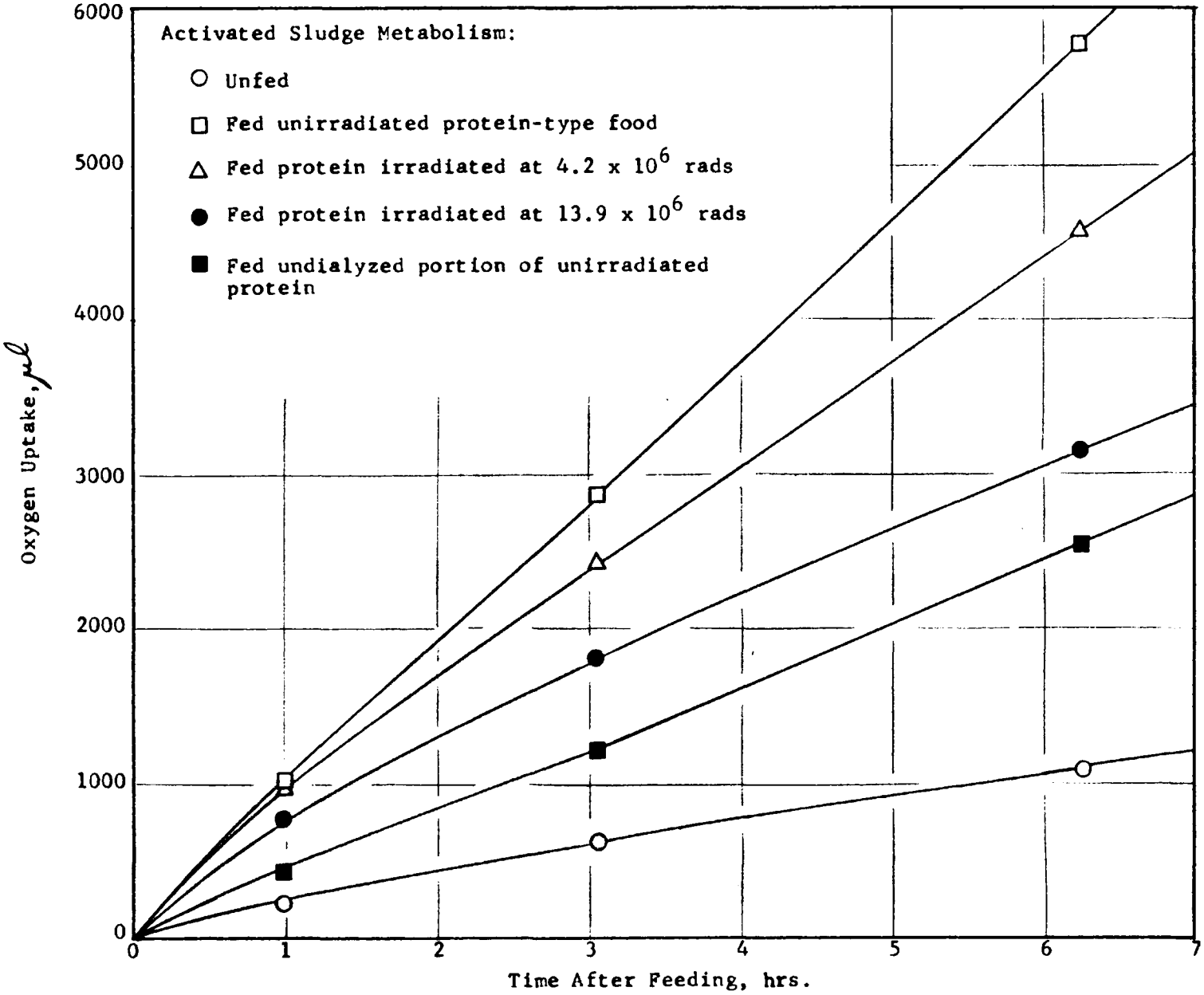

FIGURE 3.4 RATE OF METABOLISM DURING DIGESTION OF PROTEIN-TYPE FOOD

which would indicate that polymerization was occurring and was increasing with dosage as would be expected.

3.3 When the synthetic detergent (ABS) was used as a food, the irradiated portion resulted in consistently greater oxygen uptake after being fed to the activated sludge (See Figures 3.5, 3.6). This would indicate that the aromatic compound (ABS) was degraded by high energy radiation, and, hence, more easily assimilated by the micro-organisms in the sludge. Those ABS samples subjected to higher radiation also produced higher oxygen consumption than those with lighter doses. For example, consider a time four hours after feeding the activated sludge. The ratio of oxygen consumption of 3.6×10^6 rad ABS to unirradiated ABS is approximately 5, whereas this ratio is approximately 2 for 8.3×10^5 rad ABS.

3.4 The same trend persisted at low dosages (less than 9×10^4 rads), but the significance is questionable, since all the low dosage curves in Figure 3.5 lie within the range of experimental precision observed between Warburg flasks (paragraph 3.1).

3.5 Significant color changes were observed visually in both the protein and detergent foods after heavy irradiation, although no sharp cut-off point was observed. The protein-type food changed from deep orange to medium yellow after 9.7×10^6 rads. The detergent changed from a clear liquid to medium yellow after 38.7×10^6 rads, and the sudsing action was reduced to nil.

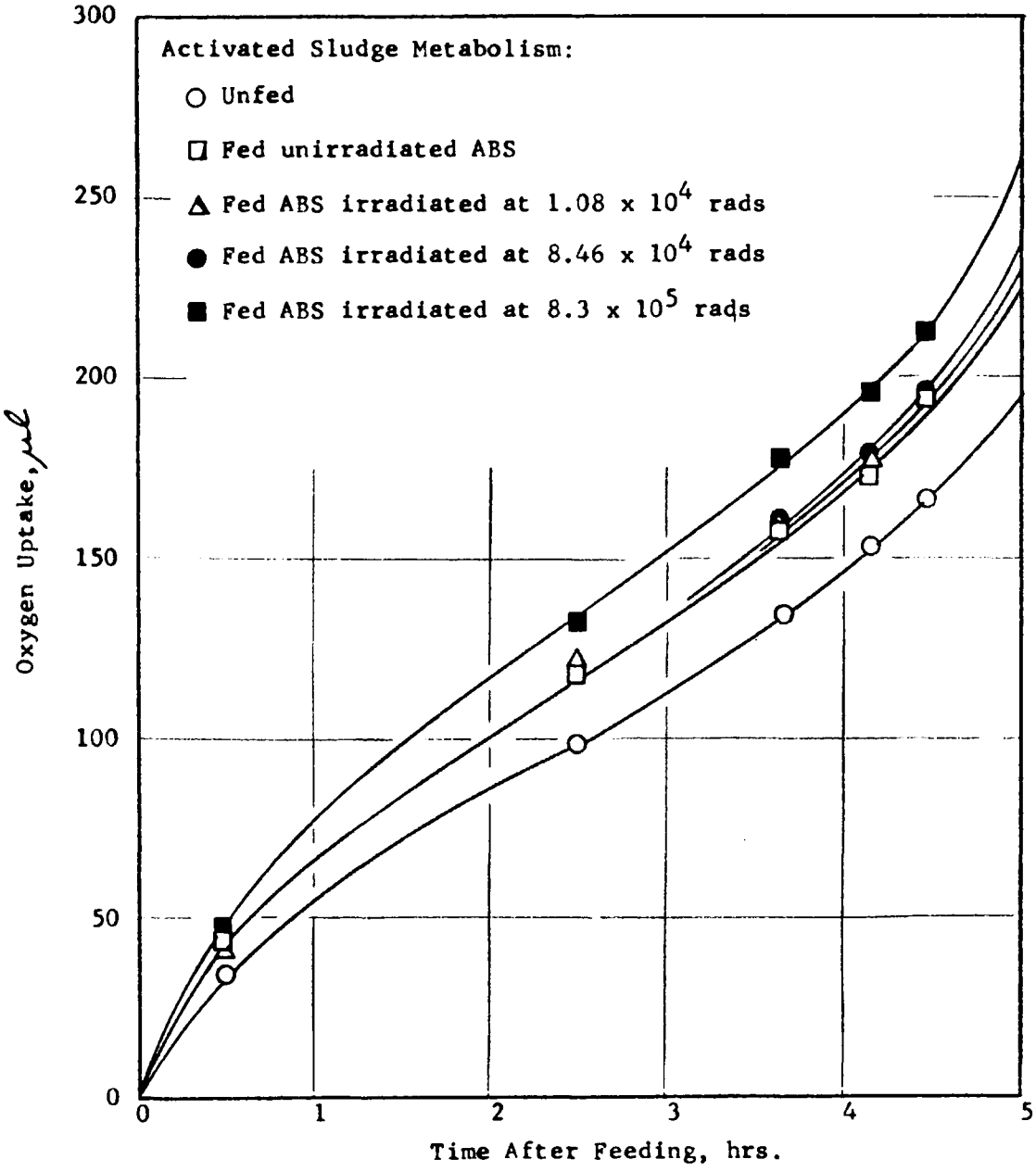

FIGURE 3.5 RATE OF METABOLISM DURING DIGESTION OF DETERGENT (ABS)

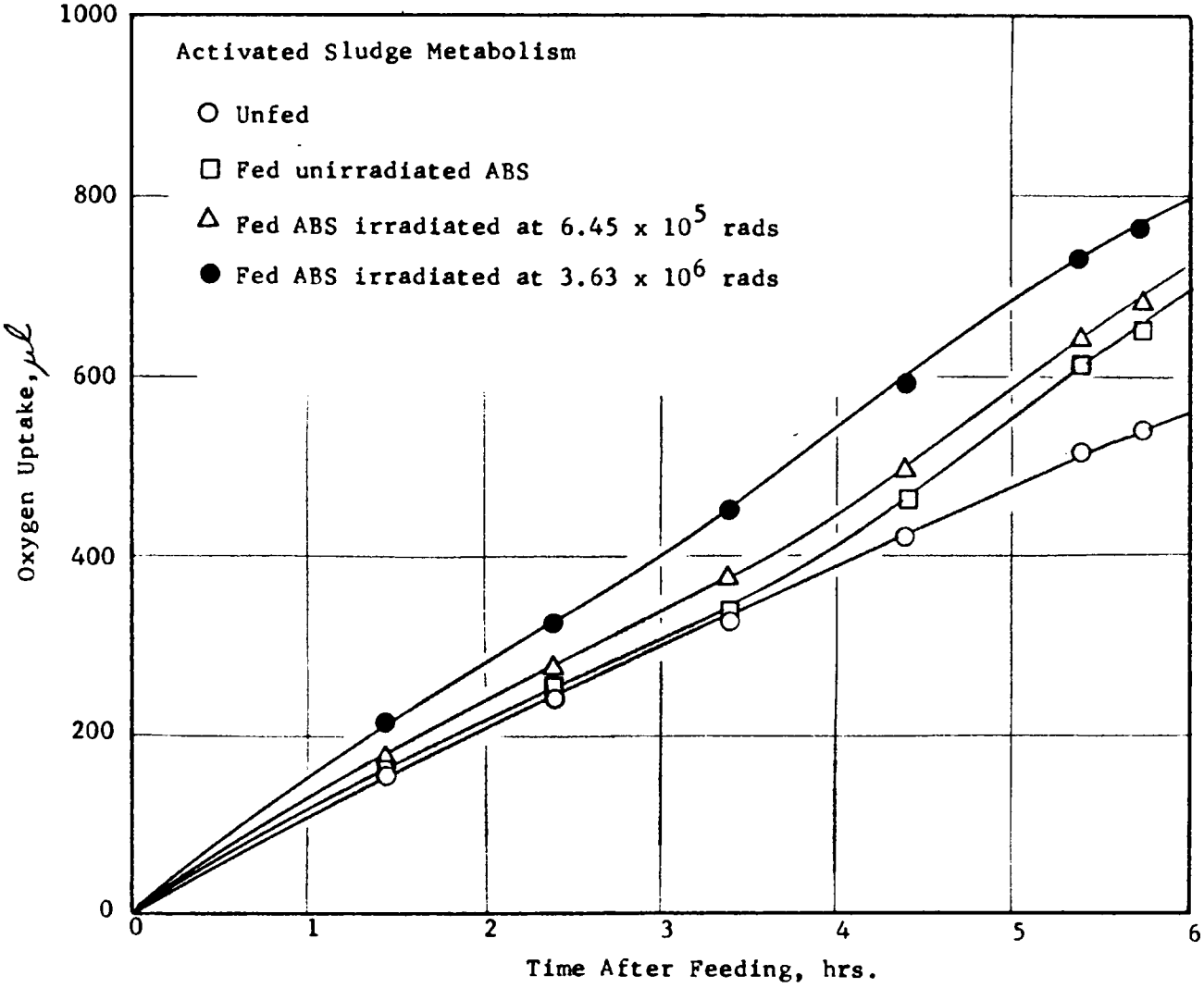

FIGURE 3.6 RATE OF METABOLISM DURING DIGESTION OF DETERGENT (ABS)

CHAPTER 4

DATA ANALYSIS

4.1 General

4.1.1 Since the primary objective was to observe the gross effects of high energy radiation on nutrients provided to activated sludge samples, there were many variables (temperature, atmospheric pressure, sample sizes and composition, actual radiation dose absorbed, time, cleanliness, etc.) that affected accuracy of measurement. The experiment was designed to control these variables and to reduce or eliminate as many experimental errors as possible. Two techniques were principally used. First, data were collected from duplicate experimental arrangements while the most easily controlled conditions were kept as nearly identical as possible. Second, measurements were made while permitting only one of the many parameters to vary in each experimental run. These measurements at least provided relative, qualitative results within each run, although, of course, extreme caution must be used if data from one experimental run are to be compared with those from another.

4.2 Electron Interactions

4.2.1 During stable operation of the electron accelerator it is reasonable to expect to adjust the beam voltage within ± 4 per cent of the metered value, and to adjust the beam current within

±1 per cent. A beam voltage of 0.7 Mev was chosen in order to provide for stable accelerator operation, to permit a substantial portion of the beam to penetrate through structural supports and into the organic food material, and to provide nearly total beam absorption in the experimental sample. The total radiation dose had an upper limit equal to the beam power output (beam voltage times beam current) of the accelerator, and this is the most energy that could possibly be absorbed in the sample. However, this maximum absorbed dose must be immediately reduced by allowances for attenuation and scattering of the electron beam after it leaves the accelerator.

4.2.2 The calculation of the electron beam energy lost in the organic sample is complicated by the following:

(1) X-Rays are formed to some extent in the titanium accelerator window, the air between the window and the test sample, and in the test sample.

(2) The accelerator window and air path cause a scattering and attenuation of the electron beam.

(3) The "slowing down" of the electrons and absorption of X Rays may produce secondary electrons.

(4) Losses of electron energy by bremsstrahlung radiation, and those by ionization and

excitation are difficult to differentiate, but the fraction of total energy loss in the form of bremsstrahlung[5] is less than 1 per cent in our case where the irradiated material is principally water. Much of this soft X-Ray radiation will be absorbed early in its path through the sample.

4.2.3 The divergence and location of the electron beam was defined by observing the pattern of color change of a polyvinylchloride strip placed in front of the sample holder. Approximately 15 per cent of the beam did not strike the sample holder, and was presumed lost to our experiment. The losses in beam voltage because of air attenuation (0.038 Mev) and in the aluminum face of the sample holder [8] (0.092 Mev) permitted 0.57 Mev beam voltage to enter the organic sample. The beam should dissipate its energy within approximately 0.3 cm depth of the sample.[9]

4.2.4 The mixing of the organic food as it was pumped in front of the accelerator beam was checked with a dye, and it appeared to be satisfactory, and in all cases but for the very light doses the liquid was recycled through the beam many times. The liquid food was again thoroughly mixed after irradiation; before a test sample was withdrawn. Therefore, the error was negligible.

4.2.5 The bulk temperature of the liquid under irradiation was kept below that of the Warburg constant temperature bath ($30^{\circ}C$) where it was subsequently placed. This procedure eliminated any

temperature effects during irradiation that might, for example, contribute to polymerization, and thereby obscure the direct results of the radiation.

4.3 Warburg Measurements

4.3.1 If absolute measurements of oxygen are required, the uniformity of temperature throughout the bath is more critical than the bath temperature. A change in the overall bath temperature (or change in atmospheric pressure) will be compensated by the thermobarometer (paragraph 2.3.4), and if the proper temperature dependent flask constant is used, this error will be compensated. However, if the bath temperature differs by as little as $0.05^{\circ}C$ between 2 flasks, a pressure difference corresponding to about 1.7 microliters per 10 ml of gas volume will result.[4] In our case this would correspond to about 18 microliters of gas. In the case of the protein measurements an error of this size could be less than 1 per cent of the reading, but in the case of the ABS the error would nearly approximate the reading itself. To reduce this error the Warburg bath must be kept out of drafts, the flask kept well covered with water, and the water must be vigorously stirred. Under these conditions the apparatus should be controllable to within $0.0028^{\circ}C$.

4.3.2 If the Warburg manometer-flask systems are calibrated using McKinney's water method,[3] the volume can be determined within 2 per cent. This error combined with a 1 to 2 per cent accuracy in reading the manometer level, will produce a significant portion of the experimental error mentioned in paragraph 4.3.3.

4.3.3 The precision with which activated sludge sample sizes (20 ml) and food supplies (2 ml) could be duplicated in each flask presented another source of error. The use of a single master sample provided the following advantages:

(1) Nearly the same type of microorganisms were present in each sample, because pH, temperature, and internal sludge food supply is nearly the same throughout the master sample.

(2) The growth cycle (paragraph 1.1.8) of all samples will be at the same phase.

(3) The master sample was continuously stirred to provide uniformity. In this regard it was not possible to withdraw a sample with uniform density of solid particles, but the 20 ml sample was large compared with the particle sizes.

4.3.4 To obtain an idea of the degree with which data could be reproduced, four runs were made with duplicate flasks prepared under as nearly identical conditions as possible. The observed variations of 5 to 10 per cent were small compared to the 200 to 400 per cent changes observed for the designated variables (Figure 3.1, 3.2).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 The following conclusions are based on the data obtained in these experiments:

(1) The interaction of 0.57 Mev electrons with protein material causes a decrease in its rate of assimilation by activated sludge, which is consistent with an increase in radiation dosage in the range from 6.5×10^4 rads to 13.9×10^6 rads.

(2) Within the dose range stated in (1), increased radiation causes increased polymerization of the protein material.

(3) The interaction of 0.57 Mev electrons with detergent (ABS) causes an increase in its rate of assimilation by activated sludge, which is consistent with an increase in radiation dosage in the range from 6.5×10^5 rads to 3.6×10^6 rads.

(4) The detergent receiving radiation doses less than 10^5 rads produced results within the range of

possible experimental error, and hence were not significant.

(5) The protein material is much more easily assimilated by the activated sludge than is the detergent.

(6) Radical color changes occurred in the protein material and detergent after a dose of approximately 10^7 rads.

5.2 Recommendations for Further Study

5.2.1 Further investigations are indicated in the following areas:

(1) To extend this investigation to cover the fat, oil, and carbohydrate components of sewage.

(2) To observe the effects of lighter radiation (10^3 to 10^5 rads) on protein material to determine if the protein is degraded before it begins to polymerize.

(3) To determine if there is a relationship between the effects observed in these experiments with those observed by Unidynamics[1] in the sedimentation experiments.

(4) To determine the limits of radiation induced polymerization in protein material.

(5) To perform quantitative identification of protein constituents before and after irradiation.

APPENDIX A

MEANING OF THE FLASK CONSTANT

The flask constant as derived by Umbriet[4] enables one to calculate the amount of gas that will dissolve in a liquid. After one observes the change in gas pressure (h) in the manometer open arm, and if one knows the gas volume of the flask (V_g) to the manometer reference point (150 mm), the volume of the liquid in the flask (V_f), the temperature of the operation in absolute degrees (T), the solubility of oxygen in the liquid (α), and the density of the manometer fluid (P_o), it is possible to calculate the amount of oxygen that is transferred to the liquid.

$$x_{\text{amount of gas exchanged}} = h_{\text{change in gas pressure}} \; k_{\text{flask constant}}$$

$$\text{where } k = \frac{V_g \frac{273}{T} + V_f \alpha}{P_o}.$$

In our case $T = 303^{\circ}K$ and $\alpha = .026$. P_o is conveniently set at 10,000 mm by using Brodie's Manometer Fluid which has density of 1.033 gm per cm^3. Therefore, all that is required is V_g, V_f, and h in order to compute the amount of oxygen transferred to the liquid.

APPENDIX B

SAMPLE DOSAGE COMPUTATION

The following example is typical of the method used to calculate the amount of radiation energy absorbed by the irradiated sample:

> Assume a beam current of 500 microamps and a beam voltage of 0.7 Mev. The beam voltage will sustain losses in air (0.038 Mev) and in the aluminum face of the sample holder (0.092 Mev) in the flight of the electrons into the sample. This results in $(0.5 \times 10^{-3}$ amps) $(0.57 \times 10^{6}$ ev) = 285 watts of beam power. However, about 15 per cent of the beam did not strike the sample, so only 242 watts were actually absorbed. Now 1 watt = 10^{7} ergs/sec and 1 rad = 100 ergs of absorbed energy per gram of material. Therefore, 242 watts = 242×10^{7} ergs/sec = 242×10^{5} rad gm/sec. Then, for example, if 121 grams of food are irradiated at the above conditions for 10 seconds, the food would receive 2,000,000 rads of radiation.

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