REMOVAL OF BEET COLOR FROM WASTE BY TREATMENT WITH TRICKLING FILTERS

by

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INTRODUCTION

Discussion of Problem

The problem of stream pollution in Oregon has been greatly improved since 1939, when the Oregon State Sanitary Authority was organized; however, in the near future more complete treatment, to abate individual pollution problems, will be required. One of these problems occurs in the canning industry and is that of the color produced when red beets (Beta vulgaris) are canned.

During the canning of beets a large volume of water is used. This water becomes intensely colored from being in contact with the beet waste. The water, in most cases, is used to convey the waste to the municipal sewers and hence to the municipal sewage treatment plant.

The solids which are in beet waste cause many operational problems at sewage treatment plants. The chlorine demand of the sewage is greatly increased because of the high organic content of beet waste. The large amounts of sludge, which are settled from the beet waste, overload and upset the digestion process.

Additional heat must be added to the digesters to bring the large volumes of sludge to a digestion temperature of 90°F. After the sludge has been digested it must be disposed of. The addition of lime to the digesters may be necessary to keep the sludge at a proper pH for digestion. A major portion of the solids could, however, be removed at the cannery by adequate screening.

Primary sewage treatment plants, which serve the cities of Oregon that are located on large streams, remove or decrease the beet color little or none even though they remove a large percentage of the waste solids. It is not possible for primary treatment to remove color, since its function is based on the sedimentation and flotation properties of waste. Since beet color is in solution, the only color reduction affected at a primary treatment plant is caused by the chlorine which is added to the waste for bactericidal reasons.

To the layman the color, which passes through a primary treatment plant and subsequently appears in the receiving stream, is an indication of pollution, and judged to be a menace to fish life, recreation, and health, even though it may have little pollution potential.

As the Willamette Valley becomes more densely populated, and because of the fact that people have an

increasing amount of recreation time and monies with which to enjoy a wider variety of recreation, there is, and will be, greater numbers of people aware of the fact that our streams can be re-created by increased waste treatment. This awareness will create interest and action which will dictate secondary sewage treatment for all Willamette Valley cities in the near future. Since color will be considered by the layman to constitute pollution, it is important that the secondary treatment provided affect a high removal of color. Even though the discharge from a secondary treatment plant would be sufficiently low in pollution potential, if it were colored it would yet be an unsatisfactory effluent for disposal in a stream.

High-rate trickling filters are the most common secondary treatment provided for municipal sewage treatment; therefore this research was to determine if conventional high-rate trickling filters would remove beet color when treated in conjunction with domestic sewage.

Chemical Composition of Beets

The components of beet waste are determined by the composition of beets. The organics present in settled beet waste depend upon the relative solubilities and concentrations of the beet constituents. It can be

seen from the following table that beets are high in proteins and carbohydrates.

The United States Department of Agriculture reports that raw beets for household use are twenty-five per cent waste. This is about half as much waste as obtained when they are commercially canned. The chemical composition of beets is as follows: (7, p.26 and 47, p.14)

Constituent	Per Cent by Weight
Moisture	87.6
Protein	1.2 - 1.6
Fat	0.1
Ash	0.8 - 1.1
Total Carbohydrates	7.2 - 9.6
Fiber	0.7 - 0.9
Calcium	0.027
Phosphorus	0.043
Iron	0.001
Thiamine	0.00002
Riboflavin	0.00005
Niacin	0.0004
Ascorbic Acid	0.010
Fuel Value Per Pound	155 calories

Plant pigments can be divided into two groups, the plastid pigments, which are associated with the protoplasmic structure of the plant and the group of glycosides called anthocyanins, which exist in solution in the cell sap. The anthocyanins give the colors of blue, purple, violet, mauve, magenta, and reds. Anthocyanins yield a sugar, possibly an organic acid and anthocyanidin (15, p.1315-1340). The beet pigment, then, fits into the group of glycosides even though it is not a true anthocyanin, since it contains nitrogen.

Occurrence and Quantity of Beet Waste

To deal intelligently with a problem it is necessary to know not only the size but also the nature of the problem. With the cooperation of the Northwest Canners and Freezers Association and their members, it was found that four canneries in the Willamette Valley process beets. In general, the processing of beets is as shown in the flow diagram (see Figure 1). The four canneries were visited at the end of the 1956 beet canning season, and each cannery manager was asked the following questions:

1. What does your beet canning process consist of?
2. How many weeks does the pack take?

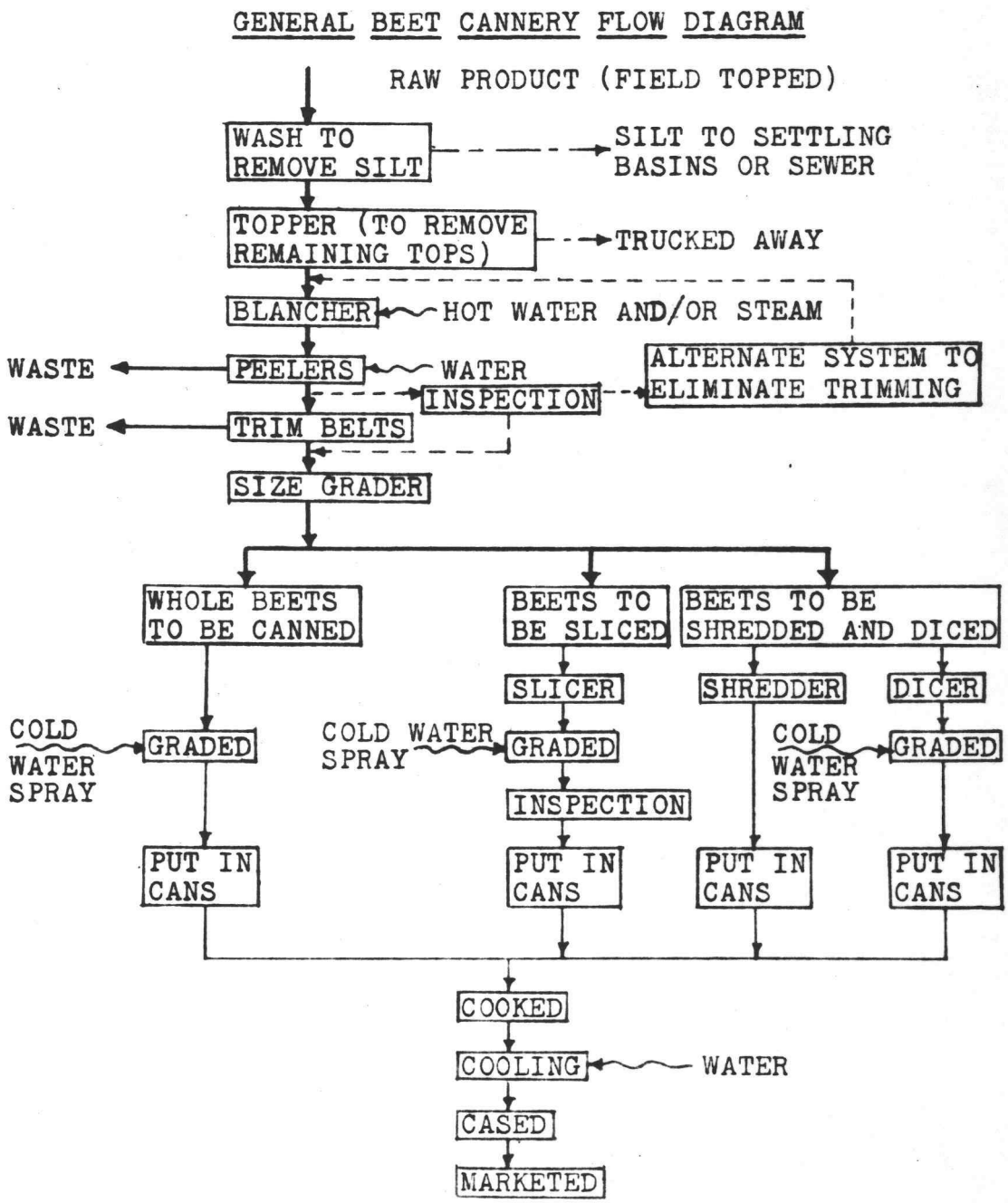

GENERAL BEET CANNERY FLOW DIAGRAM
RAW PRODUCT (FIELD TOPPED)
WASH TO REMOVE SILT
SILT TO SETTLING BASINS OR SEWER
TOPPER (TO REMOVE REMAINING TOPS)
TRUCKED AWAY
BLANCHER
HOT WATER AND/OR STEAM
WASTE
PEELERS
WATER
INSPECTION
ALTERNATE SYSTEM TO ELIMINATE TRIMMING
WASTE
TRIM BELTS
SIZE GRADER
WHOLE BEETS TO BE CANNED
BEETS TO BE SLICED
BEETS TO BE SHREDDED AND DICED
SLICER
SHREDDER
DICER
COLD WATER SPRAY
GRADED
COLD WATER SPRAY
GRADED
INSPECTION
COLD WATER SPRAY
GRADED
PUT IN CANS
PUT IN CANS
PUT IN CANS
PUT IN CANS
COOKED
COOLING
WATER
CASED
MARKETED

Figure 1

3. How many tons of raw product are received?
4. How many cases of product are produced per ton of raw product?
5. What percentage of the raw product is lost in the canning process?
6. How much water is used in the process?
7. What is the temperature of the water used?
8. What treatment is now provided for the cannery waste?

In all four cases the plant managers were very willing to supply the data which they had, but data were lacking in all cases as to the amounts of water used in each step of the canning process.

No direct reference will be made to the canneries supplying data, since all information was given with this understanding.

The pack lasts for a period of about nine weeks in the months of August, September, October, and/or November depending on the particular growing season.

The total raw product received at the canneries is about 30,000 tons in a season. This weight includes silt which clings to the beet. One cannery reports that the silt commonly constitutes three to five per cent of

the gross weight and has been as much as eight per cent of the gross weight.

An average of seventy cases of twenty-four number 303 cans are produced per ton of raw product. This figure varies from sixty-five to seventy-three cases per ton depending on the quality and size of the raw product and the form of the product produced, i.e., whole, sliced, diced, or shredded.

None of the canneries had any figures of the percentage waste of the raw product, but from the figure of the cases produced per ton of raw product, and taking the drained weight of a number 303 can as 10.5 ounces, it was calculated that from forty to forty-five per cent of the beet is waste. A questionnaire of the Northwest Canners and Freezers Association, with four canneries reporting, sets the percentage waste at 38.4. If, for example, forty per cent of the raw product is waste, then about 12,000 tons of beet waste is produced each year in the Willamette Valley.

Only one cannery had water usage data available. This one figure yields the information that twenty-five gallons of water is used to can a case of twenty-four number 303 cans of beets. If the figure is true for all four canneries, 50,000,000 gallons of beet waste is

discharged to municipal sewers in a year. Assuming a canning season of fifty days would mean that 1,000,000 gallons of beet waste is produced per day.

The major portion of the color is produced at the abrasive peeler. A blancher cooks the outer layers of the beet so that the abrasive peeler can easily grind them off. The shredded beet skin is then washed away by water. The combination of heat, abrasion, and water produce an intensely colored waste at this point. After the beets leave the peeler there are two methods of removing bad spots; either the spots can be hand trimmed or the beets can be returned to the blancher and peeler to remove another layer of outer surface. Each time the beets pass through the blancher and peeler the diameter of the beet is decreased by 1/8 to 1/4 inches. Water is used to convey trimmings to the municipal sewer.

After the beets pass the trimming tables or inspection they are graded and prepared for canning as whole, sliced, diced, or shredded beets. In some cases water is used to flume these products throughout the cannery.

The beets are placed in cans or jars and cooked either by a continuous steam process or a batch process. In the batch process the hot water which is used for cooking is discharged to the municipal sanitary sewers or storm sewers. In some cases this hot water is reused

in the cannery. After cooking, by either method, the containers are cooled by water, and the cooling water meets the same fate as the cooking water.

It can be said, that only a small portion of the water used in beet canning is colored. The major portion of water is used to cook and cool the product. Actual values of component water usage are impossible to obtain; none of the canneries interviewed have taken component water measurements.

All waste containing suspended solids is passed over a twenty mesh rotary or vibrating screen, and the liquid waste which passes the screen is discharged, in all cases, to the municipal sewers. The solids which are removed by the screen retain little or none of their color. During the short time which the beet waste is in contact with steam and water, it undergoes almost a complete color extraction.

As the beets are unloaded at the cannery they are washed with a spray to remove the silt which clings to them. Two of the canneries pass the water containing silt through a settling basin before the water from this initial wash is discharged to the sewer. The screenings are hauled to local garbage dumps or similar areas. In

only one cannery is there any effort made to separate the waters which contain waste from those which are cooling waters and need no treatment.

Trickling Filters

Trickling filters consist of a bed of filter media, a mechanism to spread settled sewage on the media, the organisms growing on the media, and an effluent collection system. In high-rate filters the filter media is rocks 2½ to 4 inches in diameter. These filters are commonly six to eight feet in depth. The microorganisms growing on the media are those obtained from seeding the filter with sewage. The filter growth consists of bacteria, fungi, algae, protozoa, worms, and insects. The growth is able to absorb, coagulate colloidal material, and to flocculate and strain out suspended solids. As the growth ages parts of it slough off and are washed from the filter. The effluent is settled and the sludge which is obtained is anerobically digested with the sludge from the primary treatment.

The organisms of the filter, then, can be considered as a population which needs food to work and grow. The sewage or waste, which is trickled over the organisms, must be suitable for their use as "food" or it will pass through the filter unchanged. As the growth becomes old

and the by-products of life build up, the growth sloughs off of the media and is removed, making room available for new growth. To insure a rapid and more complete use of the "food", media is used and the filter is designed such that aerobic conditions prevail in the filter.

Selectivity of Food

It is common practice for canneries to discharge the screened waste to municipal sewers. The screened beet waste consists of fine particles of beet and soluble organic compounds. This waste is diluted by sewage in the municipal sewers. As this mixture of sewage and beet waste is passed over the biological growth in a trickling filter the various organisms use, as food, that portion of the waste which is easiest for them to consume. It is possible that the molecules of beet color are of such a nature that organisms will not attack them until a major part of the original waste is broken down and they are forced to use the color as a source of nutrition, or it may require specific organisms or specific enzymes of an organism to attack the beet color. In this study there was no attempt to select specific organisms. While it would be interesting to know if such organisms exist, it would probably be of little practical value, since in

waste treatment it would be impossible to maintain a pure culture.

Microorganisms must have nitrogen to synthesize new cell material. W. B. Bollen states that for good oxidation a carbon nitrogen ratio of forty to one is required (5, p.277). Beet waste has a C/N ratio of 18.4 and, therefore, readily fulfills this requirement. The pigment molecule, with its twenty carbon atoms and two nitrogen atoms, has a C/N ratio of 8.57; therefore from a standpoint of the necessary nitrogen the color could be easily oxidized; however the nitrogen must be available to the organisms. It is also known that cyclic structures, which the molecule contains, are more stable than open chained molecules; therefore it might be expected that microorganisms would attack the color molecule only after the more easily oxidized, open chain molecules, which are present in sewage and cannery waste, have been used. The action of symbiosis, depending upon the extent to which it existed in the filter, could cause a removal of the beet color even though the pigment might be difficult for a single organism or a group of organisms to break it down.

To break down beet color it would be necessary for extracellular enzymes of the organisms present to break up the color molecule by hydrolytic cleavage. Since it can be said that colored organic molecules generally are

large and have a large carbon to hydrogen ratio, the cleavage of the molecule would cause the color to be changed or to disappear entirely. It is also possible that by cleavage the enzymes could remove a chromophore group or modify a color producing bond in such a way as to render the molecule or its components colorless. After extracellular cleavage the cell would use the molecule fragments, by the agent of entracellular enzymes, to produce new cell material and energy.

Recirculation

In secondary treatment of the trickling filter type it is common practice to return a portion of the effluent from the filter to the filter influent. The ratio of the amount of sewage returned from the filter effluent to the influent, to the amount of settled sewage, from primary treatment units, applied to the filter is called the recirculation ratio. Recirculation increases the BOD (biochemical oxygen demand) removal, but it reaches a point of diminishing returns; therefore a recirculation ratio of over three is seldom used.

If a filter was operated as a batch process, where the same waste was applied to the filter until it became colorless, and then another batch treated, it would require ten or more passes through the filter to produce

an amber effluent (48, p.72-73). This type of operation would require excessive pumping and long periods for treatment; therefore recirculation, as explained in the preceding paragraph, is used to increase the extent of treatment possible with trickling filters.

In practice the amount of recirculation is limited by the cost of pumping, the size of pumps, and the size of the distribution system as well as the washing effect of a large hydraulic filter loading. Since the BOD of the waste is harder to satisfy as it decreases, the greatest benefits of recirculation are obtained at a recirculation ratio of three or less. In practice a recirculation ratio of one is common, but the use of a recirculation ratio of three is rare or none existent in municipal sewage treatment.

River Dilution

In all cases in the Willamette Valley waste treatment, to some degree, makes use of the dilution effect of a stream. If we were to consider color of the waste only, it is natural that dilution be considered, particularly in an area where a river as large as the Willamette is available.

It was determined in this work that beet color could be detected at an optical density of 0.05 (see Table 1). In all cases the Willamette River would probably provide enough dilution to dispose of the beet color. The only assumption which must be made is that complete mixing occurs as the waste is discharged. This assumed condition, which is all to oftenly made for waste disposal, does not occur since the discharge point is in all cases a single outfall conduit which discharges at a point close to the bank of the river. Mixing does not occur until the waste has traveled several hundred yards down stream along the bank. It is evident that dilution is not a possible method of disposal unless mixing is obtained, and in a river large enough to accept the color it is impossible to obtain adequate mixing until the waste has traveled a considerable distance downstream. Deep water, mid-stream outfalls may provide an adequate means of disposing of a colored effluent, but these are costly to construct and would constitute a maintenance problem.

BASIC ASPECTS OF COLOR

Molecules owe their color to the absorption of visible light. Chemists have found that to have color the molecule must possess certain definite characteristics. The molecule must have a high carbon content, which suggests that colored molecules would contain benzene rings. The molecule must also have chromophores, which are combinations of C, H, O, and N. The important chromophores are C=C, C=O, C=S, C=N, N=N, N=O, and NO_2. Before a molecule will develop its full color potential it must have an auxachrome (color-aid). Auxachromes contain oxygen and may be =O, -OH, SO_3Na and others. The rearrangement of the molecule by breaking a double bond or moving or replacing an auxachrome or chromophore will change its color characteristics. Cleavage of the molecule will also change its color properties.

Molecules are excited to discrete energy levels. The difference between these energy levels determines the wave length of light which will be absorbed, because the energy of the light depends upon its wave length, and the energy must be enough to cause the discrete energy change in the molecule.

Saturated hydrocarbons are colorless because they hold their valence electrons very tightly, consequently,

the electrons cannot vibrate and absorb light in the visible region. Since light of all wave lengths passes through these solutions, they appear colorless. Only light in the ultraviolet spectrum possess enough energy to excite these tightly held electrons. Chromophores and auxachromes contain electrons which are loosely held and, therefore, can be excited by light in the visible region. The difference in discrete energy levels is not as great for molecules containing chromophores and auxachromes as those of saturated hydrocarbons; consequently, light possessing certain wave lengths is absorbed by the molecule, and that visible light which is not absorbed gives the molecule its apparent color. In beet waste the predominate color not absorbed is red.

There are two theories commonly used to explain the phenomena of light, the corpuscular theory and the wave theory. Color, as we know it, is the sensation transmitted to our brain by a receiver, our eyes. The receiver is sensitive, through a marvelous chemical reaction and energy transmission, to light of different nature. Whether the difference is the spacing between packets of energy or the wave lengths of light did not constitute a problem in this study. Many light phenomena can be explained by one or both of the theories. Einstein assumed that light consists of packets of energy which he

called photons (19, p.499), but many light phenomena can be better explained in terms of waves. In either case we are attempting to explain light in terms of things possessing properties with which we are physically aware of, but there is no reason that we should assume that light should resemble either a particle or a wave (19, p.719). In the field of colorimetry the wave theory of light is used to express and explain the observations obtained. We speak of the wave length at which light is measured and picture light as consisting of many waves of different lengths. The color of each wave is assumed to be determined by its wave length.

Color, with its irreducible psychological content, is a sensory experience and must be considered as well as the physical properties of light. Color can be defined in terms of three parameters; hue, examples of which are red, yellow, green, and blue; saturation, the proportion of full pure hue in the color; brightness, intensive aspect of visual sensation. Color is defined by the Committee on Colorimetry of the Optical Society of America as the characteristics of light other than spatial and temporal inhomogenieties; light being that aspect of radiant energy of which a human observer is

aware through the visual sensations which arise from the stimulation of the retina of the eye.

In this study the psychological aspect of color in a natural stream was the controlling factor, but the beet color was expressed as an intensity, optical density or per cent transmission, at a particular wave length as measured by an accurate instrument. The instrument, a spectrophotometer, was used to do away with expensive and variable observers. The color as measured by the spectrophotometer was tied back to the psychological aspect by one group of observations (see Table 1).

Psychologically, colors produce many emotions and illusions. Colors are used to describe feelings or as adjectives to describe people, a coward is yellow, a person feels blue. We are accustomed to particular colors for our foods (4, p.167). To observe red induces a feeling of warmth, while blue and green induce a feeling of coolness (4, p.169). Red is an ardent and passionate color and stirs a man to action, while green and blue lead to meditation. A surrounding of red makes objects seem heavier and time to pass slowly (4, p.172). The foregoing facts point to a few of the many color expressions and associations which we use and are subjected to.

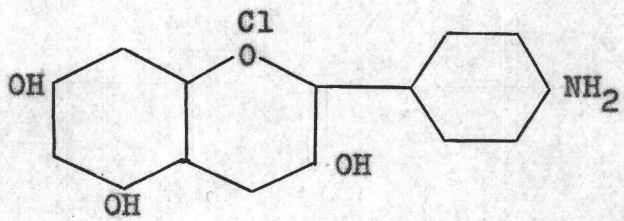
A large portion of the color which we observe in nature is green and blue. A sportsman thinks of a green or blue stream bordered by green trees and grass. To have this picture interrupted by a red strip of beet waste or waste having another "action" color would disrupt the meditating mood and cool surroundings of the green and blue. The beet color also indicates the flow of sewage from a municipal sewage treatment plant, which stimulates many unpleasant associations.

As Birren states,"seeing is as much in the mind as in the eye" (4, p.188). It is certain that the psychological effect of a particular color on an observer cannot and must not be overlooked. Photometric measurements can be made and used as a method of expression, but must be examined in the light of the particular color and its associations.

PREVIOUS STUDIES OF BEET PIGMENT

The first published work on the composition of beet pigment was by Gustav Schudel at Zürich, Switzerland in 1918. He reported the pigment, betanin, to be a glucoside (44, p.1-64). He found that glucose was split off the betanin. Analysis of the betanin showed it to be 55.16 per cent carbon, 4.96 per cent hydrogen, and 8.57 per cent nitrogen. The sugar free derivation betanidin was obtained in the ethylated condition and was found to contain 60.24 per cent carbon, 5.27 per cent hydrogen, and it also gave a qualitative test for nitrogen.

Alice and Robert Robinson in 1932 and 1933 reported attempts to establish the structure of betanin and related nitrogenous anthocyanins by synthesis. They established that betanin was closely related to the following structure:



Believing that Schudel's work could be questioned, because of the use of a mixture of amyl alcohol and acetophenone containing dichloropicric acid to prepare the pigment, Ainley and Robinson in 1937 isolated the

pigment by adding sodium chloride and extracting the pigment with isoamyl alcohol. The extract was then returned to a smaller volume of water after it was mixed with light petroleum. The procedure was then repeated. The solution was next evaporated in a vacuum and the residue extracted with alcohol. The final residue was washed with water and dried in a vacuum. Their results indicated a formula of $C_{20}H_{19-23}O_7N_2Cl \cdot 3H_2O$ for the molecule (36, p.1439-1445 and 37, p.25-29).

Ainley and Robinson found that the color of the pigment changed when various aqueous solutions were added.

Sodium bicarbonate	- more red then brown
Concentrated HCl	- bluer tone
$FeCl_3$	- brown and distruction of pigment
NH_3	- yellowish-brown
NaOH	- yellow - after ten minutes color cannot be regenerated on acidification, but can be regenerated after thirty seconds.
Sodium nitrite	- stable

Nitrous acid	- immediate distruction, yellow solution
$BaCl_2$, $FeSO_4$, $SnCl_2$	- no visible reaction
Lead acetate	- pale yellow solution, pale pink precipitate
Basic lead acetate	- no color change

Shortly after Ainley and Robinson's work Otto Schmidt prepared the pigment by the Willstätter and Schudel method (43, p.284) and found that it had 5.4 per cent nitrogen, half of which was amino nitrogen. This confirmed that Schudel's value for nitrogen was high.

Pucher, Curtis, and Vickery in 1938 reported that betanin is related to pigments in the petals of many flowers. Betanin is not a true anthocyanin since it contains nitrogen. They found the pigment was somewhat unstable and difficult to prepare in pure specimens. They reported that no information on the light absorption of the pigment was available in the literature.

They prepared the pigment by precipitating, with lithium hydroxide, an acid alcohol extract of the dried root. The precipitate was then purified by precipitation

with lead acetate and subsequent separation from acidified aqueous solution, or by precipitation from alcohol solution with peroxide ether.

The prepared pigment in its solid form is nearly black with a green luster; it closely resembles such dyes as crystal violet and basic fuchsin in appearance. The streak is purplish red. The pigment is hydroscopic and therefore must be isolated from moisture. The solution is purplish red at a concentration of 0.005 mg. per ml. (pH 5.2) and has an extinction coefficient of 0.398 when measured in a one cm cell with a Zeiss spectrophotometer with a S-53 filter.

In addition to the chemical properties of the solution which Ainley and Robinson reported; Pucher, Curtis, and Vickery found that if soluble phosphate is present with lead acetate the precipitate removes nearly all the pigment. They also found that the color is destroyed by permanganate such that the two nitrogen atoms in the pigment can be titrated to a colorless end point by eight oxygen atoms from the permanganate.

Pucher, Curtis, and Vickery found the composition of the pigment to be as follows:

	Per Cent by Weight	
	Found	Corrected for Ash
C	52.18	53.13
H	4.77	4.87
N	5.93	6.06
Cl	1.54	1.02
O	----	34.74
Ash	2.11	

The molecular formula proposed was $C_{21}H_{23}N_2O_{10}Cl \cdot 3H_2O$. This formula corresponds to a glycoside of a nitrogenous anthocyanidin. They were unsuccessful in establishing the nature of the nitrogen present, but concluded, however, that there is probably no aliphatic amino group, and the evidence of an aromatic group is inconclusive, but the presence of ring nitrogen is possible. They found the maximum absorption of light by a solution of the pigment to occur at a wave length of 530 mμ (23, p.71).

Irena Chmielewska prepared the pigment by the use of plumbous salts and found that when the lead salt was treated with ethel alcohol it yielded two monoglucosides, one red and the other violet, the red being a derivative of the violet (8, p.164 and 9, p.1-8).

PREVIOUS LABORATORY AND FIELD STUDIES OF BEET WASTE

Many authors have reported the effects of beet waste on sewage plant operation. They wrote concerning the added operation problems caused by a strong waste which overloaded their treatment plants, but none of these authors reported any quantitative data on color removal.

Eldridge (11, p.17) reported that coagulation with lime would reduce the BOD of a tomato-beet waste by only 42.3 per cent, and found that beet waste could be treated with lime and $FeSO_4$, but he did not mention color removal.

W. Rudolfs and W. D. Hanlon worked extensively with color in waste and methods of detecting and removing it, but did not work with beet waste.

R. A. Webster ran tests on combined beet and corn waste using chemical coagulation, a deep high-capacity biofilter, and a high-rate filter, but he made no study of color removal (50, p.1432-1437).

The most complete work on the treatment of cannery waste is that of L. F. Warrick, F. J. McKee, H. E. Wirth, and N. H. Sanborn. In cooperation with the National Canners Association, these authors made a study of many cannery wastes including beet waste. Types of treatment used were chemical, biological, sand filtration, and carbon filtration. They found that treatment of beet

waste with lime to a pH of 11.0, which required about ten pounds of lime per thousand gallons of waste, produced a light orange or yellow supernatant and an average BOD reduction of fifty-nine per cent (48, p.28). This would mean the waste would be discharged with a BOD of 1000 ppm which is about twenty times as strong as domestic sewage after secondary treatment. Activated carbon failed to remove BOD. The addition of four pounds of lead acetate per thousand gallons of waste removed thirty-eight per cent of BOD, but the sludge after one hour constituted fifty-one per cent of the volume of the waste treated (49, p.29). Bentonite was not a satisfactory method of treatment since it could not be dispersed. Treatment with alum and lime gave an average BOD reduction of thirty-six per cent (49, p.29). They also reported that the addition of four pounds of ferrous sulfate per thousand gallons of lime treated waste increased the BOD removal and the sedimentation rate of the floc. Although only a forty-five per cent reduction was obtained in a full scale plant; the ferrous sulfate-lime treatment was reported as an effective, practical, and fairly efficient chemical treatment for beet waste (49, p.29). The use of ferric chloride with lime gave comparable results to those obtained with ferrous sulfate. Zinc chloride was

found to give a BOD reduction of eighty-five per cent and produce a water clear supernatant when ten to fourteen pounds per thousand gallons was used (49, p.30).

Warrick, et al also subjected beet waste to biological treatment consisting of two trickling filters, one with rock media and the other with tile media. It was found that the rock filter was more efficient than the tile filter. It was also found that beet waste could be treated biologically if enough contact time and sufficient filter capacity are available (49, p.42). To produce an amber effluent from full strength beet waste it was necessary to pass the waste through the filter eight to eleven times. The rock filter effected a sixty-one per cent BOD reduction after six passes through the filter. No report of quantitative color removal was included in the work of Warrick, et al.

INITIAL EXAMINATIONS

Photometric Curve

Using filtered beet waste, it was found that the maximum absorption occurred at a wave length of 530 mμ. The value was obtained by constructing a per cent transmission curve using data obtained with a model "B" Beckman spectrophotometer (see Figure 2). These data agree with the values found by Ainley and Robinson for the isolated color pigment (23, p.71).

It was found that the transmission curve of basic carbol fuchsin, a bacterial stain, was very similar to that for beet waste, and it was suspected that the chemical structure might be similar, but upon the addition of a base to both beet waste and carbol fuchsin it was found that beet waste became amber while the carbol fuchsin became a deeper red; also carbol fuchsin is a more intense dye than beet color. From these observations it was evident that while the two materials had similar effects on light they were not chemically similar.

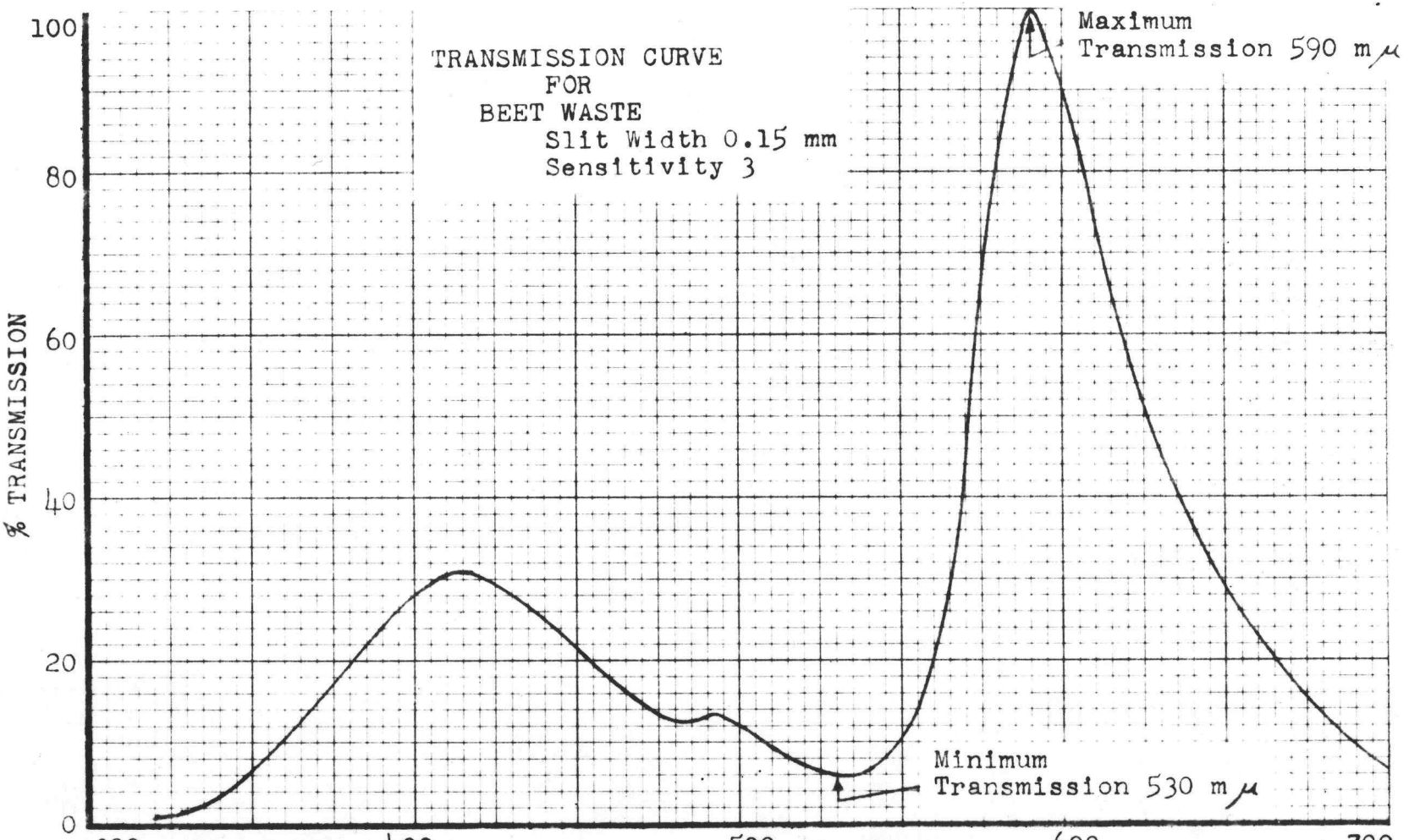

TRANSMISSION CURVE
FOR
BEET WASTE
Slit Width 0.15 mm
Sensitivity 3
Maximum
Transmission 590 mμ
Minimum
Transmission 530 mμ
% TRANSMISSION
100
80
60
40
20
0
300
400
500
600
700
WAVE LENGTH - mμ

Figure 2

Dilution Curve

The results of color removal are expressed in this thesis as per cent of optical density removal; therefore a dilution curve was run on beet waste to determine if it followed the Lambert-Beer Law. The dilution curve is linear in the region which the pilot plant samples fell (see Figure 3). The equation of the line obtained was:

$$\text{Optical Density} = (K)\ (\text{Units of Waste}) - 0.002$$

$$\text{Optical Density} = (0.016)\ (\text{Units of Waste}) - 0.002$$

Since the Lambert-Beer Law generally applies only to dilute solution, it would be expected that the dilution curve would not be linear for intensely colored wastes such as those at a cannery.

River Observations

In the waste treatment field it is very costly and seldom necessary to remove all the undesirable constituents of a waste. This would also be true for color removal; therefore it was necessary to determine the level at which color could be detected in a stream.

A test was conducted in which four impartial observers took part. Varied concentrations of waste were mixed in a pyrex tube two inches in diameter and eighteen inches

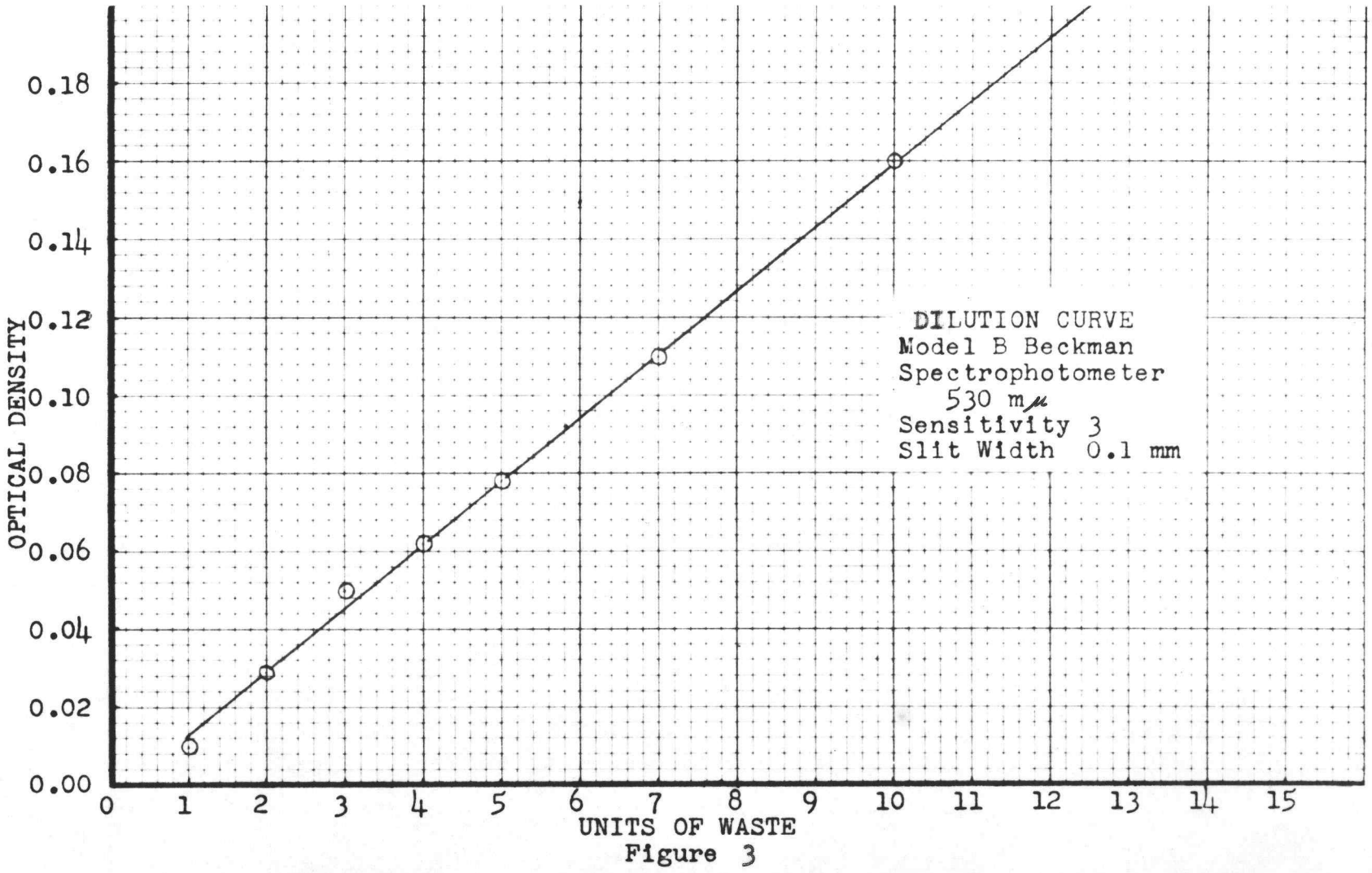

DILUTION CURVE
Model B Beckman
Spectrophotometer
530 mμ
Sensitivity 3
Slit Width 0.1 mm
OPTICAL DENSITY
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
UNITS OF WASTE

Figure 3

long. The beet waste was diluted with river water and the tube suspended in the river to duplicate lighting conditions which would be obtained in practice. Then the observers were asked to record the color they saw and its relative intensity, which is indicated by the number of plus marks (see Table 1). The observers knew only that they were looking for a color and made their observations independently. The tube was stoppered on the lower end with a black stopper, and the turbidity in the river made it impossible to see the stopper. Samples were taken from each dilution and the optical density taken after the samples were filtered. The observers recognized the color as red, pink, or violet and became aware of it at an optical density of about 0.05 as measured with the spectrophotometer at a wave length of 530 mμ and a sensitivity of three.

TABLE 1

Test No.	ml. Waste	O.D.	Relative Observed Color				Remarks
			1	2	3	4	
1	0	0.028	0	0	0	0	
2	1	0.038	0	0	0	0	
3	2	0.050	+	0	+	+	
4	2	0.042	+	+	++	++	Color Recognized
5	4	0.066	++	+	++	++	
6	3	0.040	+	+	++	+++	
7	5	0.078	++	+	++	+++	
8	7	0.085	+++	++	+++	++++	
9	10	0.100	++++	+++	++++	+++++	

Time Study

The waste produced by the peelers at the cannery is pulverized beet skin, much of which cannot be removed by screens. Sedimentation will, however, remove a great proportion of this material but obviously affects no color removal. The color of the liquid waste may increase during sedimentation because of the extended time of contact between the pulverized beet and its carrier.

To evaluate the effects of time of contact between the waste and its carrier, a laboratory scale test was carried out. A batch of waste was made up by shredding

whole beets and placing them in contact with 40°C water. The effects of time on the total solids, pH, and per cent transmission of the settled waste were as shown in Figure 4. It was apparent that to separate the suspended solids from the waste as quickly as possible would be very desirable and would keep the waste strength in terms of total solids and color intensity at a minimum. From Figure 4 it can be seen that the total solids and color increase rapidly during the first hour of contact.

Molecular Size

In an attempt to determine if the beet color was in suspension as a colloid or was a true solution, a portion of filtered waste was passed through a membrane filter, which has a pore size of 0.5 microns. No color was retained on the membrane. The colored liquid which passed through the membrane filter was placed in a visking container which was suspended in a beaker of distilled water. The color passed through the visking into the distilled water. From this observation it can be said that the particle weight of the color is less than 1000, and the color is not a colloid.

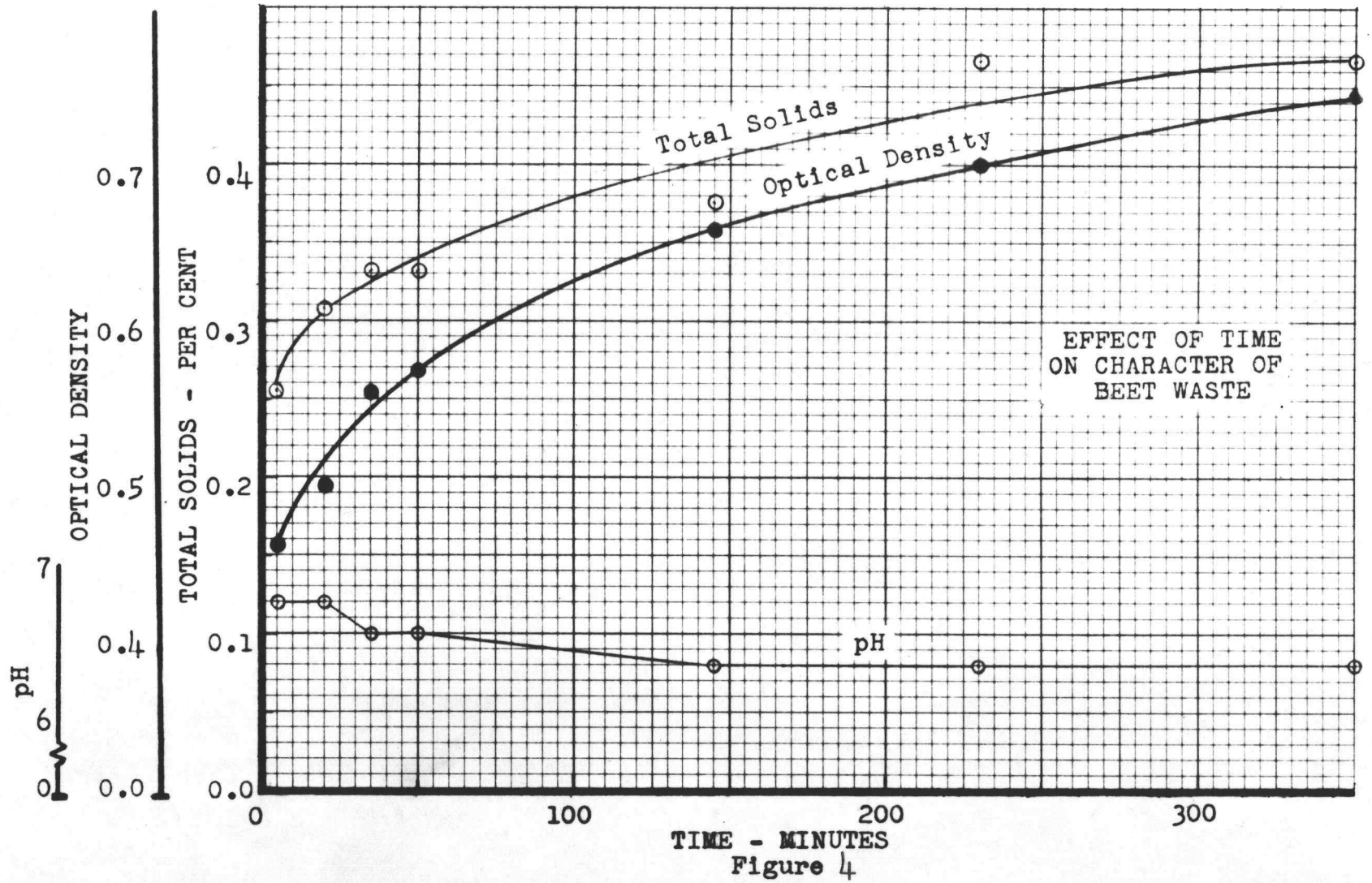

Total Solids
Optical Density
pH
EFFECT OF TIME
ON CHARACTER OF
BEET WASTE
OPTICAL DENSITY
TOTAL SOLIDS - PER CENT
pH
0.7
0.6
0.5
0.4
0.4
0.3
0.2
0.1
0.0
7
6
0
0
100
200
300
TIME - MINUTES

Figure 4

Cannery Tests

The beet waste releases organics to the water which is carrying it. After the settleable solids are removed from the water those organics which are in suspension and solution exert a biochemical oxygen demand (BOD). The five day BOD was found to be about 2,500 ppm. Eldridge reported that the five day BOD was 2,500 ppm and was produced in the quantity of 0.520 pounds per case of number two cans (12, p.17-18). Bollen found the five day BOD to be 3,000 ppm and the twenty day BOD to be 6,200 ppm (5, p.278). Several others have reported the five day BOD to be about 2,500 ppm. It is evident then that the five day BOD is in the range from 2,500 to 3,000 ppm. The waste then is about twenty-five to thirty times as strong as settled domestic sewage. One thousand gallons of this waste would be equivalent to the settled sewage from 270 people.

To determine the characteristics of beet waste, samples were taken from the Corvallis cannery. Samples were taken at 10 A.M. and 3 P.M. for eight days, and on one day samples were taken every hour for nine hours.

The procedure was to take a sample from the cannery effluent to the sewer and return to the laboratory and run tests. At the time the sampling was done the cannery

had not yet installed a screen and was grinding larger solids and returning them to the sewer. All silt from the initial wash was also being discharged to the sewer.

The average values from fourteen samples over a period of eight days for settleable solids was 100 ml. per liter or ten per cent by volume, for total solids was 3,340 ppm, and for volatile solids was 3,050 ppm.

The samples which were taken each hour for nine hours on October 21, 1955 were returned to the laboratory and the following tests ran, with the average values shown obtained:

TABLE 2

B & L Monochromatic Colorimeter = 550 mμ

Test	Average Value
Raw Sample	
Transmission (2,505)	3%
pH	6.9
Settleable solids	58 ml. per liter
Total solids	3850 ppm
Settled Sample	
Total solids	2810 ppm
Suspended solids	1470 ppm
Dissolved solids	1340 ppm

It is possible to remove twenty-seven per cent of the solids from the waste by sedimentation for about two hours.

The waste was noted to foam easily, had a deep red color, and contained pieces of beet up to 1/4 inch, which made accurate solids determinations difficult. The beet pulp itself was found to contain eighty-nine per cent moisture.

PRELIMINARY TRICKLING FILTER STUDIES

Glass Filters

As a preliminary study to the pilot plant at the Corvallis Sewage Treatment Plant two small trickling filters were set up in the laboratory. These were constructed from two glass pipes four inches in diameter and ten feet long. The pipes were filled to a depth of six feet with 1/2 to 3/4 inch rock (see Figure 5).

Figure 5: Glass Filters

The filters were seeded with sewage to start a growth on the rocks and then switched to beet waste. The construction of the units was crude and the similitude

poor; therefore no quantitative tests were run on these small filters. It was evident, however, from observations that trickling filters could remove beet color.

A 100 ml. sample of the growth from the filters was found to have a total count of 1×10^9 organisms per ml. The growth was dark brown in color and had a decided earthy odor. The media used for total counts was nutrient agar, and the plates were incubated at 30°C for twenty-four hours. A hanging drop slide examination disclosed that the growth had numerous algae of which most were circular, but there were a few filimentous forms present. Many motile protozoas were also observed, but no macroscopic organisms were observed in the growth.

Stains from representative colonies on the total count plates showed that most of the bacteria were small $gram^-$ rods; however, there were a few $gram^+$ packets and a few large $gram^+$ rods.

Laboratory Filters

As a further pilot study, four trickling filters were constructed in the laboratory from concrete asbestos pipe having an internal diameter of one foot. The filters were filled to a depth of six feet with 2½ to 4 inch

river run rock. The waste spreader system consisted of a small rotating rubber disk over each filter (see Figure 6, 7, and 8).

Waste for the filters was prepared by extracting the color from shredded beets which were obtained locally and prepared in the laboratory with a small food chopper.

Time limitations and the building of the four foot pilot plant filter at the sewage plant, for the main study, prevented an adequate study with these filters. The small amount of data taken showed that these filters would remove about fifty-five per cent of the color and about fifty per cent of the BOD from beet waste. The loading was from fifty-three to ninety-two pounds of BOD per thousand cubic feet per day. The waste applied to the filters had an optical density of 0.50 and a BOD of 730 ppm. No recirculation was employed. These data were obtained from a one day run of the four filters. The growth was well established on the filter media, since the filters had been in operation for three months.

Figure 6

Laboratory Trickling Filters During Construction

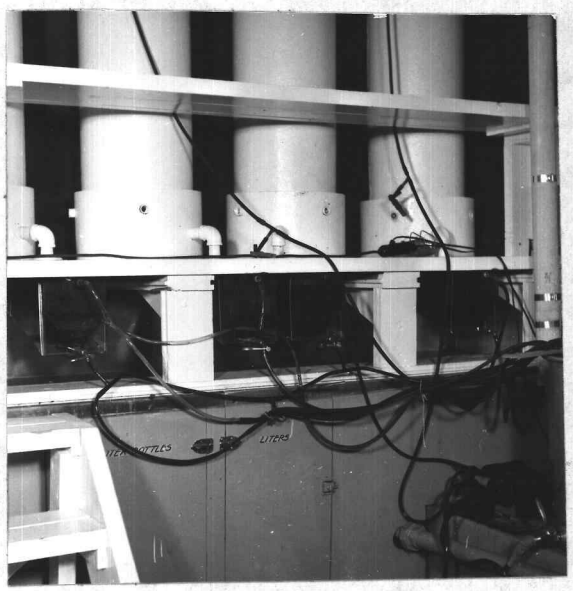


Figure 7

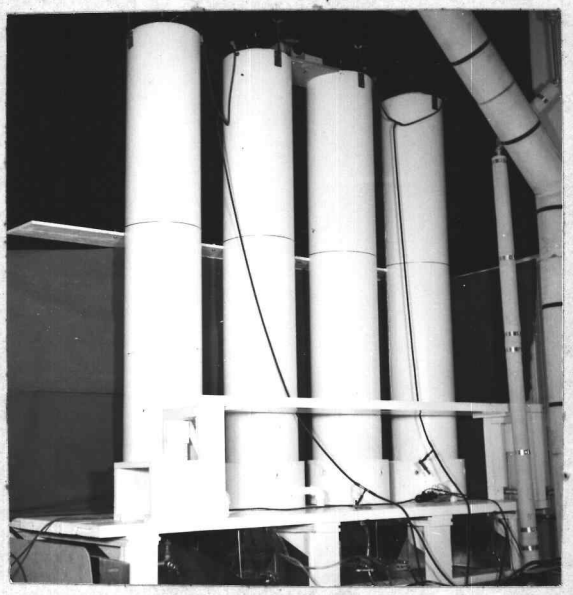


Figure 8

Laboratory Trickling Filters During Operation

Preliminary Conclusions

The purpose of the preliminary tests with laboratory filters was to determine the feasibility of the removal of color from beet waste by the use of conventional high-rate trickling filters. It was determined that color could be removed, but further testing of the laboratory filters was prevented by a lack of time, and it was apparent that the tests would have little significance because of the inability of such a laboratory study to duplicate field conditions.

PILOT PLANT

Construction

The pilot plant was built adjacent to the clarifier at the Corvallis Sewage Treatment Plant. The trickling filter was built from a wood stave cylinder which was four feet six inches in internal diameter and seven feet tall. The secondary clarifier, which was placed next to the filter, was a wood stave tank four feet in diameter and four feet deep.

A concrete slab 4.5 feet wide, ten feet long, and six inches thick was poured as a base for the filter and clarifier. The underdrain for the filter was constructed from alternate 2 x 2's and 2 x 6's. The 2 x 6's acted as support for the rock and 2 x 2's acted as spacers and were slopped to bring the flow to the front of the filter where it was collected in a metal trough (see Figure 9).

The wood stave cylinder, from which the filter was constructed, was in poor condition; therefore to prevent leaking from the sides, the tank was lined with plastic before the rock was placed in the filter (see Figure 10).

The rock was obtained from a gravel plant on the South Santiam River. The rock was taken from deposits of gravel in the river and screened by a $2\frac{1}{2}$ inch and 4

Figure 9

Figure 10

Construction of Pilot Plant

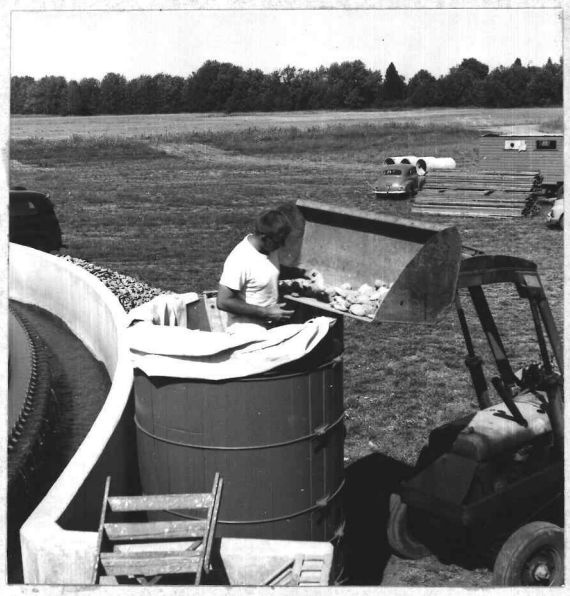


Figure 11

Hand Placing Rock
in Filter

Figure 12

Pilot Plant Filter
in Operation

inch screen to obtain rock which would pass through a 4 inch screen but be retained by a 2½ inch screen. This rock was hand placed in the filter; and broken, extreme flats, and very low density rocks were discarded. The final depth of the rock in the filter was six feet (see Figure 11).

The type, size, and depth of the rock was the same as that commonly used in secondary treatment plants of the Willamette Valley. It was assumed that designers will continue to specify comparable filter media; however the difference in the results obtained because of a variance in commonly used filter media would be small.

The filter spreading mechanism consisted of a quarter horsepower electric motor which drove a vertical shaft that was located over the center of the filter. A small rubber disk, six inches in diameter, was attached to the end of this shaft. The rubber disk was notched and modified until a desirable distribution of the filter influent was obtained (see Figure 12).

The influent for the filter was pumped from the outer edge and near the surface of the sewage plant's clarifier by a small centrifugal pump which delivered the flow to the spreader mechanism on top of the filter (see Figure 12). The waste flowed down through the filter and was

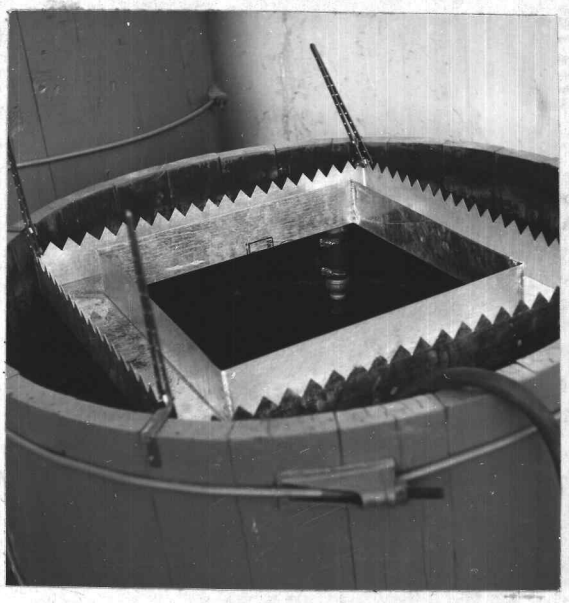


Figure 13

Clarifier Collection Weir

Figure 14

Trickling Filter Collection Trough

Figure 15

Pilot Plant Clarifier in Operation

Figure 16

Pilot Plant During Testing Period

collected in a trough at the front of the filter (see Figure 14). From the trough the flow was pumped, by another centrifugal pump, to a point in the center and six inches from the bottom of the pilot plant clarifier (see Figure 15). After the treated waste was settled it flowed over v-notched weirs into a collection trough (see Figure 13). From the weir collection trough, the treated waste flowed by gravity to a distribution tank where a portion could be recirculated to the spreader mechanism on the filter and the remainder discharged to the sewage plant outfall. The complete flow diagram is given in the drawing of Figure 17.

Test Period

The length of the beet pack at the Corvallis Cannery is determined by the crop, weather, and cannery personnel. The cannery completed the pack in two periods during 1956. Two eight hour shifts were run six days a week from July 31, 1956 to September 8, 1956, and one eight hour shift was run from October 1, 1956 to October 13, 1956.

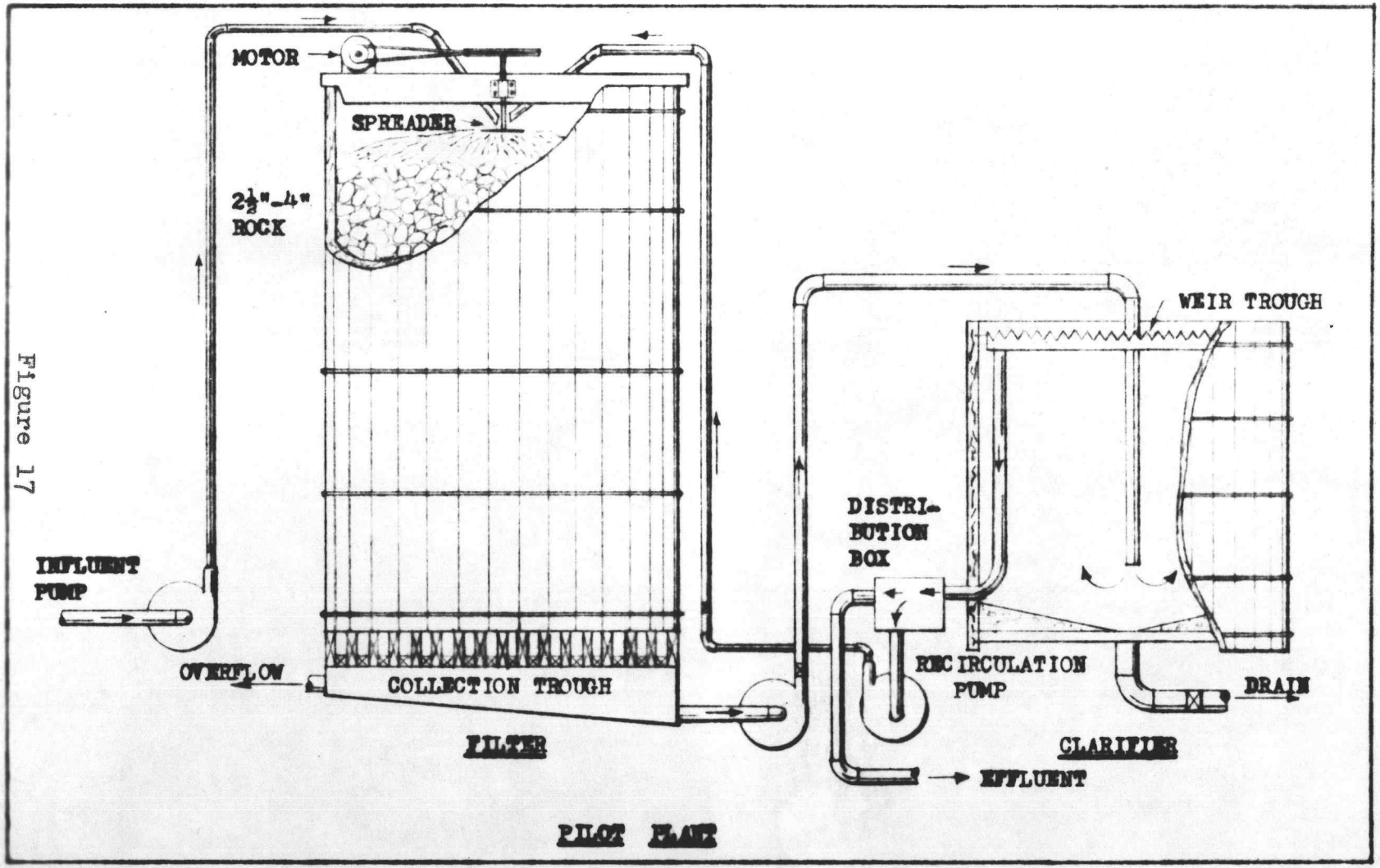

MOTOR
SPREADER
2½"-4"
ROCK
WEIR TROUGH
DISTRI-
BUTION
BOX
INFLUENT
PUMP
OVERFLOW
COLLECTION TROUGH
RECIRCULATION
PUMP
DRAIN
FILTER
CLARIFIER
EFFLUENT
PILOT PLANT

Figure 17

Filter operation was as follows:

Date	Remarks
July 20, 1956	Put rock in filter.
July 31, 1956	Beets started. Started filter.
August 13, 1956	Noted filter flies on filter.
August 16, 1956	Growth became evident on rocks.
August 22, 1956	Started dosage of sodium thiosulfate to neutralize chlorine residual in sewage from sewage treatment plant.
August 29, 1956	Noted algae growth at edges of filter surface.
August 31, 1956	Ran BOD, optical density, and pH tests on hourly samples. No recirculation.
September 1, 1956	Loading 61 pounds five day BOD per thousand cubic feet per day.
September 5, 1956	Ran BOD, optical density, and pH tests on hourly samples. No recirculation.
September 6, 1956	Loading 41 pounds five day BOD per thousand cubic feet per day.
September 8, 1956	Beets stopped.
October 1, 1956	Beets started.

Date	Remarks
October 4, 1956 October 5, 1956	Ran BOD, optical density, and pH on samples taken every two hours. Recirculation ratio one. Loading 71.4 pounds five day BOD per thousand cubic feet per day.
October 11, 1956 October 12, 1956	Ran BOD, optical density, and pH on samples taken every two hours. Recirculation ratio two. Loading 61.5 pounds five day BOD per thousand cubic feet per day.
October 13, 1956	Ran BOD, optical density, and pH on samples taken every two hours. Recirculation ratio three. Lost BOD data because of bad dilution water. Beets stopped for season.

During periods when beets were not being canned the filter was fed settled sewage at a loading of about seventy-five pounds of five day BOD per thousand cubic feet per day. When beets were being canned the filter was conditioned as long as possible for its next test period by operating it under conditions equal to those under which it would be tested. This period was only one day between the recirculation ratios of two and three, because the cannery finished the beet pack sooner than originally expected. Figure 18 shows the beet pack in relation to the other cannery packs and the test days.

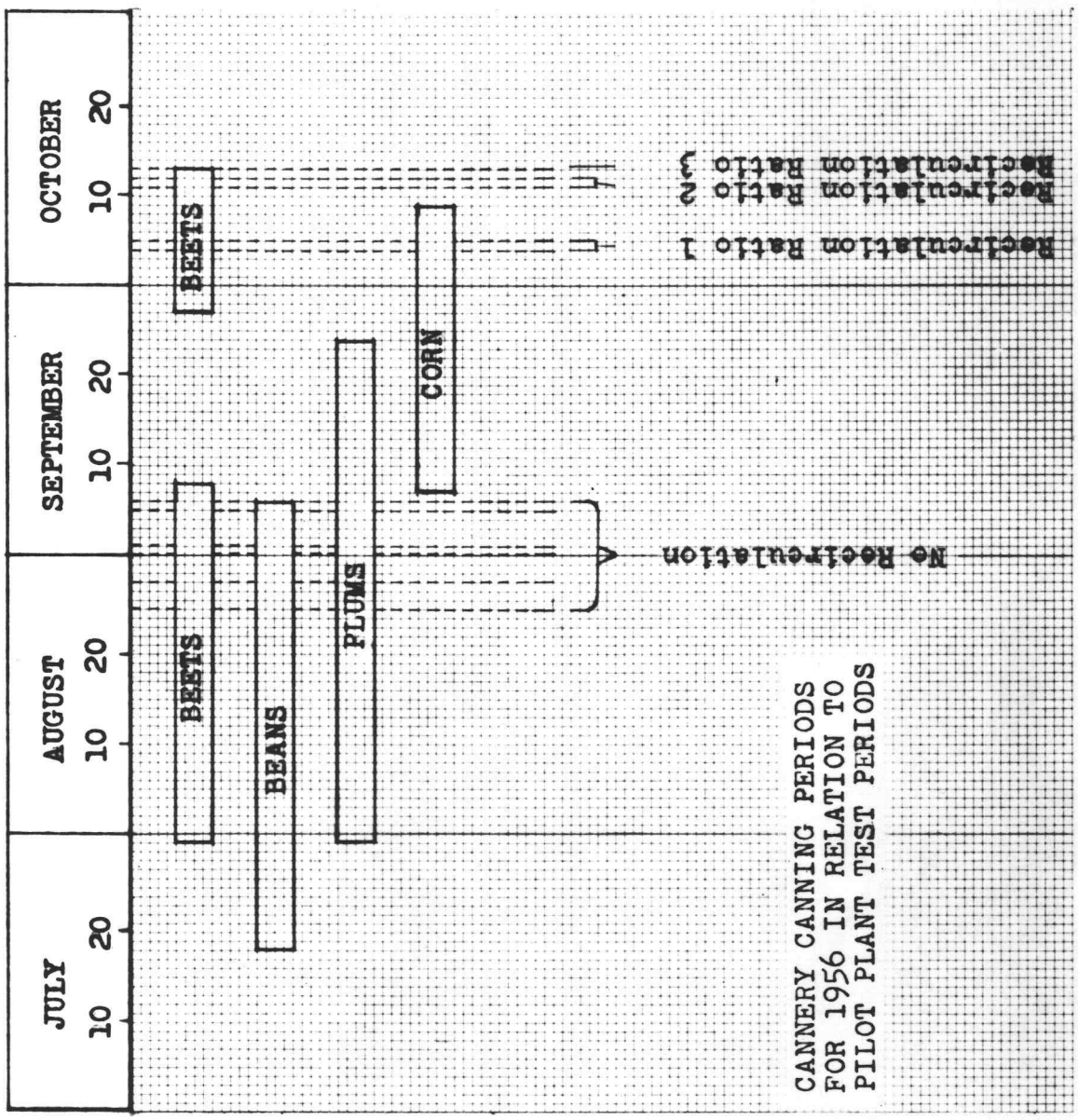

JULY
AUGUST
SEPTEMBER
OCTOBER
10
20
BEETS
BEANS
PLUMS
CORN
BEETS
No Recirculation
Recirculation Ratio 1
Recirculation Ratio 2
CANNERY CANNING PERIODS
FOR 1956 IN RELATION TO
PILOT PLANT TEST PERIODS

Figure 18

During the period from July 31, 1956 to August 13, 1956, in which the growth was being established in the filter, preliminary data were being taken to determine the strength of the waste and the condition of the filter. The following data were taken:

TABLE 3

Date	Sample	BOD Inf.	BOD Eff.	O.D. Inf.	O.D. Eff.	Loading $\frac{\text{Lbs. BOD}}{1000 \frac{\text{Cu Ft}}{\text{Day}}}$	pH Inf.
8-21-56	8AM to 5PM Composite Sample	Bad Dilution Water		0.096	0.092	---	6.9
8-21-56	6PM to 11PM Composite Sample	230	240	0.105	0.105	142	7.0
8-22-56	11AM to 8PM Composite Sample	230	210	0.122	0.106	140	6.6
8-23-56	9AM to 7PM Composite Sample	260	280	0.085	0.095	160	6.6
8-24-56	10AM to 8PM Composite Sample	350	350	0.115	0.110	210	6.8

Since the filter loading was twice that which would be used in normal operation and the growth was not yet established there was no BOD or optical density removal.

Test Procedure

The cannery began its operation at 8 A.M. six days a week and the waste reached the sewage plant at about 8:30, but by the time it made its way through the sewage plant clarifier and to the influent of the pilot plant it was about 10 A.M. At times color arrived at the pilot plant before 10 A.M. because of a late cleanup at the cannery from the previous days operation.

When it was desired, a sample was taken from the filter influent and from the filter effluent. The pH was immediately taken on both samples with a Beckman pH meter. A 300 ml. sample of the influent was immediately iced, and a liter effluent sample was placed in an imhoff cone which in turn was placed in a refrigerator at 4°C to allow sedimentation. After a one hour period, a 300 ml. sample was taken from the imhoff cone and iced. At the end of the day the samples were transported to the laboratory and BOD's set up in three dilutions for each sample. The dilution water was as specified in Standard Methods for the Examination of Water, Sewage, and Industrial Wastes (1, p.262). Dissolved oxygen was determined by the Winkler method using the sodium azide modification as given in Standard Methods for the Examination of Water, Sewage, and Industrial Wastes (1, p.255). BOD's

were incubated in a constant temperature, light tight, 20°C, water bath. A Beckman model B spectrophotometer (see Figure 19) was used to determine the optical density of a portion of the sample which had been filtered through a burnt asbestos mat to remove turbidity. Optical density was measured at a wave length of 530 millimicrons (mμ), sensitivity three, and a slit width of 0.1 mm or less.

Several times during each test period a time-weight determination was made to determine the quantity of flow being applied to the pilot plant filter. This flow data and the BOD data were then used to calculate the pounds of five day BOD being applied to the filter.

Figure 19: Beckman Model B Spectrophotometer

Filter Mats

To determine the optical density of a sample it is necessary to remove all turbidity. Standard Methods (1, p.289) states that samples for color examination should be cleared by using a filter aid. It was found that samples which were passed through filter aid, as prescribed, still retained turbidity from sewage and did not give reproducible results. Asbestos fiber mats which were burnt were found to remove enough turbidity from sewage to give a transmission of ninety-ninety per cent at a wave length of 530 mμ at sensitivity three on the spectrophotometer. These were the same conditions which were used to analysis the samples from the pilot plant. The filtrate appeared clear and the results were reproducible. Asbestos mat is inert and would absorb little or no color. When samples were ran, a portion of the sample was filtered to allow the mat to absorb what color it would and then the sample for color analysis was collected. Examination of the used mats revealed that they were not discolored by the waste; therefore little or no color was absorbed by the asbestos fiber, but they were very effective in removing turbidity.

Pilot Plant Results

After precautions were taken to prevent a chlorine residual from being applied to the filter from the sewage plant, the filter growth became well established; however, because of the washing action of the spreader the usual algae growth did not form to the usual extent on the top layer of the filter media.

During the first two days of pilot plant testing, August 25, 1956 and August 28, 1956, the filter was being loaded at a rate of about 170 pounds BOD per thousand cubic feet per day, about twice too much. This occurred because of underestimating the BOD of the waste. The data for these two days were not used because the efficiency of removal was low, and the operation was not comparable to that of a full scale plant, which would be loaded at about seventy-five pounds BOD per thousand cubic feet per day or less.

Reducing the BOD load applied to the filter increased the removal of BOD and optical density. On August 31, 1956 and September 1, 1956 the filter was loaded at an average rate of sixty-one pounds of BOD per thousand cubic feet per day and a BOD and optical density reduction of 23.8 per cent and 11.0 per cent respectively

were obtained. On September 5, 1956 and September 6, 1956 when the average rate of loading was decreased to forty-one pounds BOD per thousand cubic feet per day the BOD and optical density removals were increased to 33.7 per cent and 21.7 per cent respectively. During these four days, August 31, September 3, 5, and 6, 1956, the filter was operated without recirculation.

The BOD and optical density removal can be increased by recirculation as shown in Figures 20 and 21. The average rate of loading when a recirculation ratio of one was employed was 71.4 pounds BOD per thousand cubic feet per day, and the average rate of loading was 61.5 pounds of BOD per thousand cubic feet per day when a recirculation ratio of two was used. The points plotted in Figures 20 and 21 at no recirculation are average values from August 31, 1956 and September 1, 1956. As stated before, the average loading on these two days was sixty-one pounds BOD per thousand cubic feet per day.

During the testing difficulty was experienced with the standard BOD dilution water (1, p.367) and several blocks of BOD data were consequently lost. This difficulty was the cause of not having BOD data for the recirculation ratio of three, and since that test day was the last one on which the cannery canned beets, it was

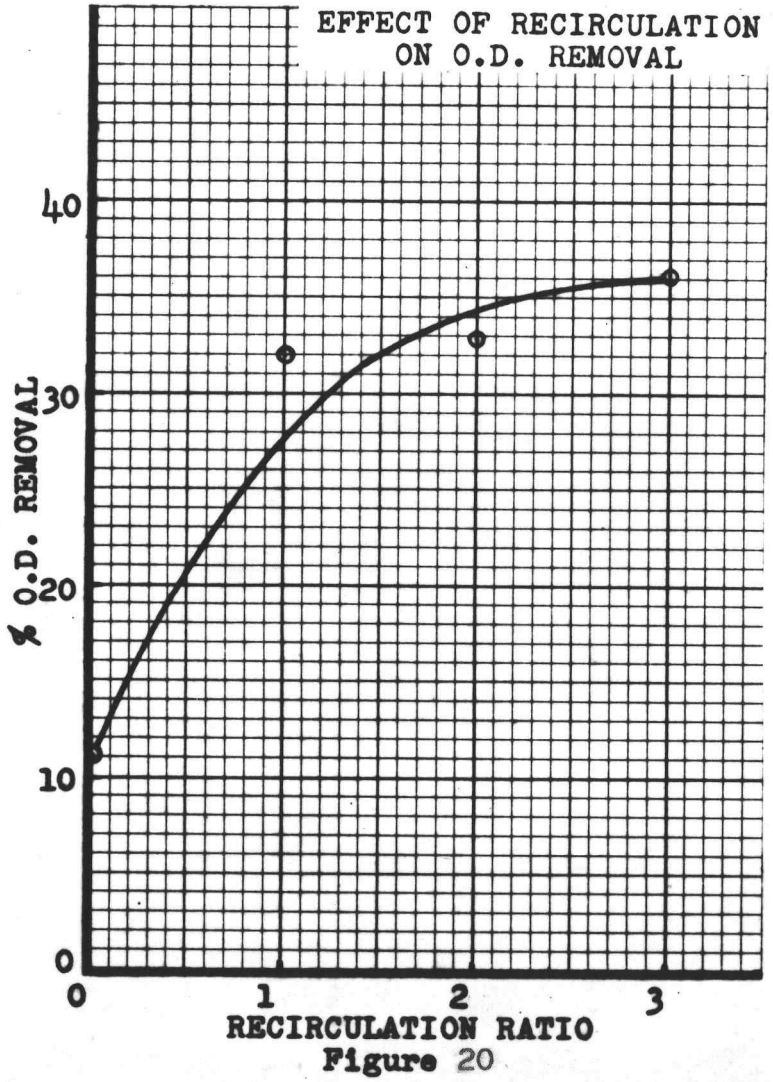


Figure 20

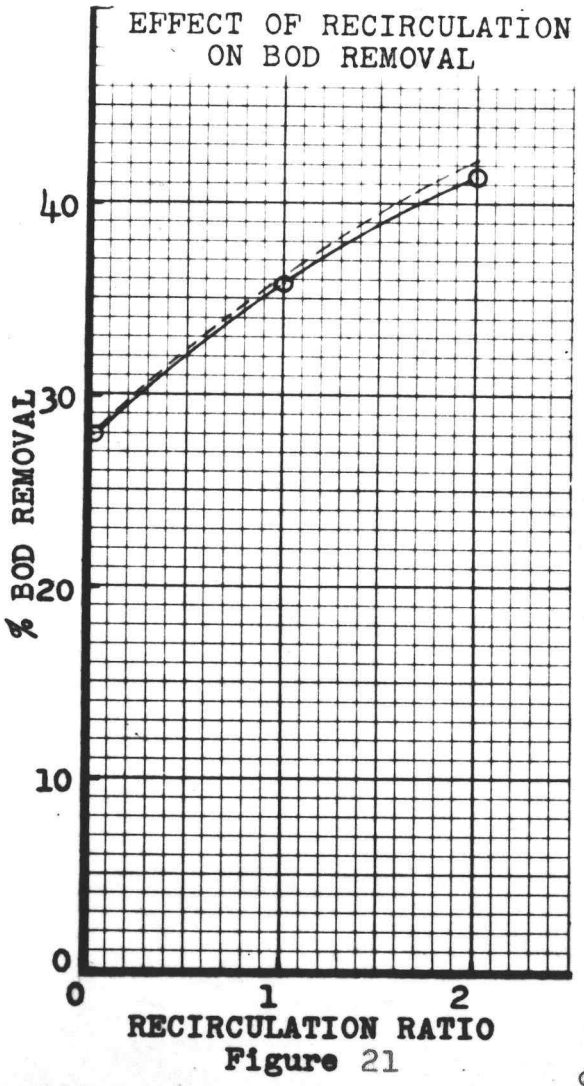


Figure 21

impossible to duplicate the test. The hydraulic loading rate, however, was maintained equal to that for the tests on recirculation ratios of one and two, and since the BOD values are comparable from day to day, it can be assumed that the BOD loading was comparable. The points on the graphs of Figure 20 and 21 are average values for BOD and optical density removal at recirculation ratios of zero, one, two, and three, while the filter was being operated in an interval of loading from 61 to 71.4 pounds of BOD per thousand cubic feet per day. This loading rate is comparable to that commonly used for the design of high-rate trickling filters for treating municipal sewage.

Since the color of beet waste constitutes a portion of the BOD of the waste, it was anticipated that for BOD removed from the settled waste there would be a proportional amount of optical density removed. Figure 22 shows that there is a general trend toward an increase in optical density removal with BOD removal, but the wide scattering of points makes it impossible to draw a conclusion statistically.

Figure 23 shows that an increase in the BOD of the settled waste corresponds to an increase in the optical density. Since the BOD of the cannery waste is high as

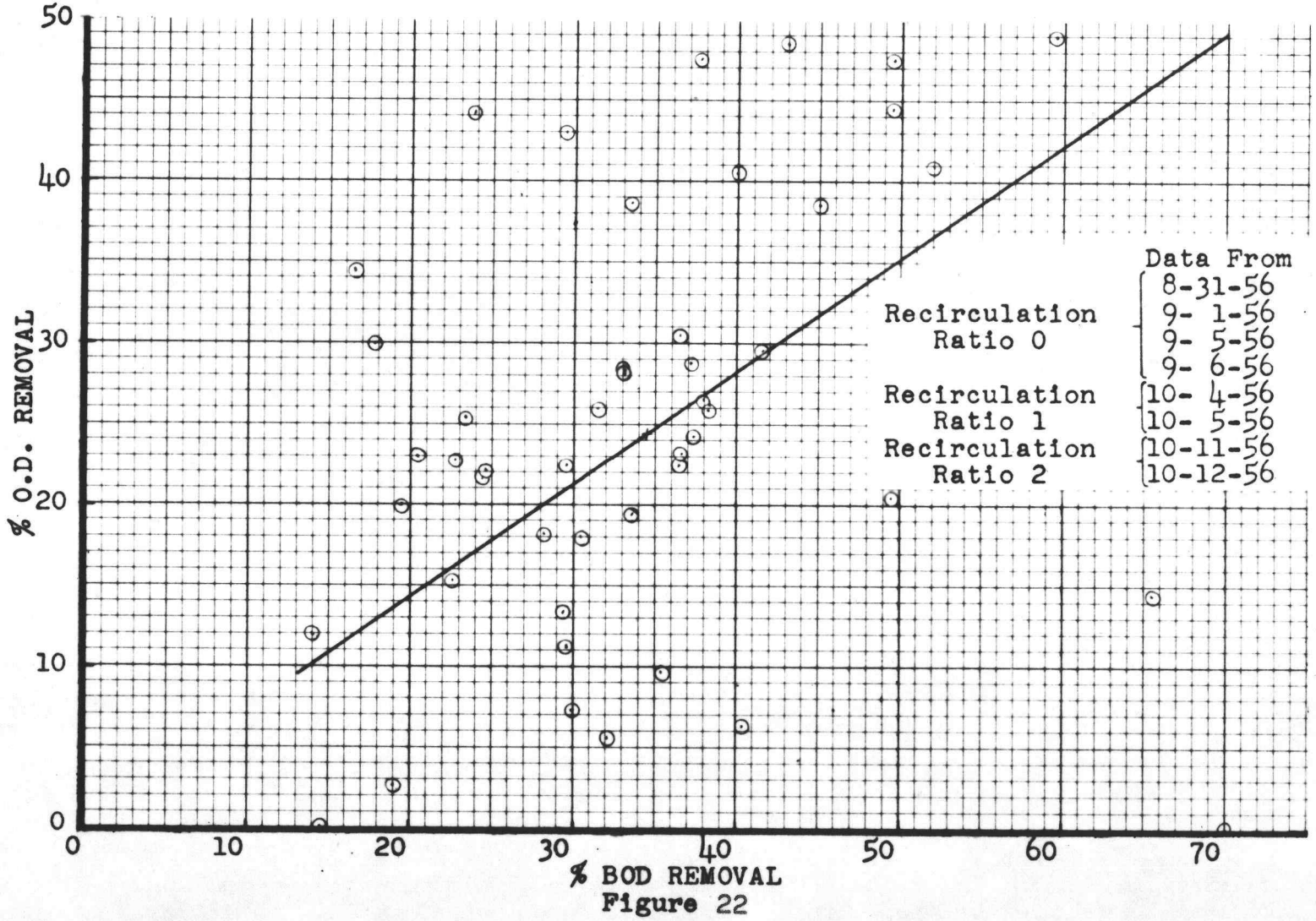

50
40
30
20
10
0
% O.D. REMOVAL
0
10
20
30
40
50
60
70
% BOD REMOVAL
Data From
Recirculation Ratio 0
8-31-56
9- 1-56
9- 5-56
9- 6-56
Recirculation Ratio 1
10- 4-56
10- 5-56
Recirculation Ratio 2
10-11-56
10-12-56

Figure 22

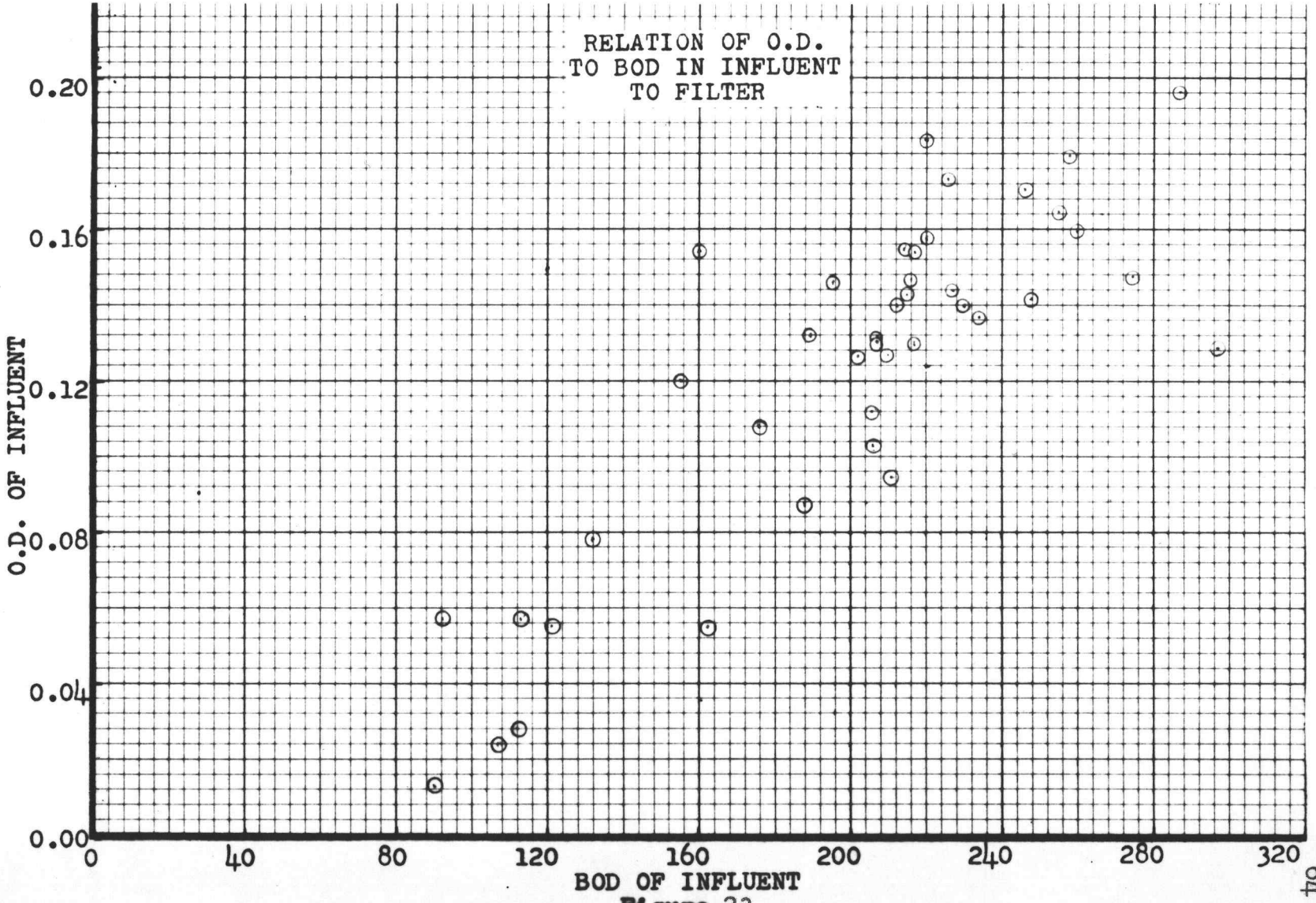

RELATION OF O.D.
TO BOD IN INFLUENT
TO FILTER
0.20
0.16
0.12
0.08
0.04
0.00
O.D. OF INFLUENT
0
40
80
120
160
200
240
280
320
BOD OF INFLUENT

Figure 23

well as the color and the waste was diluted with domestic sewage, it would be expected that such a trend would exist.

The broken line in Figure 21 was arrived at by the use of the equation:

$$F = \frac{1 + \frac{R}{I}}{\left[1 + (1-f)\frac{R}{I}\right]^2}$$

F = recirculation factor

I = rate of incoming sewage

R = rate of recirculation

$\frac{R}{I}$ = recirculation ratio

f = a factor which considers the effect of removing putrescible matter with each pass through the filter

Fair and Geyer give the value of f as about 0.9 (14, p.719). The f value used for the dashed line in Figure 21 was 0.85. It can be seen that the filter's response to recirculation was good in comparison to past filter experience, since the equation previously given is an empirical one which expresses the effect on BOD removal to be expected from recirculation.

To determine if the red color would return to biologically treated waste, portions of the treated waste were acidified and made basic. No color change was observed in either case; therefore if a clear effluent could be produced by treatment with a trickling filter there would be no return of color in the dilution stream.

Figure 24 shows the optical density of each effluent in comparison with the average optical density of the influent to the pilot plant filter, also the optical density of the beet color which the four observers identified in the river is shown. The observers were at a distance from the sample tube which would simulate an observer in a boat on the river. From greater distances the color would not be noticed until it became more intense, but from Figure 24 it can be seen that the filter fell far short of producing a desirable effluent. The BOD removal of the filter was low in comparison to filters treating only domestic sewage. Filters treating only domestic sewage have efficiencies of between seventy and eighty per cent, while the best average efficiency of the pilot plant, while treating combined domestic and beet waste, was 41.5 per cent. This low efficiency could have been caused by either the character of the waste or the condition of the filter.

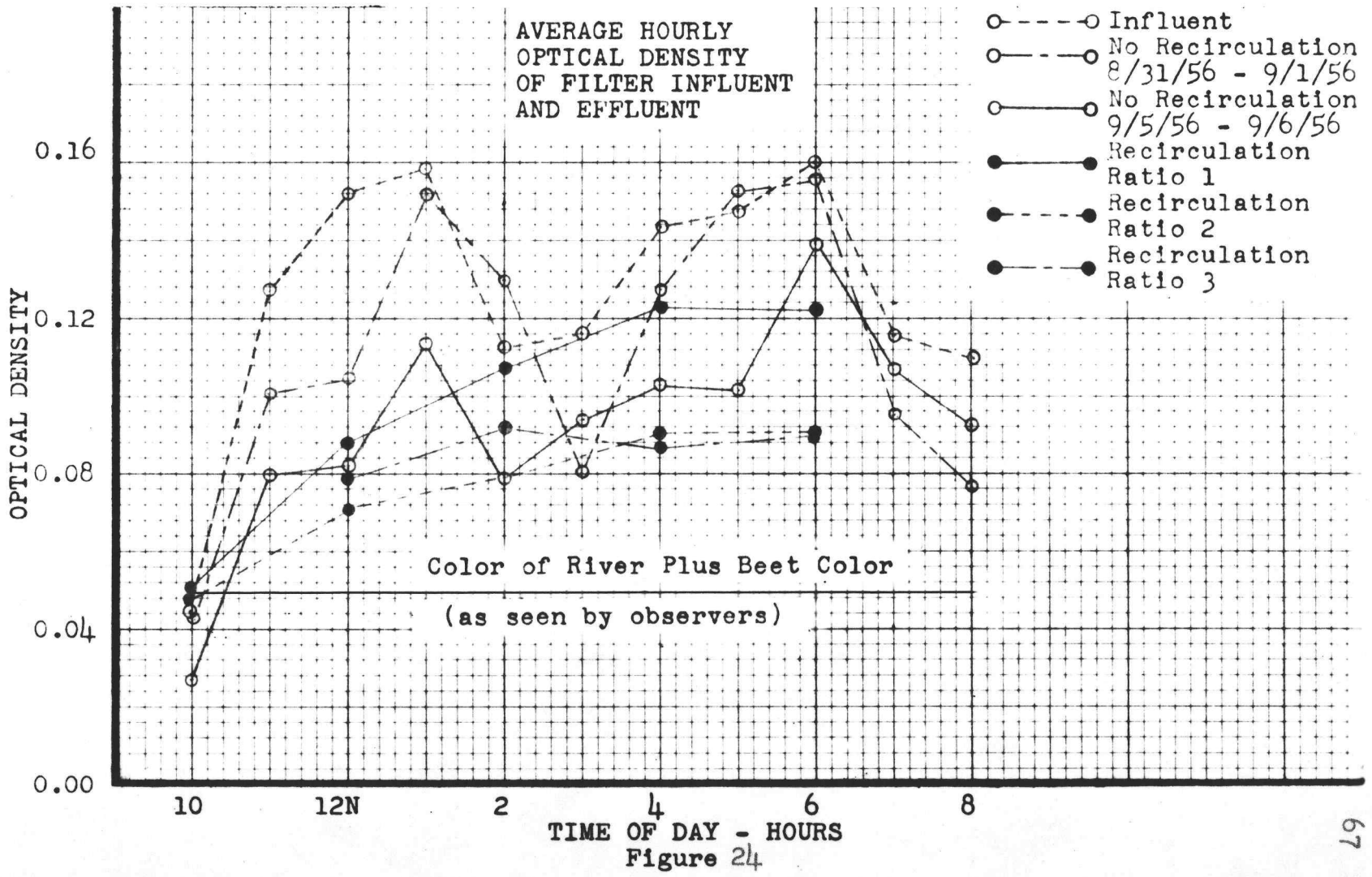

AVERAGE HOURLY
OPTICAL DENSITY
OF FILTER INFLUENT
AND EFFLUENT
Influent
No Recirculation
8/31/56 - 9/1/56
No Recirculation
9/5/56 - 9/6/56
Recirculation
Ratio 1
Recirculation
Ratio 2
Recirculation
Ratio 3
OPTICAL DENSITY
0.16
0.12
0.08
0.04
0.00
Color of River Plus Beet Color
(as seen by observers)
10
12N
2
4
6
8
TIME OF DAY - HOURS

Figure 24

Statistics

Statistics is a tool to predict something about an entire population (crops, people, rainfall, or in this study trickling filters) from a sample of that population.

In this study, however, the sample consisted of only one filter, this filter being only a model of the filters used in practice. It is evident that it must be assumed that by careful construction and operation comparable results would be obtained in a full scale plant. The use of only one filter to predict something about future filters is like taking one person and predicting something about all people. It could be said that all people have two arms, two legs, two eyes, a nose, etc., but it could not be said that all people have brown hair, wore glasses, and were seventy-two inches tall. The data presented from one filter then is only partly quantitative and is subject to its own characteristics.

The use of statistics is not necessary to see that trickling filters remove color, since from examination of the data in Appendix II this is evident, because the majority of the percentage removals are positive.

By the use of analysis of variance (21, p.47) it was determined that recirculation increased the removal of BOD. The data were tested to see if the means of BOD

removal were the same regardless of the recirculation ratio. It was found that at a ninety-five per cent significance level the means were not equal; therefore the recirculation increased the BOD removal (see Appendix IV).

The data were tested to see if the optical density removal was increased with recirculation. Again, as with the BOD removal, the means of the data for each recirculation ratio were tested to see if they were equal, and they were found to be unequal at the ninety-five per cent significance level. The conclusion was, then, that recirculation increased the removal of optical density or color (see Appendix V).

The line of regression obtained for the data of Figure 22 was arrived at by the method of least squares (20, p.108) (see Appendix VI).

FURTHER EXPLORATORY STUDIES

Chemical Treatment

While considering color removal from beet waste many types of chemical treatment were brought to mind which might remove the color. In an effort to observe the effects of several chemicals on beet color and to add to the information found in the literature, the following chemicals were used: chlorine, lime, ferric chloride, sodium chloride, activated carbon, carbon dioxide, ammonium hydroxide, and sodium hydroxide.

For a test with chlorine a solution of Zonite was used, which is a 10,000 ppm solution of sodium hyperchlorite. Beet waste for all tests was prepared by slicing whole beets and extracting the color with hot water. No attempt was made to standardize the waste, since while the color could be made equal in each case the other soluble components of the waste could not be.

To determine the contact time as well as the amount of chlorine required for treatment a dosage of chlorine solution was added to a liter of waste and mixed continuously. At the end of a desired period a few crystals of sodium thiosulfate were added to stop the chlorine action, a sample filtered, and the per cent transmission

read on a Bausch and Lomb Monochromatic Colorimeter at a wave length of 550 mμ. The following data were obtained:

TABLE 4

Dosage: 100 ppm available chlorine

Time - Minutes	% Transmission
0	13
15	22
40	22

Dosage: 500 ppm available chlorine

Time - Minutes	% Transmission
0	13
5	68
15	73
30	74

Dosage	% Transmission at Beginning	% Transmission After 15 Minutes
100 ppm	17	15
250 ppm	17	22
500 ppm	17	42
1000 ppm	17	88

It was evident that complete reaction occurred within fifteen minutes, however, in practice this time would vary with the degree of mixing obtained. At 1000 ppm dosage the reaction appeared to be instantaneous upon contact. This waste did not contain as much color as full strength cannery waste. It would require over

500 ppm available chlorine to remove color from this waste. The necessary dosage would be in excess of 500 pounds of chlorine to treat 120,000 gallons of waste. At this dosage the cost of chlorine for treatment would be about fifty cents per thousand gallons of waste.

The treatment of beet waste with lime produces a floc, an increase in pH, and a change of color from red to a straw. Enough lime must be added to the waste to increase the pH to approximately eleven. At this pH the floc forms and the color change takes place. A rapid mix and then a slow mix is required to build a good floc. The floc settles fast but is voluminous. The sludge would constitute ten per cent by volume of the waste treated and would be a problem to dispose of in a full scale plant. When the straw colored supernatant is acidified it returns to a red color but is less intensely colored than originally.

To determine the amount of color which could be removed by lime treatment the following data were obtained. (Transmission measurements were made as with the chlorinated waste.)

TABLE 5

% Full Strength Waste	Initial % Trans.	ml. Lime Solution Added	Final pH	Final % Trans.	ml. Sludge
100	18	24.5	11.3	70	70
50	28	13.5	11.6	85	30
25	41	7.5	11.6	90	15

The supernatant was straw colored, but when it was acidified with sulfuric acid the red color returned and the per cent transmissions were as follows:

TABLE 6

% Full Strength Waste	% Transmission Treated Waste	% Transmission Treated Waste Acidified
100	70	41
50	85	73
25	90	86

The lime solution used contained forty grams of calcium hydroxide per liter. Treatment of the waste, then, would require 8.5 pounds of lime per thousand gallons of waste. At this dosage the cost of lime for treatment would be fifteen cents per thousand gallons of waste.

Since the optical density of the initial waste was 0.745 and that of the lime treated waste was 0.155, it would seem that seventy-nine per cent of the color was removed. Also, the color was not straw and appeared

very satisfactory. When acidified, however, the red color returned and the optical density became 0.39; therefore only forty-eight per cent of the color had been removed. It became apparent that it would be necessary to know at what pH the red color returned; therefore the following data were taken to determine at what pH the red color returned to the lime treated waste.

TABLE 7

Instrument: B & L Monochromatic Colorimeter
Wavelength: 550 mμ

	ml. of 1.8 M H_2SO_4 Added	pH	% Trans.	Remarks
Fresh Waste		6.9	22	Red
Lime Treated		12.0	88	Yellow
	1.2	11.0	84	Yellow
	0.1	9.2	79	Yellow
	0.1	7.4	79	Light Red
	0.1	4.7	70	Light Red
	0.3	3.0	70	Light Red
	15.0	1.0	77	Light Red

It was apparent that the red color returned at a pH of 7.4. Since the Willamette River has a pH of 7 or less, some of the treated waste was added to a sample of river water, and it was found that the red color did not return. From the standpoint of color the lime treatment would produce a good effluent.

While treating with lime, it became apparent that a better effluent could be obtained with less sludge produced if the liquid was separated from the beet shreds as soon as possible. The lime probably precipitates the pectins, and the calcium pectinates formed produce the large volume of sludge. Some of the color is trapped in the precipitate or held chemically in the precipitate to be removed with it. The color molecule also undergoes a structural change in the presents of lime at a pH of eleven to become straw colored. The lime does not act selectively on the color but instead it acts primarily to remove a large portion of the soluble waste, and secondarily it removes some of the color and alters that remaining in solution. No color removal is obtained unless the precipitate forms, and an adequate precipitate does not form until a pH of about eleven is obtained.

When ferric chloride is added to beet waste it becomes brown but no precipitate is formed. The solution returns to its original color when it is acidified. If the beet waste is first acidified, the addition of ferric chloride will cause no change in color.

If lyophobic colloids were present and an excess of an electrolyte were added a precipitate would be expected; however, the addition of sodium chloride caused no change in the waste.

Activated carbon has long been used as a means of color removal. Although it was realized that the high turbidity would probably make the activated carbon impractical; it was used to see if the beet color could be absorbed. It was found that large amounts of carbon would be required to remove insignificant amounts of color.

Dry ice was used as a source of carbon dioxide to observe its effect on beet color. No color change was brought about by the carbon dioxide.

Since lime caused a change in color and a precipitate, it was thought that perhaps any other base might do as well if the change was due only to the pH change and not the calcium. The addition of ammonium hydroxide caused the beet waste to take on a deeper red color and produced no floc, while the addition of sodium hydroxide produced a straw to amber color but produced no floc. It was evident that the pH change alone was not enough to cause a precipitate or a color change.

Sodium hydroxide was added to the beet waste until the maximum amber color was obtained, no precipitate was formed, calcium chloride was then added and a precipitate immediately formed. It was apparent that while calcium is not necessary to produce the color change, it is necessary to form the floc.

On the several occasions when the waste was heated to determine total solids it was noted that its color became brown. The residue left after evaporation had the appearance and odor of burnt sugar and was sticky in consistency.

By drying shredded beets at 105°C, it was found that their moisture content was eighty-five per cent. Storage of beets will cause this figure to vary some if the room is not humidified.

Any chemical treatment should be preceded by fine screens or sedimentation to remove the large amounts of shredded beet contained in the waste and thereby reduce the amount of chemicals necessary for treatment.

Activated Sludge

A small activated sludge pilot plant was set up in the laboratory and a sludge formed with sewage. Beet waste was added to the activated sludge unit, and a amber effluent was produced. Because of the poor similitude of the unit used and the lack of control of the process no effort was made to do a quantitative study.

Land Disposal

Since the cannery operates during a period of the year when evaporation is high, it is believed that it may be possible to dispose of beet waste by land disposal. It would be necessary to have a large land area available, however, and also a separate industrial sewer to deliver the waste to the site of disposal.

Four undisturbed soil samples four inches in diameter and eighteen inches long were taken from a location near the Willamette River at Corvallis. The soil appeared to be a silty loam. These samples were placed in the laboratory and provided with a bottom drain system, and dosed with beet waste once every five days. The dosages were equal to 0.5, 1.0, 1.5, and 2.0 inches. The two samples being loaded at 1.5 and 2.0 inches became anerobic immediately and would not absorb the waste. The sample being loaded at 1.0 inches became anerobic at the end of two weeks, and the sample being loaded at 0.5 inches became anerobic in three weeks. Failure was caused by a clogging of the upper layers of the soil, anerobic conditions predominating, and the surface vegetation dying. These conditions in the field would cause complete failure of the treatment process.

A sample tube of porous sand was prepared and seeded with sewage and soil organisms. No quantitative data were taken, but the effluent produced after the beet waste slowly passed through the sand filter was very clear and light straw in color. It has long been recognized that sand filters are capable of producing very excellent effluents, but the usual high cost of land areas near existing canneries makes it necessary to transport the waste to areas outside the city where the cost of the necessary land area is not prohibitive. The laboratory testing did not duplicate the evaporation conditions which would exist in the field. In the Willamette Valley the average evaporation from April to October is 29.3 inches. This evaporation would be a determining factor in the success or failure of land disposal.

From the laboratory tests it can be concluded that soil or sand filtration can affect an excellent removal of color from beet waste, but the loading rate would probably be very low if local land areas were used.

Combined Treatments

To this point only singleton treatment processes have been considered or studied. It is possible that by the proper integration of two or more treatment processes color could be removed from beet waste. Several such processes might be trickling filters followed by sand filters, activated sludge, chlorination, lime treatment, or land disposal. These are only a few of the possible combinations of biological and chemical treatment.

Regardless of the form of treatment used the prerequisites to it would be the separation of the cannery waters so that only those waters containing waste were treated, and the removal of solids from the waste waters as soon as possible.

CONCLUSIONS

1. As high-rate trickling filters are now designed for municipal sewage treatment plants, they would not produce adequate treatment to remove enough beet color from combined beet waste and domestic sewage to prevent its detection in a receiving stream.

2. Increasing the recirculation ratio increases the removal of beet color by trickling filters.

3. Increasing the recirculation ratio increases the removal of biochemical oxygen demand by trickling filters.

4. Decreasing the filter loading increases the removal of optical density and BOD.

5. It requires large amounts of chlorine to remove the color from beet waste, but the contact time could be short, and no sludge would be produced.

6. Lime treatment produces a good color reduction, but would require settling basins and disposal of large volumes of sludge.

7. Activated sludge will produce an amber effluent.

8. Land disposal would be very effective as a means of disposal, but large land areas close to the cannery would be necessary.

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APPENDICES

APPENDIX I - TERMS

BOD	- biochemical oxygen demand
O.D.	- optical density
ppm	- parts per million
$\frac{\text{lbs. BOD}}{1000 \frac{\text{cu. ft.}}{\text{day}}}$	- pounds of five day BOD applied in 24 hours for each 1000 cubic feet of filter media
Recirculation Ratio	- $\frac{\text{quantity of effluent recirculated}}{\text{quantity of influent}}$
% Transmission	- amount of light which passes through a sample in comparison to the amount of light which will pass through distilled water
T	- total
N	- number of observations
x, y	- individual observation
$\bar{x}$, $\bar{y}$	- average of observations
GT	- grand total, sum of T's
Σ	- sum of
SS_x	- $\Sigma (x-\bar{x})^2$
SS_y	- $\Sigma (y-\bar{y})^2$
SP	- $\Sigma (x-\bar{x})(y-\bar{y})$
b	- slope of regression line

APPENDIX II - PILOT PLANT DATA SUMMARY

NO RECIRCULATION 8-25-56

Time	Loading lb. BOD / 1000 ft.^{3}	BOD Inf.	BOD Eff.	% BOD REMOVAL	O.D. Inf.	O.D. Eff.	% O.D. REMOVAL
8AM	181	295	260	11.8	0.075	0.058	22.8
9	138	225	240	- 6.7	0.058	0.058	0.0
10	108	175	155	11.4	0.040	0.040	0.0
11	151	245	225	8.2	0.132	0.110	16.7
12N	169	275	265	3.6	0.165	0.165	0.0
1PM	206	335	290	13.4	0.115	0.115	0.0
2	172	280	255	8.9	0.080	0.105	-31.2
3	172	280	255	8.9	0.101	0.092	9.0
4	185	300	265	11.7	0.130	0.140	7.1
5	155	245	280	-14.3	0.145	0.140	3.4
6	178	290	325	-12.1	0.223	0.191	14.3
7	175	285	305	- 7.0	0.154	0.128	16.8
8	157	255	250	2.0	0.130	0.133	- 2.3
9					0.197	0.132	
10					0.145	0.136	

NO RECIRCULATION 8-28-56

8AM	194	315	285	9.5	0.097	0.085	12.4
9	126	205	215	- 4.9	0.065	0.055	15.4
10	111	180	180	0.0	0.040	0.031	22.5
11	151	245	225	8.2	0.120	0.100	16.6
12N	191	310	290	6.5	0.165	0.160	3.1
1	138	225	300	-33.3	0.145	0.145	0.0
2	166	270	235	13.0	0.115	0.110	4.5
3	175	285	320	-12.3	0.140	0.100	28.6
4	175	285			0.105	0.088	16.2
5					0.160	0.131	
6					0.192	0.192	
7					0.150	0.150	
8					0.125	0.100	

NO RECIRCULATION 8-31-56

Time	Loading lb. BOD / 1000 ft.3	BOD Inf.	BOD Eff.	% BOD Removal	O.D. Inf.	O.D. Eff.	% O.D. Removal
8AM					0.075	0.096	
9					0.070	0.075	
10					0.044	0.045	
11					0.128	0.107	
12N					0.126	0.111	
1PM					0.238	0.180	
2					0.085	0.067	
3	59	218	154	29.4	0.142	0.082	43.0
4	72	248	185	25.4	0.138	0.154	-11.6
5	75	259	274	- 5.8	0.200	0.190	5.0
6	60	207	237	-14.5	0.140	0.170	-21.4
7	67	233	199	14.5	0.100	0.100	0.0
8	63	219	165	24.7	0.095	0.074	22.1

NO RECIRCULATION 9-1-56

11AM	51	175	102	41.7	0.135	0.095	29.6
12N	55	191	121	36.7	0.130	0.100	23.1
1PM	67	232	154	33.6	0.155	0.125	19.3
2	59	205	147	38.3	0.167	0.195	-16.8
3	53	182	128	29.7	0.090	0.080	11.1
4	57	196	158	19.3	0.125	0.100	20.0
5	59	203	142	30.0	0.125	0.116	7.2
6	72	248	175	29.4	0.165	0.143	13.3
7					0.082	0.091	
8	50	173	131	24.3	0.102	0.080	21.6

NO RECIRCULATION 9-5-56

Time	Loading lb. BOD / 1000 ft.^{3}	BOD Inf.	BOD Eff.	% BOD Removal	O.D. Inf.	O.D. Eff.	% O.D. Removal
10AM	26	121	93	23.2	0.055	0.041	25.4
11	40	189	119	37.1	0.132	0.094	28.8
12N	44	207	128	38.2	0.131	0.097	25.9
1PM	46	216	152	29.6	0.147	0.114	22.4
2	43	202	145	28.2	0.127	0.104	18.1
3	49	234	181	22.6	0.137	0.116	15.3
4	45	212	142	22.8	0.140	0.108	22.8
5	46	217	140	35.4	0.113	0.102	9.7
6	44	210	151	28.1	0.127	0.136	- 7.1
7	45	215	146	32.1	0.143	0.135	5.7
8	43	206	123	40.3	0.112	0.105	6.2

NO RECIRCULATION 9-6-56

9AM	23	107	73	32.0	0.024	0.037	-54.0
10	19	90	27	70.0	0.013	0.013	0.0
11	33	155	118	23.8	0.120	0.067	44.2
12N	44	207	129	37.7	0.132	0.069	47.7
1PM	55	260	174	33.1	0.160	0.115	28.1
2	40	188	125	33.5	0.088	0.054	38.7
3	45	211	132	37.4	0.095	0.072	24.2
4	49	230	189	17.8	0.140	0.098	30.0
5	52	248	166	33.1	0.142	0.102	28.2
6					0.171	0.142	17.0
7					0.065	0.080	-23.1
8	42	206	104	49.5	0.103	0.082	20.4

RECIRCULATION RATIO 1 10-4-56

Time	Loading lb. BOD / 1000 ft.^{3}	BOD Inf.	BOD Eff.	% BOD Removal	O.D. Inf.	O.D. Eff.	% O.D. Removal
10AM	48	145			0.054	0.038	
12N	71	217	110	49.5	0.154	0.081	47.5
2PM	98	297	189	36.5	0.129	0.100	22.5
4	85	258	155	40.0	0.180	0.107	40.5
6	75	227	155	31.5	0.144	0.107	26.0

RECIRCULATION RATIO 1 10-5-56

10AM	35	112	106	11.5	0.028	0.065	-132.0
12N	69	216	109	49.5	0.173	0.096	44.5
2PM	67	214	133	38.0	0.155	0.114	26.5
4	77	246	171	30.5	0.171	0.140	18.0
6	90	287	182	36.5	0.197	0.137	30.5

RECIRCULATION RATIO 2 10-11-56

10AM	36	113	97	14.0	0.057	0.050	12.0
12N	71	220	96	79.0	0.184	0.063	66.0
2PM	54	166	132	20.5	0.108	0.083	23.0
4	82	255	145	43.0	0.165	0.085	48.5
6	89	275	132	52.0	0.148	0.087	41.0

RECIRCULATION RATIO 2 10-12-56

10AM	55	173	60	65.5	0.055	0.047	14.5
12N	53	161	65	59.5	0.155	0.079	49.0
2PM	43	132	107	19.0	0.078	0.076	2.5
4	73	221	121	45.0	0.158	0.097	38.5
6	61	186	155	16.5	0.146	0.096	34.5

RECIRCULATION RATIO 3 10-13-56

12N					0.169	0.079	53.3
2PM					0.114	0.092	19.4
4					0.142	0.087	38.8
6					0.135	0.090	33.3

APPENDIX III - AVERAGE O.D. OF INFLUENT AND EFFLUENT

EFFLUENT O.D.

TIME OF DAY	10	11	12N	1PM	2	3	4	5	6	7	8
8/31/56	0.045	0.107	0.111	0.180	0.067	0.082	0.154	0.190	0.170	0.100	0.074
9/ 1/56		0.095	0.100	0.125	0.195	0.080	0.100	0.116	0.143	0.091	0.080
AVERAGE	0.045	0.101	0.105	0.152	0.131	0.081	0.127	0.153	0.156	0.095	0.077
9/ 5/56	0.041	0.094	0.097	0.114	0.104	0.116	0.108	0.102	0.136	0.135	0.105
9/ 6/56	0.013	0.067	0.069	0.115	0.054	0.072	0.098	0.102	0.142	0.080	0.082
AVERAGE	0.027	0.080	0.082	0.114	0.079	0.094	0.103	0.102	0.139	0.107	0.093
10/ 4/56	0.038		0.081		0.100		0.107		0.107		
10/ 5/56	0.065		0.096		0.114		0.140		0.137		
AVERAGE	0.051		0.088		0.107		0.123		0.122		
10/11/56	0.050		0.063		0.083		0.085		0.087		
10/12/56	0.047		0.079		0.076		0.097		0.096		
AVERAGE	0.048		0.071		0.079		0.091		0.091		
10/13/56			0.079		0.092		0.087		0.090		

INFLUENT O.D.

TIME OF DAY	8AM	9	10	11	12N	1PM	2	3	4	5	6	7	8
8/25/56	0.075	0.058	0.040	0.132	0.165	0.115	0.080	0.101	0.130	0.145	0.223	0.154	0.130
8/28/56	0.097	0.065	0.040	0.120	0.165	0.145	0.115	0.140	0.105	0.160	0.192	0.150	0.125
8/31/56	0.075	0.070	0.044	0.128	0.126	0.238	0.085	0.142	0.138	0.200	0.140	0.100	0.095
9/ 1/56				0.135	0.130	0.155	0.167	0.090	0.125	0.125	0.165	0.082	0.102
9/ 5/56			0.055	0.132	0.131	0.147	0.127	0.137	0.140	0.113	0.127	0.143	0.112
9/ 6/56		0.024	0.013	0.120	0.132	0.160	0.088	0.095	0.140	0.142	0.171	0.065	0.103
10/ 4/56			0.054		0.154		0.129		0.180		0.144		
10/ 5/56			0.028		0.173		0.155		0.171		0.197		
10/11/56			0.057		0.184		0.108		0.165		0.148		
10/12/56			0.055		0.155		0.078		0.158		0.146		
10/13/56					0.169		0.114		0.142		0.135		
AVERAGE	0.082	0.054	0.043	0.128	0.153	0.160	0.113	0.117	0.145	0.148	0.163	0.116	0.111

APPENDIX IV

STATISTICAL ANALYSIS OF BOD REMOVAL

RECIRCULATION RATIO	0	1	2
	29.4	49.5	14.0
	25.4	36.4	79.0
	- 5.8	40.0	20.5
	- 14.5	31.5	43.0
	14.5	11.5	52.0
	24.7	49.5	65.5
	41.7	38.0	59.5
	36.7	30.5	19.0
	33.6	36.5	45.0
	38.3		16.5
	29.7		
	19.3		
	30.0		
	29.4		
	24.3		
T	356.7	323.4	414.0
N	15	9	10
$\bar{x}$	23.780	35.933	41.400
$\frac{T^2}{N}$	8482.33	11620.84	17139.60

$GT = 1094.1$

$\Sigma N = 34$

$\sum\left(\frac{T^2}{N}\right) = 37242.77$

$\Sigma x^2 = 46420.27$

ANALYSIS OF VARIANCE CALCULATIONS

FOR BOD REMOVAL

Source of Variation	Total of Squares	No. of items Squared	Observations per Squared Item	Total of Squares per Observation
Correction	1197054.81	1	34	35207.49
Recirculation Ratio				37242.77
Individual Observations		34	1	46420.27

ANALYSIS OF VARIANCE

Variation Due to:	Sum of Squares	Degrees of Freedom	Mean Square	F
Column	2035.28	2	1017.64	3.44
Error	9177.40	31	296.045	

F value at 95% significance level for 2 and 31 degrees of freedom is 3.31.

Hypothesis: Population means are equal.

Conclusion: Population means not equal using 95% significance level, or recirculation increases BOD removal.

APPENDIX V

STATISTICAL ANALYSIS

OF OPTICAL DENSITY REMOVAL

RECIRCULATION RATIO	0	1	2	3
	43.0	47.5	12.0	53.3
	- 11.6	22.5	66.0	19.4
	5.0	40.5	23.0	38.8
	- 21.4	26.0	48.5	33.3
	00.0	44.5	41.0	
	22.1	26.5	14.5	
	29.6	18.0	49.0	
	23.1	30.5	2.5	
	19.3		38.5	
	- 16.8		34.5	
	11.1			
	20.0			
	7.2			
	13.3			
	21.6			
T	165.5	256.0	329.5	144.80
N	15	8	10	4
$\bar{x}$	11.03	32.00	32.95	36.20
$\frac{T^2}{N}$	1826.017	8192.000	10857.025	5241.760

$GT = 895.8$

$\Sigma N = 37$

$\Sigma\left(\frac{T^2}{N}\right) = 26116.802$

$\Sigma x^2 = 5831.58$

ANALYSIS OF VARIANCE CALCULATIONS

FOR O.D. REMOVAL

Source of Variation	Total of Squares	No. of items Squared	Observations per Squared Item	Total of Squares per Observation
Correction	801741.00	1	37	21668.68
Recirculation Ratio				26116.80
Individual Observations				35437.26

ANALYSIS OF VARIANCE

Variation Due to:	Sum of Squares	Degrees of Freedom	Mean Square	F
Column	4448.12	3	1482.71	5.25
Error	9320.46	33	282.44	

F value at 95% significance level for 3 and 33 degrees of freedom equal 3.32.

Hypothesis: Population means are equal.

Conclusion: Population means not equal, or recirculation increases O.D. removal.

APPENDIX VI

CALCULATIONS FOR LINE OF REGRESSION IN FIGURE 22

N	=	53				N	=	53
Σx	=	1756.2				Σy	=	1185.7
$(\Sigma x)^2$	=	3084238.44				$(\Sigma y)^2$	=	1405884.49
$\frac{(\Sigma x)^2}{N}$	=	58193.18	$\frac{(\Sigma x)(\Sigma y)}{N}$	=	39289.18	$\frac{(\Sigma y)^2}{N}$	=	26526.12
Σx^2	=	71435.52	Σxy	=	48555.64	Σy^2	=	42763.09
SS_x	=	13242.34	SP	=	9266.46	SS_y	=	16236.97

$$b = \frac{SP}{SS_x} = \frac{9266.46}{13242.34} = 0.699$$