THE UNIVERSITY OF MANITOBA

PHYSICOCHEMICAL TREATMENT OF SIMULATED

LYE-PEEL POTATO WASTEWATER

by

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ABSTRACT

Physicochemical treatment of lye-peel potato waste-water using a solution containing $FeCl_3/AlCl_3$ as coagulants was shown to be possible. COD reductions of about 91% were achieved at 10° C as compared to 88% at 50° C.

The effect of dose of coagulant used was highly significant. The best results were achieved at the highest dose rate. The stirring speed was found to be significant at the 5% level but insignificant at the 1% level. Higher COD reductions were achieved at higher stirring speeds.

The iron content of the purified water was well within the permissible limits, for the food canning industry (0.4 mg/l). The clarity was as good as that of distilled water. Fixed residue of the purified water increased as a result of the coagulation process. Volatile residue decreased from 5.2 g/l to 0.67 g/l.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The rapid growth of the Food Processing Industry has raised a serious problem of handling large volumes of wastewater that is rich in pollutants and may also be highly alkaline or acidic. The treatment method should be selected so that these wastewaters can be either reused or returned to receiving waters in acceptable condition. Other factors of importance in the selection of treatment methods include type of waste, space availability, land cost, equipment costs, efficiency, ease of operation and flexibility.

The potato is a major vegetable crop in many countries including Canada, and a major part of this crop is used by the potato processing industry. The plants using wet chemical peeling systems produce large volumes of wastewater which is highly alkaline. The peeling operation contributes 70-80 percent of the total biological oxygen demand from the entire processing plant. Water requirements are from 150 to 400 gpm. for a 40,000 lbs/h line.

The conventional methods of treatment of potato processing wastewaters are modifications of the methods used for the treatment of municipal sewage. Primary treatment, consisting of screening, sedimentation, sludge dewatering and sludge disposal, is carried out for the separation of

1

sedimentable matter. The soluble and colloidal matter is removed in the secondary treatment by the growth of micro-organisms, natural or added, which convert the complex organic compounds into simpler compounds such as CO_2 and H_2O.

Wastewaters from food processing plants are often more difficult to treat than raw sewage. They are normally of higher biochemical oxygen demand (B.O.D.) and the organic constituents differ widely from plant to plant. Wastes from fruit and vegetable processing plants tend to have a high carbohydrate and low protein content, while wastes from meat packing plants tend to have a high protein and fat content but a low content of carbohydrates.

The conventional methods are, in general, slow, require large land areas and the effectiveness is greatly affected by temperature. The quality of effluent from such plants was, in the past, adequate to meet most discharge regulations and standards. Recent more stringent pollution control regulations and more effective enforcement has focussed attention on advanced methods such as physico-chemical processes.

At this stage, overall cost comparisons cannot be made with previous process systems as a whole, until the detailed technical and cost data become available.

It may be justified to use relatively expensive processes if cheaper means are not effective to meet water quality standards.

ABBREVIATIONS

AWWA	American Water Works Association
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
CNC	Concentration
CONC	Concentrated
DOS	Dose
DF	Degrees of freedom
gal	Gallons
gpm	Gallons per minute
emf	Electro Motive Force
h	Hour
MS	Mean squares
mV	Millivolt
MSP	Mixing speed
Mins	Minutes
OD	Optical density
psi	Pounds per square inch
rpm	Revolutions per minute
SS	Sum of squares
SCD	Streaming current detector
MSP	Mixing speed
TMP	Temperature
ZP	Zeta potential

DEFINITIONS OF TERMS

BOD - The biochemical oxygen demand is the amount of dissolved oxygen, in milligrams per litre (mg/l), required during stabilization of decomposable organic matter by aerobic biochemical action.

COD - The chemical oxygen demand is the index of the amount of oxygen consumed by the sample from a chemical oxidant such as potassium dichromate.

Settleable Matter - May be defined as the matter that would settle down if the sample is allowed to stand, under standard conditions.

Tip Speed - is defined as the linear speed of the tip of the impeller.

Total Fixed Residue - May be defined as the residue remaining after combustion of the total residue, under standard conditions.

Total Residue - May be defined as the residue remaining after evaporation of water from a sample.

Total volatile Residue - is the difference between total residue and total fixed residue.

Note:-The detailed conditions to determine the above factors have been included in Materials and Methods section.

REVIEW OF LITERATURE

The Extent and Nature of the Problem

The potato processing industry is relatively young,
but its recent growth has been phenomenal. During the period
1946-1956 its growth in the United States was 700% (31). It
was reported by Hatfield (28) that in Canada the quantity of
potatoes reaching processing plants increased from 272
million lbs to 497 million lbs during the period 1960-1964.
An average sized processing plant (about 750 tons/day)
producing french-fries or dehydrated potatoes, creates a
waste load equivalent to a city of over 200,000 population
(31).

Extensive laboratory tests conducted on waste
streams by Grames and Kueneman (31) from several different
potato processing plants showed that there was considerable
variation in the nature of these wastewaters. A typical
analysis of the effluent streams as reported by Kueneman
(28) is presented in Table 1. The type and the volume of
the wastewater produced would depend on the finished products
that the plant produced, the peeling method used (steam or
caustic) and the in-plant operational practices. Atkins
and Sproul (2) reported BOD of 2700 to 3900 for the combined
waste of a potato starch factory. The BOD of the protein
water was quoted as 4500 to 8900 mg/l. The BOD of protein

5

TABLE 1

TYPICAL ANALYSIS AND QUANTITIES OF FLOW IN THE
VARIOUS PLANT WASTE STREAMS

	Wash water	Peel waste	Trim table waste	Blanch waste	Combined plant waste
pH	7.0	Lye Peeler 12.0-13.0 Steam 6.0-6.5	6.2	5.1	Lye Peeler 11.0-12.0 Steam 6.0-6.5
Settleable solids ml/litre	2.0-5.5	200-400	0.6	2-3	30-50
Total solids mg/litre	700	10,000-15,000	600	1,600	4,000
Chemical oxygen demand mg/litre	100-250	10,000-12,000	150-200	600-700	2,000-2,500
Population equiv. (Person/ton of raw potatoes)					300-400
Gallons flow per ton of potatoes	1,250-1,500	1,200-1,300	500-600	700-800	3,650-4,200

Note:-The tests conducted by Cansfield (16) at a potato processing plant in Manitoba showed that none of the samples collected from various effluent streams had pH lower than 7.0 and a COD lower than 1000 mg/l.

water was reported by Olson et al (28) to be 13,000 to 18,000 mg/l. The figures quoted by Olson et al (28) seem to be more realistic.

Regrettably, these potent wastewaters may sometimes be discharged to natural waters, but where more stringent pollution control measures are applied, physical and/or biological treatment is carried out. The treatment systems available can be divided into two types.

    A.   Conventional physical and biological systems

    B.   Advanced physicochemical systems

A. Physical Treatment

The physical treatment, commonly known as primary treatment, generally consists of screening, sedimentation sludge dewatering and ultimate sludge disposal systems (21). The object of primary treatment is to reduce the load on biological systems (39). The solids recovered are sometimes used as feed. Kueneman (28) using a primary clarifier reported overall removal of about 90% suspended solids and 70% 5 day BOD. Removal of BOD by 60% or less, as reported by Vivian and Dostal (65) and Dickinson (28) would appear to be more realistic.

Biological Systems.

The biological methods, commonly known as secondary treatment, are based upon the degradation of organic matter by microorganisms. Two basic phenomena occur:

1. Oxygen is consumed by organisms for energy and new cell mass is synthesized.

2. The organisms also undergo progressive auto-oxidation of their cellular mass.

It was reported by Mackinney (23) that these two processes are interrelated and cannot be considered as separate distinct functions.

The options for biological treatment of potato processing wastes include, activated sludge processes, trickling filter processes, aerated lagoons, spraying over-land, oxidation ditches and anaerobic processes.

Dlouhy and Dahlstrom (21) described the activated sludge process as the treatment of primary effluent in aerated basins or tanks. The aerated waste goes to a secondary clarifier where the settleable solids are recirculated back to the aeration chamber to maintain a high bacterial count. Klein (39) has discussed the factors affecting the efficiency of the process. Many variations of this process are in use. Figure 1, after Pailthorp and Filbert (28), shows some of the common variations. Using these methods COD reductions of 90-95% have been reported (21).

The biological filter is a packed bed of medium covered with slime growth. As the wastewater passes through the filter, organic material is degraded by the biological film. The function and design of trickling filters and the role microorganisms play in their efficiency

primary clarifier
  effluent

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                    ┌─────────────────┐
                    │ 1-day anaerobic │──────────┐
                    │      pond       │          │
                    └─────────────────┘          │        ┌──────────────┐
                                                 │   ────→│   aeration   │
                    ┌─────────────────┐          │        └──────────────┘
                    │ 4-day anaerobic │──────┐   │                │
                    │      pond       │      │   │                ▼
                    └─────────────────┘      │   │        ┌──────────────┐
                                             │   │   ────→│ clarification│
                    ┌─────────────────┐      │   │        └──────────────┘
                    │ 8-day anaerobic │──┐   │   │                │
                    │      pond       │  │   │   │                ▼
                    └─────────────────┘  │   │   │        ┌──────────────┐
                                         │   │   │        │   aerobic    │
                    ┌─────────────────┐  │   │   │   ────→│  oxidation   │
                    │ filter          │──┼───┼───┼───────→│    ponds     │
                    └─────────────────┘  │   │   │        └──────────────┘
                    ┌─────────────────┐  │   │   │
                    │    complete     │  │   │   │
                    │ mix activated   │──┘   │   │
                    │  sludge unit    │      │   │
                    └─────────────────┘      │   │
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to river   to waste
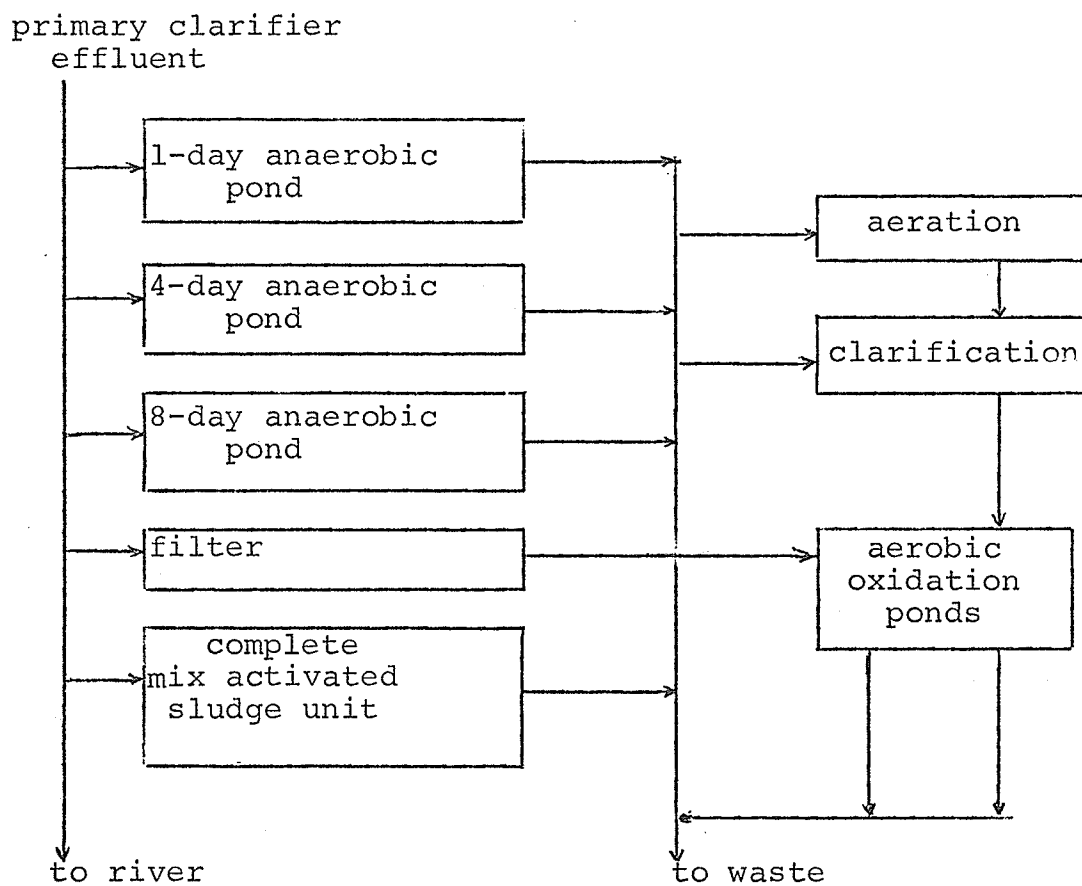
FIGURE 1.   Schematic-Secondary Treatment

was discussed by Bruce (12). Rose and Mercer (28) reported that the high alkali content of some potato wastes can seriously disrupt the treatment process.

Lagooning in oxidation ponds is a common means of eliminating organic matter from wastewater (47). Oxygen is often provided by mechanical aerators. Post-treatment by means of a sedimentation compartment is required to yield a clarified effluent. Fossum and Cooley (28) reported that when potato waste was lagooned along with domestic sewage, potato solids adversely affected the efficiency of the lagoon. Ice and snow coverage during winter months makes lagoons ineffective (47).

Specially designed simple, high efficiency oxidation ditches, invented by Pasveer (28), have been used with success for the treatment of potato wastewaters. By the use of a sufficient amount of oxygen, not only the biochemical oxygen demand is satisfied but also the oxygen demand of the sludge too. Pasveer (28) reported that high COD wastes (25,000 mg/1) had not been tried but with potato wastes of COD of about 2000-4000 mg/1 an effluent of a high standard can be achieved.

Anaerobic processes such as anaerobic lagoons, anaerobic trickling filters and anaerobic contact processes have been studied by Klein (39), Pailthorp and Filbert (28) and Nemerow (47). All must be followed by an aerobic system prior to discharging the wastewaters to receiving waters.

Black (10) reported that the high pH of the lye-peel potato waste does not affect its bio-degradation. But difficulties in treating potato wastes of pH 11.0 to 12.0 and high BOD loading have been reported by Fossum (28).

The disposal of liquid wastes by spray irrigation is the cheapest method where a sufficient area of land that will absorb water, without detrimental environmental effects is available close to the plant (43). The wastewaters are applied as fine sprays to the surface of the soil. Nemerow (47) reported that with good cover crops, wastes to a depth of three to four inches can be applied at the rate of 0.4 to 0.6 inch (1.02 to 1.52 cm) per hour. The organic loading must be carefully controlled to ensure that all the organic matter is decomposed by microorganisms as the water passes through the soil.

The process is generally limited to spring, summer and autumn i.e. when ground is not frozen. Incomplete digestion can cause contamination of aquifers. The high sodium content of lye-peel wastewater can cause puddling and surface run-off by deflocculating and swelling of clay minerals present in the soil.

B. Advanced Systems

The limitations of biological systems have led to the development of more advanced systems for water treatment. Physical and chemical systems such as distillation,

electrodialysis and reverse osmosis were studied by Rickles
(52). The high treatment costs to date have precluded their
common use for the treatment of wastewater. In addition to
these, systems that are physicochemical in nature, particu-
larly chemical coagulation and adsorption, have been
developed and applied to the treatment of domestic wastewater.

Advanced Physicochemical Systems:

Physicochemical systems involve the removal of
oxygen demanding and turbidity-producing colloidal solids
from wastewaters by coagulation using chemicals of various
types (47).

The terms coagulation and flocculation have been
used interchangeably by most research workers. La Mer (40),
however, has made a distinction between the two terms. He
defined coagulation as being a general kinetic process
brought about by the charge neutralization of the colloidal
matter. Flocculation on the other hand, was visualized as
a completely different mechanism whereby colloidal
particles are bound together by a bridging mechanism.
This, however, is oversimplification of complex phenomena.
Ries and Meyers (53) suggested that both charge neutraliza-
tion and bridging may function simultaneously.

One way of considering coagulant purification
agents is to divide them into inorganic and organic
categories (21). Inorganic coagulants including lime (as

calcium hydroxide), calcium chloride, aluminium sulphate, alums, ferric chloride and sulphate, have been mostly used. Organic flocculants can be sub-divided into natural, and polyelectrolytes. Fuoss, as reviewed by Black (3), introduced the term "Polyelectrolytes" to include those synthetic polymers which, by some ion producing mechanism, can become converted to polymers having electrical charges (ionized sites) along the lengths of the molecules. Among natural organic flocculants, starches, glue, and guar gum are sometimes used (21).

Good coagulation of the primary effluent from a raw sewage treatment plant was reported by Weber et al (66) with an iron dose of approximately 250 mg/l as $FeCl_3 \cdot 6H_2O$ and 250 mg/l of potash alum as $Al_2O_3 \cdot 18H_2O$. A lime dose of 300 mg/l was used. BOD removals of about 70% were achieved. Yoshihara et al (67) used a zinc chloride dosage of 1900-2600 ppm as zinc. Johnson et al (36) using ferric chloride and a polyelectrolyte, reported removals of phosphate up to 90%. A dose of 20 mg/l ferric chloride and 0.3 mg/l polyelectrolyte ("Purifloc A-23", Dow Chemical Co.) was used.

Similar results have been reported by others including Black and Hannah (5) and Black and Walters (8). There were no figures available for the chemical treatment of high COD lye-peel wastewaters.

The rate of settling of sludge depends on the size

of the floc particle and the density of the floc (54).

Physicochemically treated wastes are normally held in

settling tanks after treatment. A high rate of settling

would reduce the load on the settling tanks. Culp et al (20)

reported that very small diameter tubes are more effective

than shallow or deep basins.

Sludge Treatment and Disposal

Evenson et al (25) noted that optimum solution of a

total waste treatment problem could not be achieved without

including consideration of sludge disposal.

Sludge digesters are used for microbial breakdown of

sludge before disposal. The conditions of digestion can be

aerobic or anaerobic. The aerobic systems tend to be

simpler to operate as aerobic organisms are not as sensitive

to lower temperature (21). Anaerobic digestion is used

primarily to reduce the volume of sludge so as to present

less of a handling problem in subsequent dewatering steps

(21). The gases evolved from an anerobic digestion consist

primarily of methane, ammonia, carbon dioxide and hydrogen.

Occasionally these are used as a source of thermal energy.

Buswell and Buroff (14) found that polysaccharides such as

starch, decompose to give equal volumes of carbon dioxide

and methane.

British practices in the area of sludge disposal were

reviewed by Swanwick (59). Seventy-one of the 129 cities

placed sludge on land, 5 discharged sludge at sea, and 53

used lagoons. The disposal of liquid digested sludge on

land is commonly practiced in the U. S. A. Research to

determine environmental effects and agricultural benefits

from land application was described by Hinsly and Sosewitz

(35). All crops tested responded favourably to digested

sludge. Echelberger and Tenney (22) favoured vacuum filtra-

tion, followed by incineration for the disposal of sludge

from physicochemical processes because of the difficulties

involved in digesting it.

In certain areas land may not be available for sludge

disposal. Also, land disposal can cause contamination of

aquifers through seepage and the risks of build up of heavy

metals in soils and crops must be taken into account.

Incineration costs can be unjustifiably high especially if

no attempt is made to recover the coagulants.

In most cases, inorganic coagulants can be recovered

by dewatering the sludge and subsequent incineration in a

furnace. This converts the coagulants into the oxides.

Mulbarger et al (45) reported recovery of lime by incinera-

tion to oxides and used it for recarbonation. Karanik and

Nemerow (38) reported that lime recovered from treated

wastewater showed no reduction in phosphate removal

capability and measured on average make up demand of 13

percent. Yoshihara et al (67) reported economical recovery

of zinc chloride by digesting the zinc oxide from

incinerated sludge with hydrochloric acid.

Basic Mechanism of Coagulation

The substances that cause turbidity and organic colour in wastewater, are mostly colloidal (3). It is, therefore, important to understand the nature of forces that surround these particles. Colloids are historically divided into two major classes, namely, lyophobic and lyophilic. When water systems are discussed, the terms hydrophobic and hydrophilic replace the terms lyophobic and lyophilic. In general organic colloids are hydrophilic whereas inorganic colloids are hydrophobic (37). Colloids present in wastewaters include: proteins (under certain pH conditions), pectins, starches, celluloses and polypeptides, and these are all negatively charged (47).

According to Van Olphen (63) and Mysels (46) the origin of these charges may be the result of one, two, or all of the three phenomena.

1. the dissociation of reactive groups on the ends of molecules or at the edges of crystal lattices,

2. isomorphous substitution,

3. the preferential adsorption of ions from the solution phase.

For hydrophilic colloids the primary charge is generally due to the dissociation of polar groups such as $-COOH$ and $-NH_2$. Isomorphous substitution and/or preferential

adsorption of ions from the solution phase are the primary
sources of the charge of hydrophobic colloids such as clays
(63).

Since any overall system must remain electrically
neutral, a primary charge on a colloidal particle results in
the attraction of charge-compensating ions to the particle
surface (37). These ions are distributed as a diffuse ion
cloud, or "double layer". An exact quantitative treatment
of the double layer is a highly complicated problem, and as
yet all of the answers of this problem have not been deter-
mined (64). Several models of the double layer have been
proposed (63). However, the model proposed by Stern (58)
and Gouy (30) displays most of the properties of the double
layer. The Stern model shows the counter ions being composed
of an immobile layer plus a diffuse Gouy-Chapman layer
extending into the bulk of the solution. A rapid drop in
potential occurs between the particle and the stationary
layer, and a much more gradual potential drop occurs between
the stationary layer and a point in the solution at which
electroneutrality exists (3). The overall potential is
called the "chemical or Nernst potential," whereas the
lesser potential between the stationary layer and the solution
is called the "Zeta potential" (ZP). The ZP is the only
potential obtained by electrophoretic measurements (37).

The nature and the distribution of charges on
colloids play an important part in the chemical coagulant

process (3). The two most important causes of instability in colloidal solutions are considered to be Brownian movement and Van der Waal's forces (3). Stability is defined as the ability to resist coagulation into relatively large particles (47). The main stabilizing factor is believed to be the forces of repulsion between the double layer of two surfaces with like charges. The secondary factor is hydration of the colloidal particles (37). There is some disagreement concerning the importance of hydration, and Van Olphen (63) thinks that this factor is only important when considering extremely short range particle interactions, because the absorbed water layer is only a few molecules thick.

On addition of coagulants, the electrophoretic mobility is found to decrease towards zero at optimum coagulating proportions (Bier and Cooper, 26). The application of electrophoretic techniques in the field of water treatment has been pioneered by Black et al (6,8, 9). The neutralization of the repulsive potential (ZP) allows the forces of attraction between particles to bring them together (37). The ensuing buildup in particle size then enables rapid settling in accordance with Stoke's law (54). A colloid may also be precipitated by the addition of a colloid of opposite sign. This is called mutual coagulation (3). Colloids artificially produced by coagulants (usually the hydrous oxides of iron and aluminium) are mainly positively charged (47). In the case of polyelectrolytes a bridging

mechanism has been proposed by Ries and Meyers (53) and Dlouhy et al (21). In practice, more than one mechanism may take place simultaneously.

When a polyelectrolyte is dissolved in an ionizing solvent, the functional groups dissociate, causing the polymer molecule to become charged either positively or negatively (37). Certain polyelectrolytes possess both positively and negatively charged sites. These polymers may form a bridge between two or more particles. The bridging results in larger, more rapidly settling flocs (21).

In the water treatment industry polyelectrolytes have been used largely as coagulant aids. The object was to reduce the coagulant dose required for purification purposes (19). However, they can be used by themselves as flocculants (3). It has been found that the aid being used should, in most instances, be added after and not before the coagulant (3). The molecular weight of the polymer may affect its efficiency. Jones (37) reported that the floc formed by the high molecular weight polymer was more resistant to break-up. However, earlier expectations for the use of polyelectrolytes in wastewater treatments as coagulants, flocculants and aids, have not been realized (18).

Electron Microscope studies were conducted at the Frick Laboratory of Princeton University and have been reviewed by Black (3). With the aid of magnifications

greater than 160,000 diameters, the behaviour of alum as a coagulant were studied. It was reported that the first product of the interaction of aluminium ion with hydroxyl is the formation of small granules of aluminium hydroxide. These granules then aggregate to form flexible chains that grow in length, developing lateral forces. If the forces are strongly developed, the fibres line up, forming a plate-like crystal. It is possible that these flexible chains may behave like polyelectrolyte chains.

The coagulating effect of an electrolyte was determined by the valence of the ion of opposite charge to the sol (37). This generalization is now called the "Schulze-Hardy rule," which states that a bivalent ion is 50-60 times more effective than a monovalent ion, and a trivalent ion is 700-1000 times more effective than a monovalent ion (3).

Extensive work has been carried out on the physico-chemical treatment of sewage, typical references are; (36,50, 51,62,66, and 68) but there are many others. The use of chemical treatment for potato wastes was reported by Dickinson (28).   The effluent from a potato chip plant was flocculated by chemical treatment, passed through a series of vibratory screens, settled, and decanted. This was reported as an eminently practicable process which became economic when the scale of operations was large. A large number of coagulants including alum, calcium, iron and aluminium salts have been tried on simulated lye-peel

wastewater (16). Ferric chloride with aluminum chloride in molar proportions was found to be the best for this waste-water. COD reductions of about 90% were achieved, before carbon treatment.

Determination of Coagulant Dose Level

The settling rate of sludge was used for estimating dose level requirements by Camp et al (15). A series of samples were withdrawn from a depth of 2 1/4 inches above the bottom of six jars at measured time intervals. Iron determinantions were made on these samples. Thus the minimum quantity of coagulant required for fast settling could then be determined.

The Jar Test is frequently employed to determine the amount of coagulant required for good coagulation. The object is to produce the best possible floc which will properly purify the water with the least amount of chemicals.

There was a problem in the Jar Test of obtaining samples from six jars simultaneously. Also the uneven distribution of floc size resulted in inconsistent results in iron determination (17).

Cohen (17) used an improved version of the Jar Test. The apparatus was modified to give six simultaneous samples by using a vacuum manifold, and turbidity rather than residual coagulant ion, was used as a measure of settling rates.

Another factor that has been used to determine the coagulant dose is Zeta potential (24). The dose is determined by the amount of coagulant required to neutralize the potential to near zero. Elmwood et al (24) reported that colour removal with alum coagulant required neutral or slightly positive ZP. The colour removal with ferric coagulant was best with slightly positive ZP. The ZP can be changed by change of pH. However the relationship is not direct. Both must be controlled separately (53).

Bier and Cooper (26) reported that hydrophilic colloids may not coagulate over any and all ranges of zeta potential.

Automatic Control of Coagulant Dosing

There is no system available that would satisfactorly control the coagulant dose in a continuous system. Buswell (13) has reviewed a possible system based on centrifuges and photometers. Two separate streams A and B of wastewater would be provided. Stream A would pass through a photometer, while stream B would pass through a variable speed centrifuge and then through a second photometer. The speed of the centrifuge would be automatically controlled so that the two photometers read the same. This centrifuge would control a secondary centrifuge where a bleed of treated waste would be passed through and turbidity reading taken on the purified section. The secondary centrifuge would monitor the

coagulant dose until the turbidity reached the set point. A schematic diagram has been drawn on the basis of the above explanation and is presented in Figure 2. Further development would be required to make the system practicable.

Metropolitan Syracuse (N.Y.) Treatment Plant used the Streaming Current Detector (SCD) as described by Priesing et al (50). When a liquid is passed through a capillary or porous diaphragm, a potential difference is created and the emf developed is called the streaming potential (37).

The instrument developed for the measurement of streaming current consisted of a plastic block containing a dead-ended bore, silver electrodes and a loosely fitted piston which reciprocated in the bore. This movement of the piston caused a streaming flow of liquid in the annular space between the block and the piston which sheared the ionic double layer. The movement of the diffused double layer created a streaming current which was measured.

A sample of treated wastewater was fed continuously to the SCD. The instrument signal was amplified, converted to direct current and transmitted to a recorder-controller, which controlled the pump feed rate of the flocculant. A schematic diagram of SCD taken from sales publication of Waters Associates (Massachusetts, U. S. A.) is presented in Figure 3.

The instrument is not being manufactured now, probably because of the limited success obtained with it on
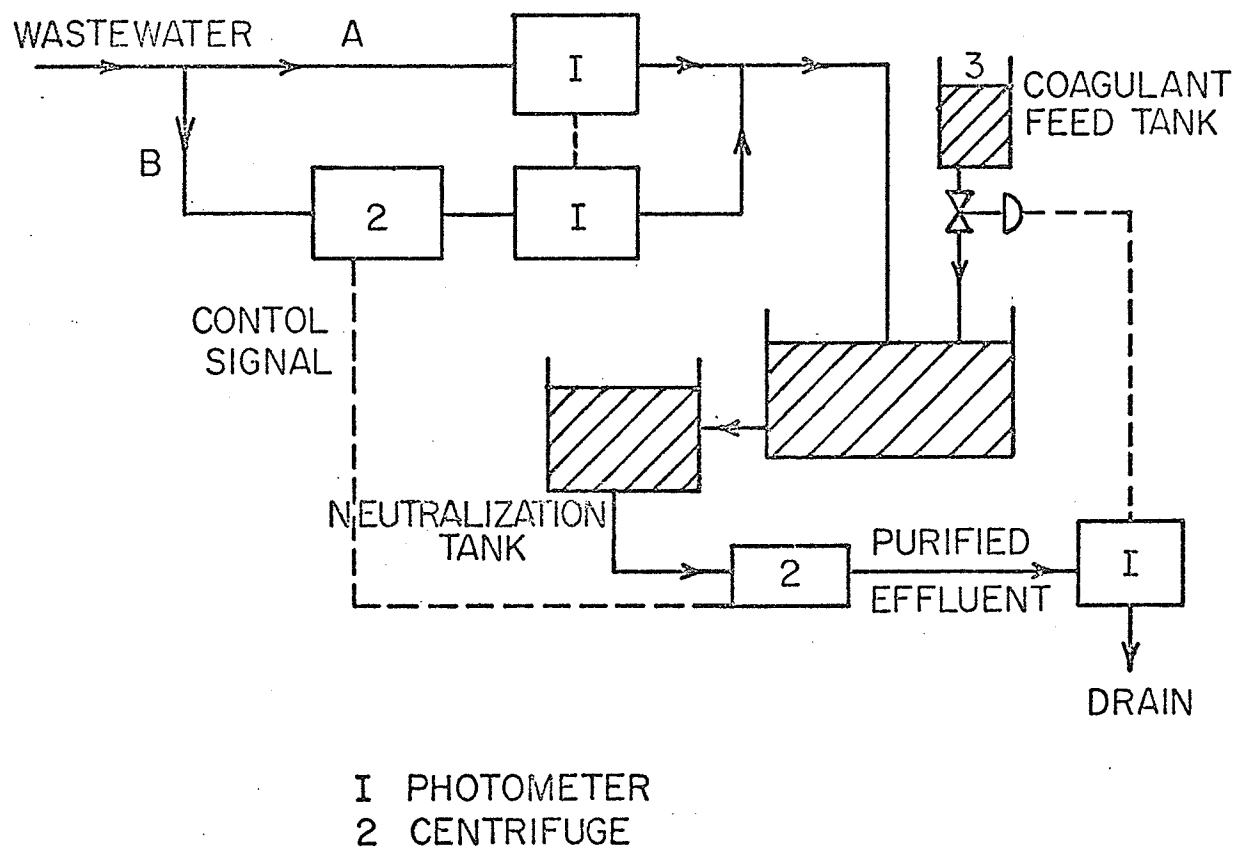
FIGURE 2   SCHEMATIC – A POSSIBLE SYSTEM
FOR AUTOMATIC CONTROL OF COAGULANT
DOSING.
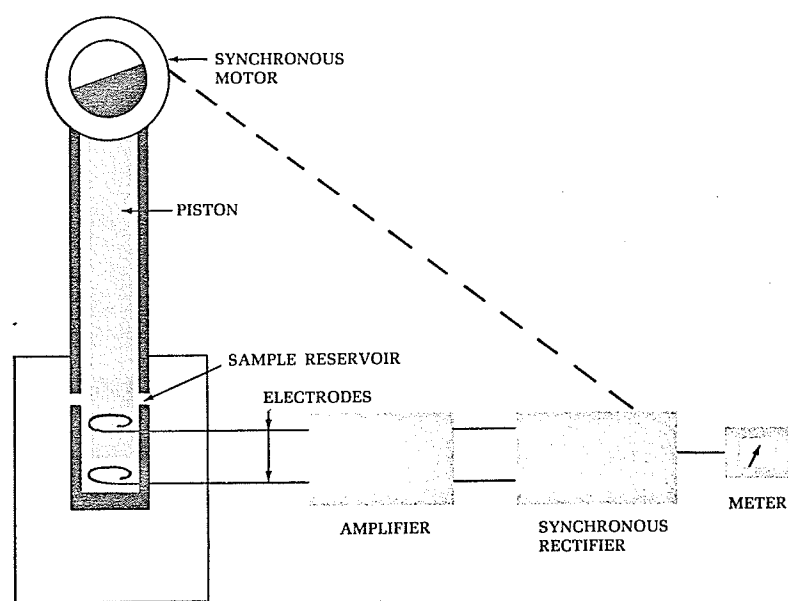
FIGURE 3. Schematic-Streaming Current Detector.

full scale trials. This is a highly complicated system and
one feels that extensive development work would be required
to make it operate satisfactorily.

SCOPE OF INVESTIGATION

The scope of this study included the construction of a pilot plant and the investigation of the physicochemical treatment of simulated lye-peel wastewater. Specifically the following areas were investigated:

1. Preliminary studies on potato wastewater of certain factors which are important for the coagulation process.

2. The effect of the following factors on COD reduction:

        (a) Temperature

        (b) Mixing speed

        (c) Concentration of coagulants

        (d) The coagulant dose

3. The levels of iron in clarified water.

4. Rate of settling of sludge.

5. Solids in clarified and untreated wastewater.

6. Percent COD reductions with increasing coagulant dose rate.

MATERIALS AND METHODS

Construction and Operational Sequence of Pilot Plant

Phase one of this investigation involved the construction of a pilot plant for the physicochemical treatment studies. Engineering specifications of major items of equipment are contained in Appendix 1. A schematic flow diagram of the pilot plant is presented in Figure 4.

The plant allowed for the following sequence of operation:

The wastewater may be pumped from the main supply tank A into tank B. The waste here may be preheated and gravity fed to one of the two tanks E. These tanks were included so that a preliminary chemical conditioning treatment could be applied prior to physicochemical treatment.

The waste was transferred to tank E. The dosing of the coagulants took place in this tank. The V/I transducer converted the millivolt signal from the millivolt meter to milliamps and fed it to the recorder controller. The output of the recorder controller in milliamps was converted to air pressure (3-15 psi) to operate an air-motor which operated a cam to control the flow rate of coagulants. A similar arrangement was used for the neutralization step.

The addition of coagulants lowered the pH value of

28

KEY TO ITEMS IN FIGURE 4

A   Feed Tank

B   Holding and Heating Tank

C   Immersion Heater

D   Mixer

E   Reaction Tank

F   Chemical Feed Tank

G   Control Valve

H   pH or mV meter/V/I Transducer

I   Recorder-Controller

J   I/P Transducer

K   Gate Valves
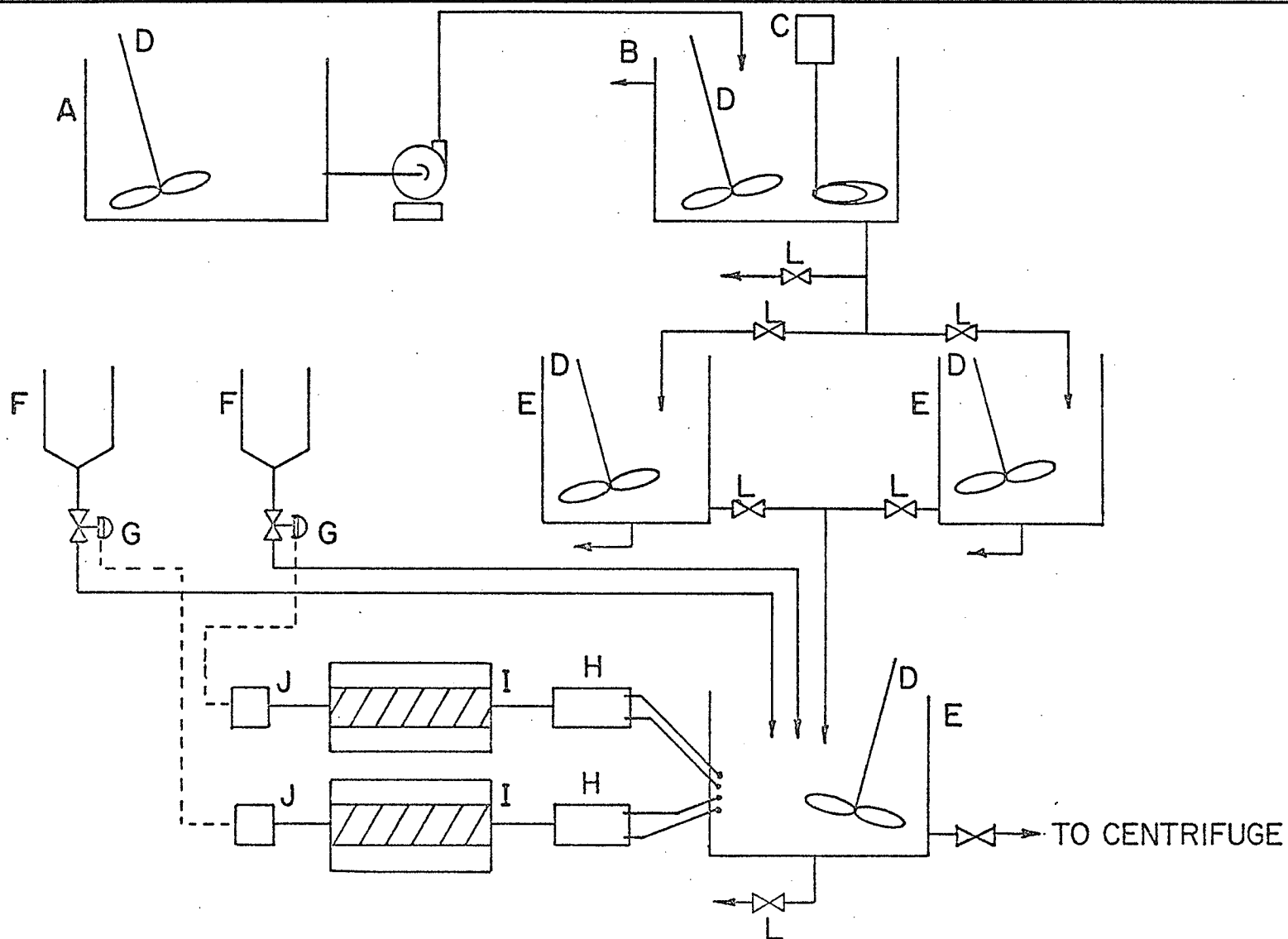
FIGURE 4 PILOT PLANT FLOW DIAGRAM

the treated wastes. The pH was then raised to neutrality
(pH 7.0) by the addition of sodium hydroxide solution. The
neutralized wastewater was clear, but contained a brown
coloured floc which could be removed in a clarifier or
centrifuge. The sludge, which contained most of the
organic material, could be dried after dewatering, and could
be used for coagulant recovery, if thought worthwhile.

In the pilot plant provision was made for the
purified water to be passed through filtration and adsorption
columns. The first column could be filled with filter grade
sand or charcoal and the second with activated carbon. A
third column could be used for additional treatments eg., by
ion exchange resins. These columns were not used for the
research reported herein as major equipment for continuous
runs was not yet available. Design details of the columns
are given in Appendix 1.

The designed capacity of this pilot plant was
100 1/h (20 gallons/h) if used on a batch basis, and with
minor modifications, it could be expected to run on a
continuous basis.

A control valve of the desired size and constructed
in material that would withstand the corrosive properties
of ferric chloride was not available from regular suppliers
of control valves. A valve was designed and fabricated in
collaboration with the Central Instrument Service, University
of Manitoba. Figure 5 shows the principle of operation but
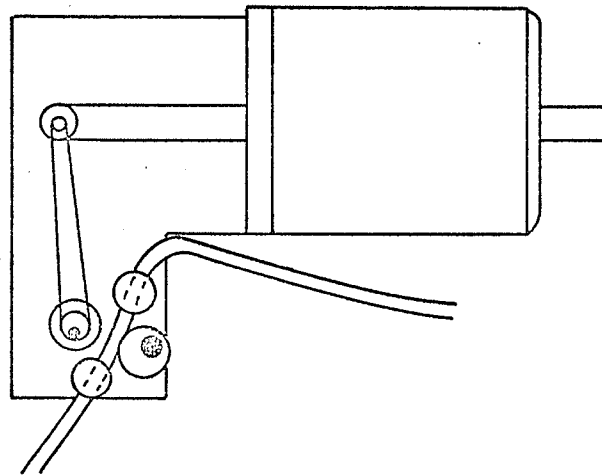
FIGURE 5   CONTROL VALVE IN THE OPEN   POSITION

does not show the details of the linkages to operate the cam. The preliminary runs showed that this valve was not satisfactory for the process. An alternate system based on Auto Titrator (Radiometer-Denmark) with a magnetic valve was used successfully on small scale experiments and could probably be modified for large batches.

Three shapes of impellers were tried. The effectiveness of each was measured with respect to COD reduction, rate of settling of sludge and turbidity removal, for a given dose of the coagulant. Two of these impellers were made in the laboratory. The shapes of these impellers are presented in Figures 6a, 6b, and 6c.

The shape of an impeller determines the flow pattern that is produced in the liquid. The standard screw impeller provided axial flow, the paddle of circular cross section provided radial flow and the wing impeller provided mixed flow.

Two standard screw impellers (2.7 inches diameter) mounted on one shaft were used for the entire study.

Analytical Procedures

Determinations of COD were performed by the dilution method described in "Standard Methods" (57). The COD of the wastewater was measured after the removal of settleable matter. Turbidity was determined with a Nephelometer (EEL, Unigalvo Type 20, U. K.). The standard was set at 100 on
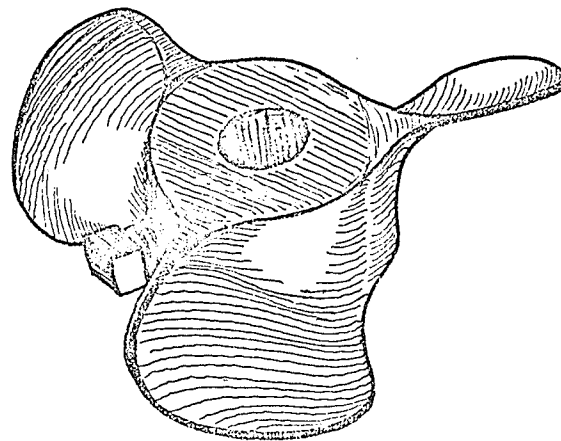
FIGURE 6a   STANDARD SCREW IMPELLER
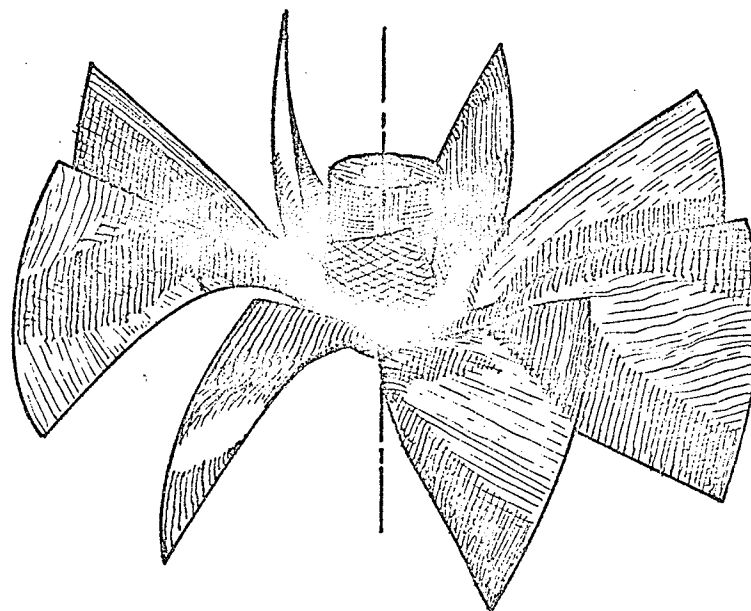
FIGURE 6b WING IMPELLER
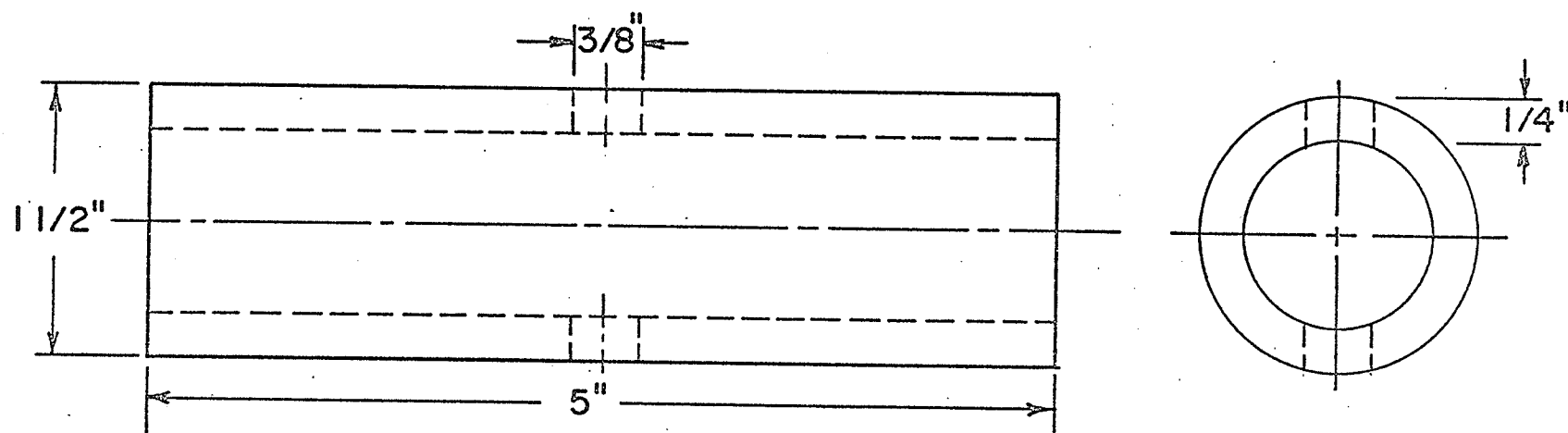
FIGURE 6c PADDLE OF CIRCULAR CROSS-SECTION

the linear scale using the sensitivity control. Distilled water at 1.33 was used as reference.

Determinations of iron were performed by the phenanthroline method described in "Standard Methods" (57). The samples were submitted to wet ashing prior to analysis. A sample of 50 ml of purified water was mixed with 0.5 ml perchloric acid (60%), 1 ml conc. sulphuric acid and 5 ml conc. nitric acid in a Kjeldahl flask. After ashing to about 2 ml, it was diluted with distilled water and brought up to a volume of 50 ml. The calibration curve is shown in Figure 7.

Settleable residue was measured in Imhoff cones, and are reported as ml/l. Total residue and total fixed residue were measured using the methods described in "Standard Methods" (57). A muffle furnace at 600° C was used for ashing the dry residue.

An Abbé refractometer (Carl Zeiss Canada Ltd., Montreal) was used for determining refractive indices.

One hundred ml graduated cylinders were used for the determination of the rate of settling of sludge.

Preparation of Simulated Wastewater

A bulk sample of 700 lbs of Netted Gem cv potatoes was obtained from the Department of Plant Science, University of Manitoba. All the tubers in this sample had been grown and stored under the same conditions. The object was

FIGURE 7   CALIBRATION CURVE FOR IRON

37
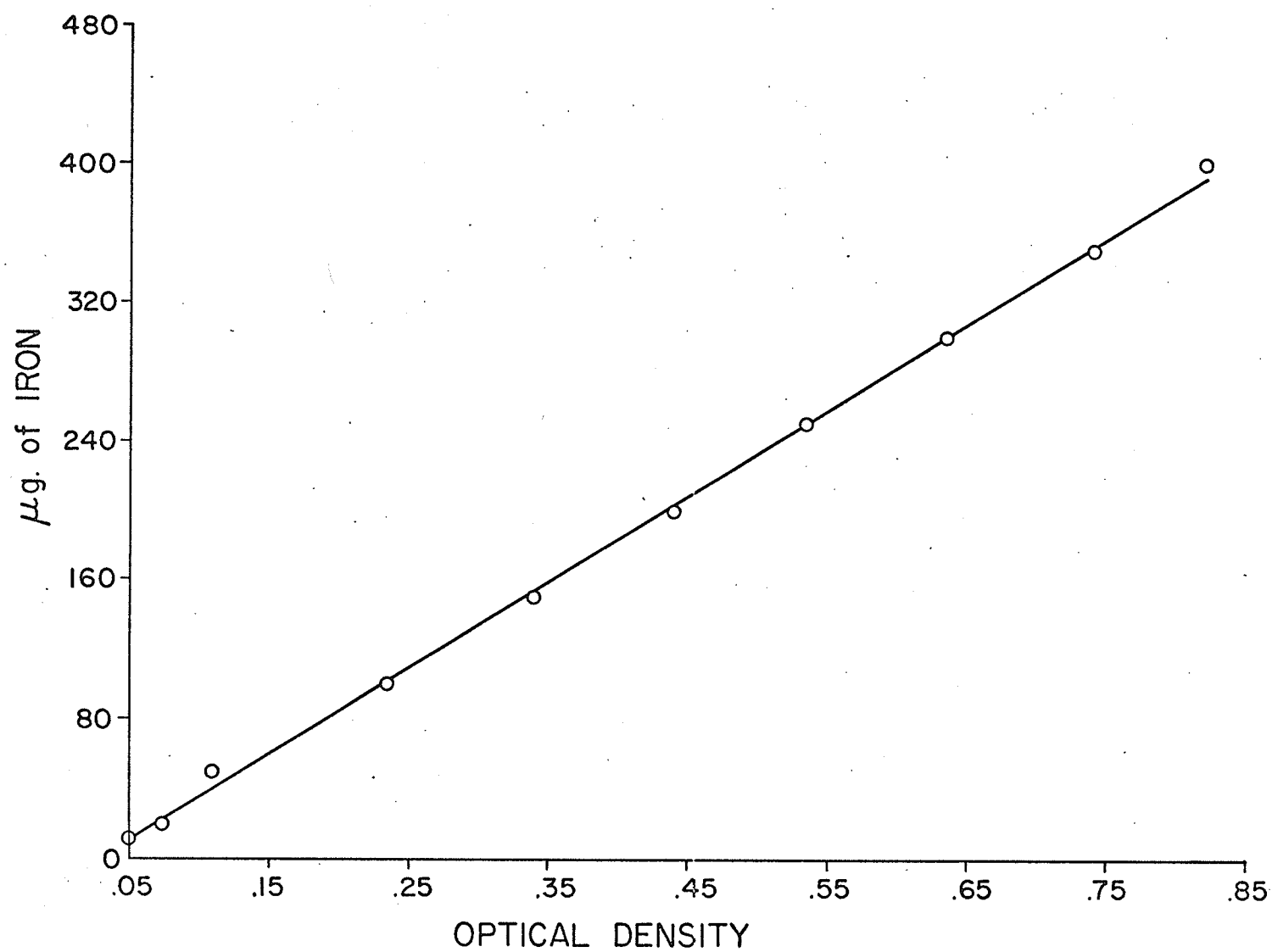
to attempt to obtain similar wastewater for all the treatment combinations. The potatoes were peeled, and the peelings were packed in polyethylene bags and stored in the deep freezer. The procedure used to obtain simulated lye-peel waste was as follows: peels weighing 2000 g. were blended with cold water in a Waring Blender for 5 mins. The mix was added to 80 l water in a steam kettle. While agitating the mix at high speed, 320 g. of sodium hydroxide flakes were added. The temperature was raised to 78° C and then allowed to cool to 20° C. The wastewater was stored in the cooler overnight at 1.7° C before using next morning. This method of preparation gave a wastewater similar to that from potato plants using lye-peeling operation.

Design of Experiments

A 2^3 x 3 factorial design was set up for the investigation of four factors affecting the physicochemical process. The preliminary investigation had indicated the importance of:

    (a)   Temperature

    (b)   Mixing speed

    (c)   Concentration of the coagulant

    (d)   Dose of the coagulant

Four replications of each treatment were carried out. The following levels were used for a batch size of 9500 g. of wastewater:

Temperature	1. $10°$ C
	2. $50°$ C
Mixing Speed	1. 400 rpm.
	2. 650 rpm
Concentration of Coagulants	1. 1.0 M $FeCl_3/AlCl_3$
	2. 1.74 M $FeCl_3/AlCl_3$

		Concentration 1	Concentration 2
Dose of Coagulants	1.	260 ml	155.4
	2.	280 ml	167.4
	3.	300 ml	179.3

Experiments were also conducted outside the factorial design to obtain additional information not covered by the factorial experiment. The analysis of variance was worked out using a computer programme described in "Package 13" available at the Computer Centre of the University of Manitoba.

The upper temperature was selected because the wastewater would be at about $50°$ C if preconditioning of wastewater was carried out before coagulation. Also, the wastewater from lye-peeling plants is normally warm. The second level at $10°$ C was chosen at a few degrees higher than the storage temperature ($1.7°$ C) to allow for the rise in temperature during handling before treatment.

A mixing speed lower than 400 rpm was found to be unsatisfactory, and at speeds higher than 650 rpm excessive

foaming of the wastewater was observed.

The molar concentration was included to attempt to reproduce data collected on laboratory scale experimental work (16). The second level at 1.74 mole was found to be the highest concentration that could be obtained at room temperature since the solubility of the two salts is not very high.

The preliminary investigations had shown that occasionally the wastewater did not purify at levels below 260 ml per 9500 g. and always purified at 300 ml per 9500 g. wastewater.

Preparation of Coagulant Solutions

Two solutions of coagulants were prepared:

1. containing 1 mole each of ferric chloride and aluminum chloride per litre of solution;

2. containing 1.74 moles each of ferric chloride and aluminium chloride per litre of solution.

Reagent grade hydrated ferric chloride ($FeCl_3 \cdot 6\ H_2O$) and aluminium chloride ($AlCl_3 \cdot 6\ H_2O$) were obtained from BDH Canada Ltd.

A 20% solution of sodium hydroxide was used for neutralization. The sodium hydroxide flakes were obtained from Standard Chemical Ltd., Winnipeg, Manitoba.

Coagulant Treatment Procedure

The wastewater was placed in the reaction tank and

maintained at the desired temperature using a 250 watt thermostatically controlled immersion heater. The measured dose of the coagulant was then added. pH and mV readings were recorded before and after the dose. A tachometer was used to adjust the speed of the air operated mixer. After a two minute reaction time, the sodium hydroxide solution was added to bring the pH back to 7.0.

The treated waste was allowed to stand in a beaker for one hour. The supernatent liquid was filtered through a Whatman No. 4 filter paper. Chemical analysis and turbidity readings were performed on the filtrate.

RESULTS

1. PRELIMINARY STUDIES

(a) Some Physical Properties of the Simulated Wastewater

Data on some physical properties important to the coagulation process, or that could reveal information on the dosage requirements for the automatic control of the process, was collected. Table 2 lists the refractive index values and the dissolved solids as measured on the Abbé Refractometer for dilutions of wastewater. Table 3 shows the density of the wastewater at the two temperatures used for coagulation. Table 4 gives pH and redox values at different temperatures.

Refractive Index values indicated that it may be used as a parameter to control the chemical dosage for this waste. An instrument sensitive at the 4th decimal place would have to be employed to monitor the wastewater, under closely controlled conditions. Monitoring devices of this type are available; they are used for monitoring effluents from chromatographic columns.

(b) The Effect of the Shape of Impeller on Mixing Properties

The shape of the impeller determines the mixing patterns produced in the liquid. Some shapes provide large mass transfer at low velocities, while others produce high

42

TABLE 2

REFRACTIVE INDICES AND DISSOLVED SOLIDS FOR
DIFFERENT DILUTIONS OF WASTEWATER

Wastewater	Added Distilled Water	Refractive Index	Dissolved Solids %
200 ml	0 ml	1.3349	1.25
180 ml	20 ml	1.3347	1.10
160 ml	40 ml	1.3345	1.00
140 ml	60 ml	1.3343	0.90
120 ml	80 ml	1.3341	0.80
100 ml	100 ml	1.3339	0.70

TABLE 3

DENSITY OF WASTEWATER AT 10° C AND 50° C

Temperature	Volume	Mass	Density
10°	100 ml	99.9	0.999
50°	100 ml	98.6	0.986

TABLE 4

THE pH AND REDOX VALUES OF THE WASTEWATER
AT DIFFERENT TEMPERATURES

Temperature (° C)	pH	Redox (mv)
10	12.3	-120
20	11.85	-120
30	11.70	-115
40	11.50	-115
50	11.30	-120

velocities and shearing action. It is important for the coagulation process to have good mixing without causing excessive foaming, or dispersion of flocs.

Three different shapes of impellers as shown in Figures 6a, 6b, and 6c were tried:

1. Standard screw impeller

2. Wing impeller

3. Paddle of circular cross-section

The effectiveness was measured as removal of turbidity, COD reduction and rate of settling of the sludge. All tests were conducted at 200 ft/min MSP and a dose of 300 ml of ferric chloride/aluminum chloride (1M) was used. Settling tests were carried out in a 100 ml graduated cylinder. The results are presented in Table 5 and Figure 8. Turbidity values were comparable for the three shapes but higher COD reductions were achieved by standard and wing impellers. The rate of settling of sludge was considerably faster for the wing type impeller.

(c) Effect of Adding Hydrochloric Acid to Ferric Chloride/Aluminum Chloride Solution on Chemical Demand for Turbidity Removal

The pH value after chemical dosing depends on the dosage if all other factors such as wastewater composition and temperature are kept constant. It was thought that pH of the mix may influence the formation of the floc and in turn the chemical demand of the wastewater. The solubility

TABLE 5

TURBIDITY AND COD VALUES OF PURIFIED WATER
FOR THE THREE SHAPES OF IMPELLERS

	Turbidity	COD
Standard Screw Impeller	2	800 mg/l
Wing Impeller	3	760 mg/l
Paddle of Circular Cross section	5	1032 mg/l

Batch Size 9500 g.

Coagulant Dose 300 ml (1M)

COD of untreated waste 7000 mg/l
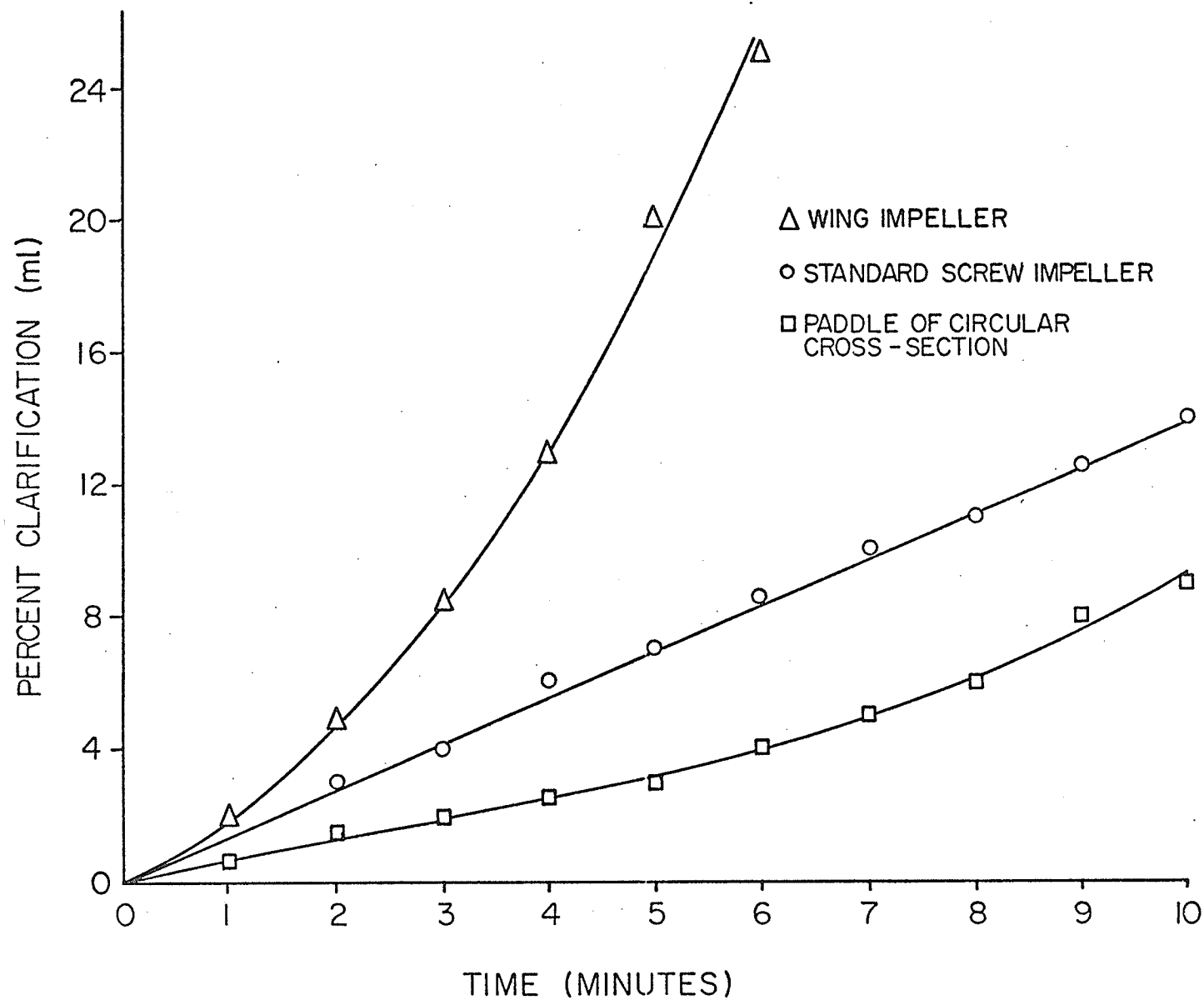
FIGURE 8   THE EFFECT OF THE SHAPE OF IMPELLER ON THE SETTLING RATE OF SLUDGE

of the hydroxides of aluminum and iron does depend on the
pH of the solution. The solutions of $FeCl_3/AlCl_3$ containing
10%, 25% and 50% conc. hydrochloric acid were used and the
chemical demand evaluated as removal of turbidity.

The results are presented in Table 6. The solution
without hydrochloric acid was more effective at a dose of
6 ml as compared to those containing hydrochloric acid.
Even when the total dose was equivalent to 6 ml of acid-free
solution, the turbidity removal was not as good. There were
three replicates for each treatment.

(d) Comparison of Capillary and Porous
    Plug Calomel Electrodes

Most of the experimental work was carried out with
a porous-plug type calomel electrode. It was observed that
occasionally the porous-plug became blocked by the floc
resulting in inconsistent readings. The capillary type
seemed less likely to get blocked because of the large
continuous flow rate of potassium chloride. An experiment
was set up to determine if readings from a porous-plug type
electrode could be reproduced on a capillary type.

To a sample of 200 ml of standard wastewater, 6 ml
of ferric/aluminum chloride was added in steps of 1 ml. The
redox and pH values were recorded. The treated waste was
neutralized and the turbidity of the purified water was
measured. There were three replicates for each treatment.
The results presented in Table 7 showed that the capillary

TABLE 6

EFFECT OF ADDING HYDROCHLORIC ACID TO
$FeCl_3/AlCl_3$ ON TURBIDITY REMOVAL

Wastewater (ml)	Total volume of flocculent (ml)	Percent hydrochloric acid	pH after dosing	Turbidity of the purified water
200	6.0	0.0	3.2	5.0
200	5.0	10.0	4.6	over 100
200	4.7	25.0	4.2	over 100
200	6.7	25.0	2.8	10
200	8.0	25.0	2.2	15
200	5.0	50.0	1.8	over 100

TABLE 7

COMPARISON OF CAPILLARY AND POROUS-PLUG
CALOMEL ELECTRODES

Waste water volume (ml)	Coagulant dose (ml)	pH (Porous-Plug)		pH (Capillary)	
		Mean*	Standard deviation	Mean*	Standard deviation
200	0.0	12.25	0.10	12.32	0.28
200	1.0	12.07	0.28	12.10	0.00
200	2.0	11.00	0.00	11.07	0.26
200	3.0	9.17	0.25	9.27	0.25
200	4.0	6.17	0.20	6.20	0.00
200	5.0	4.07	0.10	4.17	0.14
200	6.0	3.77	0.53	3.68	0.17
Turbidity after neutralization		2.3		4.0	

*Mean of three determinations in each case.

type electrode was as good as the porous-plug type.

(e) Effect of Duration of Agitation on pH
    and Redox Values After Coagulant Dosing

The object was to evaluate the influence of prolonged agitation on pH and redox values. The standard impeller of 2.7 inches diameter was used at 200 rpm in a batch of 10 litres. The initial pH and redox values were 12.4 and -120 mV. The results are given in Table 8. A chemical dose of 300 ml of 1 molal strength was used. The pH reading remained static but the redox value changed from 380 to 340 mV. This showed that it takes about 2 minutes for the mV reading to stabilize.

(f) The Change in pH and Redox Values
    with Coagulant Dose

Coagulant was added, in steps of 20 ml each, to a batch of 9500 g. of wastewater at 50° C. Redox and pH values were recorded. A similar experiment was carried out at 10° C. The results are presented in Figures 9,10, and 11. The Figures 10 and 11 indicate that the temperature has only a minor effect on the change in redox values with coagulant dose. The Figures have been drawn separately to avoid overlapping of similar curves.

The pH value drops slowly up to a dose of about 60 ml and then rapidly drops between 60 and 180 ml. The addition of more coagulant brings about a small change in pH after this point. The minimum dose of coagulant required

TABLE 8

EFFECT OF DURATION OF AGITATION ON pH AND
REDOX VALUES AFTER COAGULANT DOSE

Time (mins.)	pH	Redox (mV)
0	4.0	380
1	4.0	375
2	4.0	340
3	4.0	340
4	4.0	340
5	4.0	340
6	4.0	340
7	4.0	340
8	4.0	340
9	4.0	330
10	4.0	340
11	4.0	335
12	4.0	340
13	4.0	340
14	4.0	340
15	4.0	340
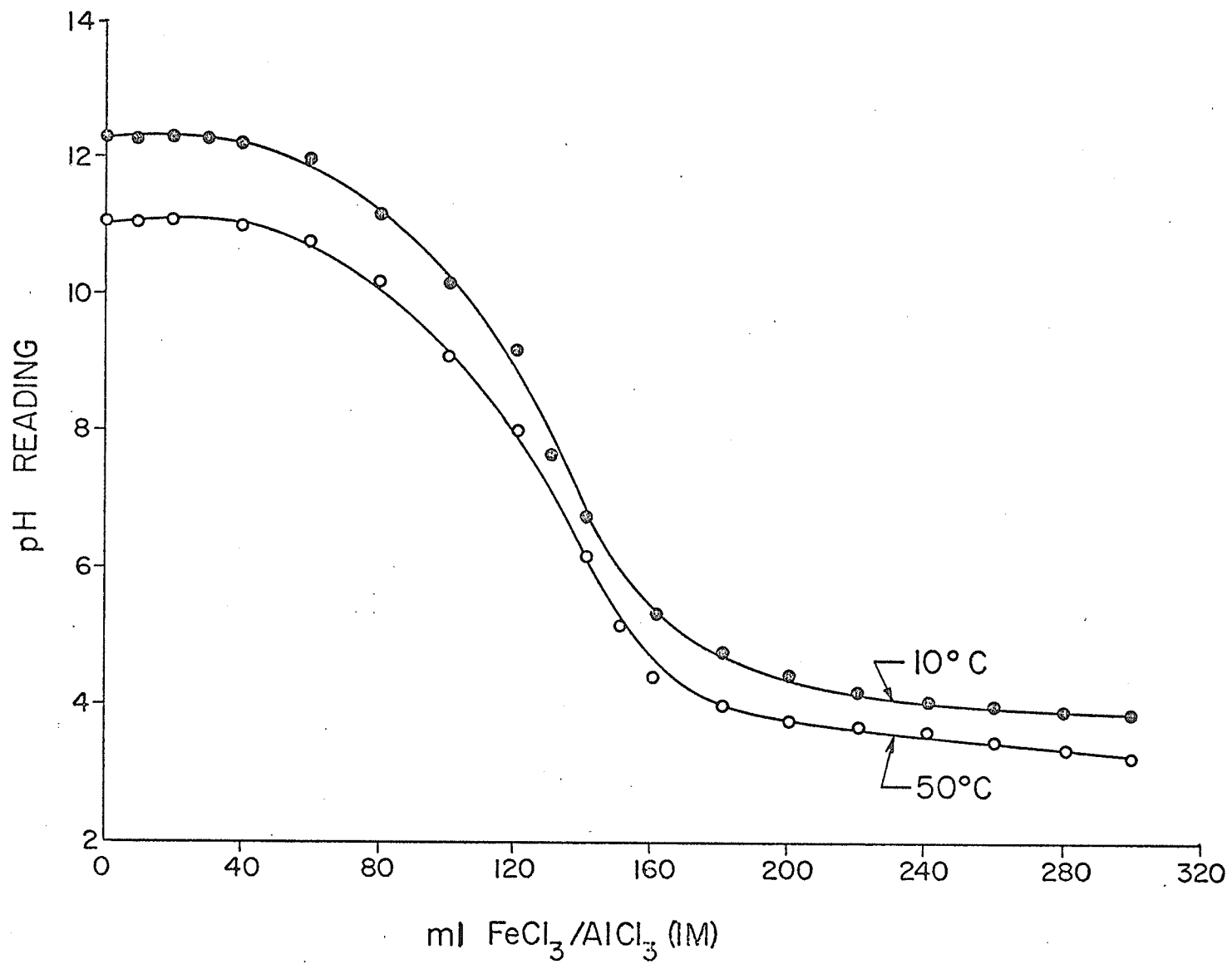
FIGURE 9   CHANGE IN pH OF WASTEWATER WITH INCREASING COAGULANT DOSE
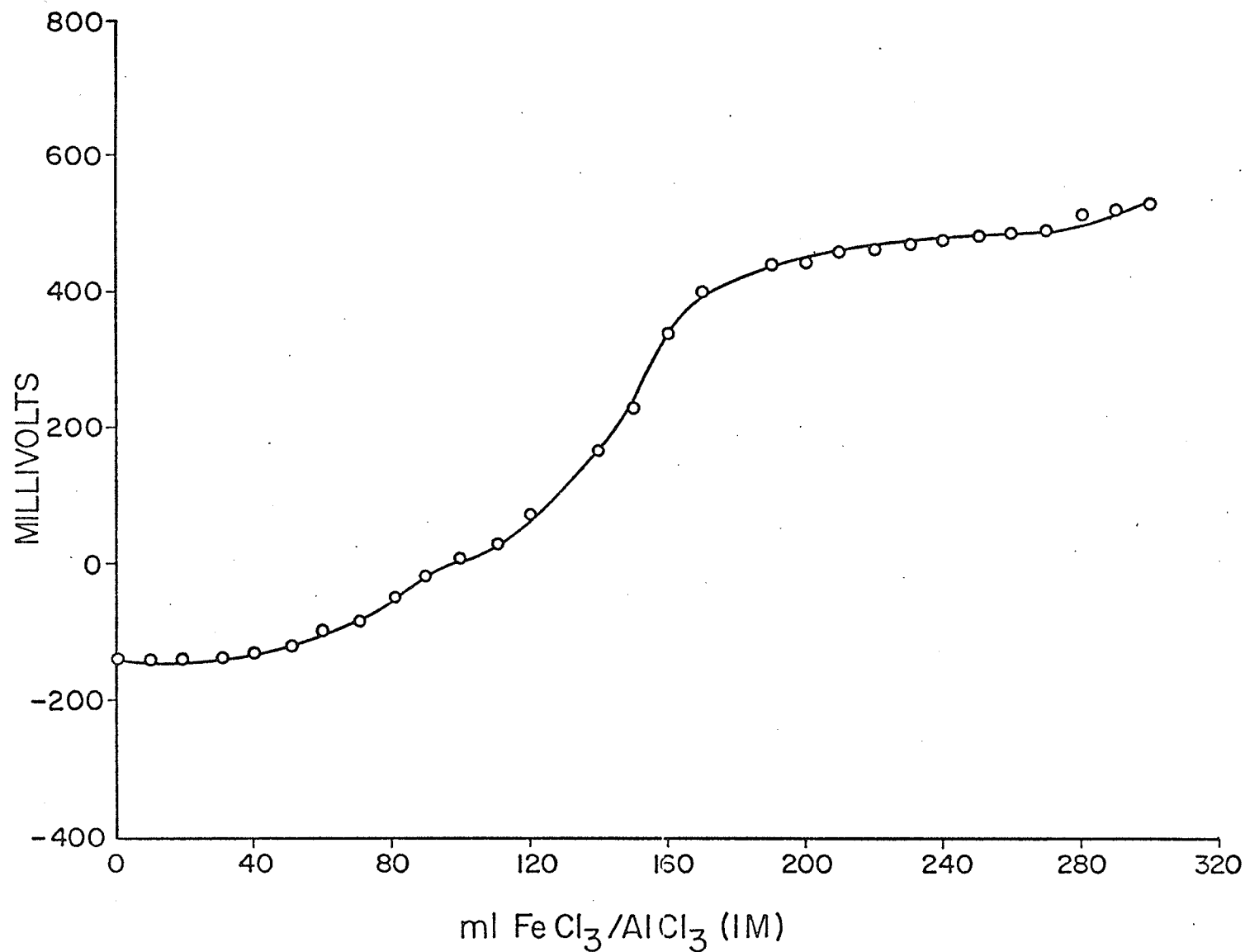
FIGURE 10 CHANGE IN REDOX VALUES WITH INCREASING COAGULANT DOSE AT 50°C
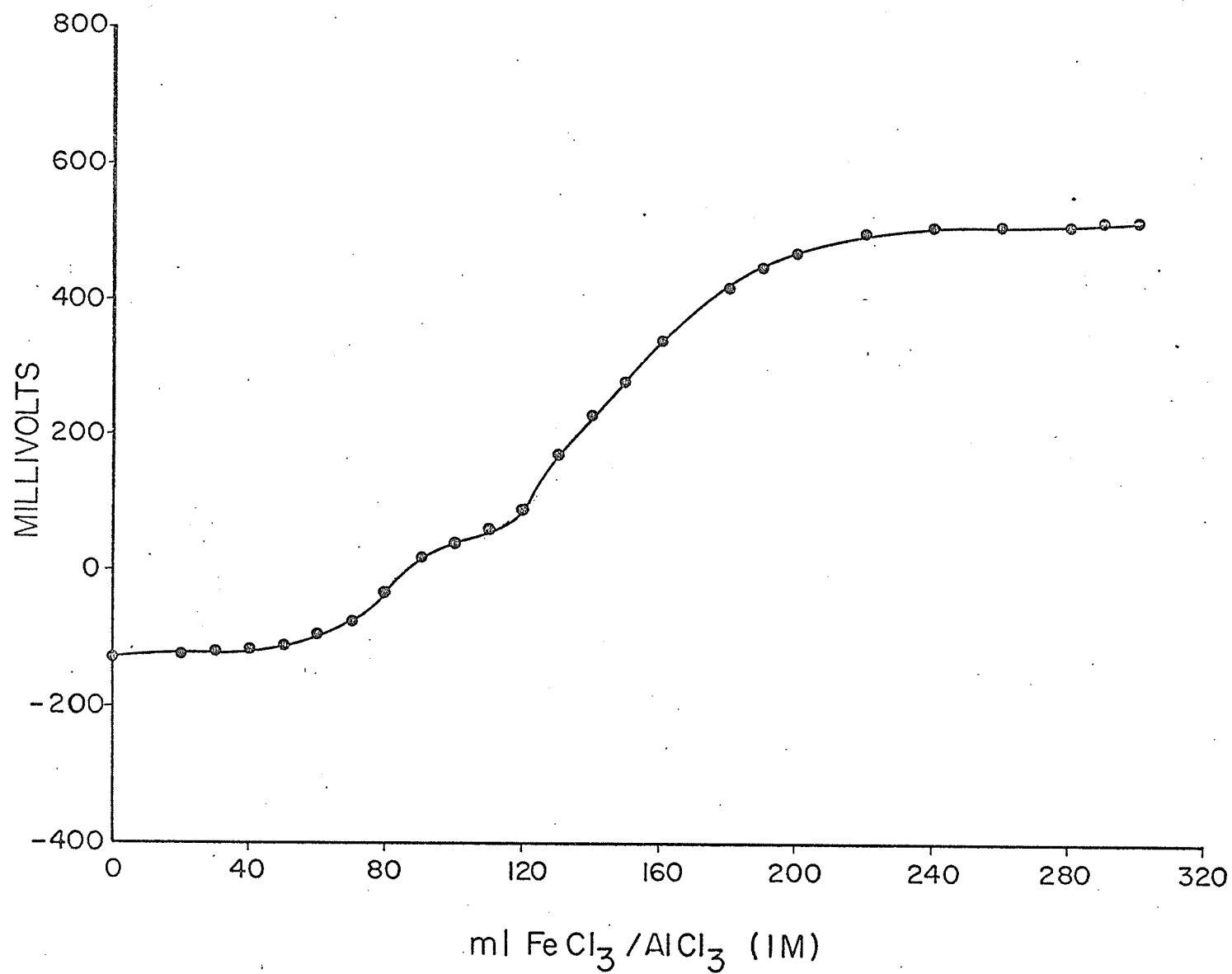
FIGURE II CHANGE IN REDOX VALUES OF WASTEWATER WITH INCREASING
COAGULANT DOSE AT 10° C

for purification is about 180 ml. This suggests that the
change in pH may be used to determine the coagulant dose for
this wastewater. Additional research would be required with
other wastes to see if a similar situation prevailed.

The redox values rise gradually and then the rate of
rise increases sharply and shows a decline at about 180 ml.
This has been considered as a means of controlling coagulant
dose. Work on this aspect is in progress at the Department
of Food Science, University of Manitoba. Success in this
field would provide a new factor to control the coagulant
dose for continuous operation of such plants.

(g) Correlation between Concentration of Wastewater
    and Redox Titration Curves

The object of this experiment was to determine if
progressive dilutions of wastewater would decrease the
coagulant demand proportionally. Six concentrations of
wastewater were used (50 to 100% in steps of 10).

Aliquotes of 100 ml each were taken and titration
curves plotted potentiometrically using the Radiometer
auto-titrator. The volumes of coagulant required for the
end point as shown by the titration curve were recorded.
Table 9 shows the actual volumes of coagulant and also
expressed as proportion of the volume used at zero dilution.

The results show good correspondence. The coagulant
demand decreased in proportion to the dilution of the waste-
water.

TABLE 9

CORRELATION BETWEEN CONCENTRATION OF WASTEWATER
AND REDOX TITRATION CURVES

Wastewater (ml)	Added distilled water (ml)	Volume of coagulant used	Proportion of the volume used at zero dilution
100	0	1.525	100%
90	10	1.390	91%
80	20	1.200	79%
70	30	1.075	71%
60	40	0.900	59%
50	50	0.750	49%

2. REDUCTION IN COD

The main object of this investigation was to determine the dose of coagulant required to achieve high, reproducible COD reductions. Preliminary work had suggested that the coagulant demand fluctuated as the nature of the wastewater changed. Factors such as temperature and intensity of mixing also affected the dose requirements.

For the preliminary investigation a solution containing one mol per litre each of ferric chloride and aluminum chloride was used but for the factorial design experiment the concentration of chemicals was included as a factor.

The lower level of each factor was given the number 1 and higher levels 2 and 3. The order of factors used in the tables is:

Factors	Levels	
Temperature	1 (10° C)	2 (50° C)
Mixing speed	1 (400 rpm)	2 (650 rpm)
Concentration	1 (1M)	2 (1.74 M)
Dose	1 (260 ml)	2 (280 ml)
		3 (300 ml)

The analysis of variance for COD reductions is presented in Table 10. The mean values of all treatment combinations and their interactions are presented in Table 11.

For the best coagulation treatment the COD was reduced from 7910 mg/l to 508.8 mg/l, i.e., by 93.5%.

TABLE 10

ANALYSIS OF VARIANCE--COD REDUCTIONS

Source of variation	DF	SS	MS	F
Replications	3	3.661	1.220	
TMP	1	298.603	298.603	313.533**
MSP	1	4.651	4.651	4.883*
TMP MSP	1	1.704	1.704	1.789
CNC	1	0.751	0.751	0.788
TMP CNC	1	17.519	17.519	18.395**
MSP CNC	1	17.949	17.949	18.846**
TMP MSP CNC	1	9.182	9.182	9.641**
DOS	2	54.364	27.182	28.541**
TMP DOS	2	10.340	5.170	5.428**
MSP DOS	2	10.547	5.274	5.537**
TMP MSP DOS	2	15.926	7.963	8.361**
CNC DOS	2	0.900	0.450	0.472
TMP CNC DOS	2	3.982	1.991	2.091
MSP CNC DOS	2	6.507	3.254	3.416*
TMP MSP CNC DOS	2	11.400	5.700	5.985**
ERROR	69	65.714	0.952	
TOTAL	95	533.699		

STANDARD ERROR = 0.976   COEFFICIENT OF VARIATION = 1.090

TMP Temperature   MSP Mixing speed   *Significant
CNC Concentration   DOS Dose   **Highly significant

TABLE 11

MEAN VALUES FOR COD REDUCTIONS
FOR FACTORS AND LEVELS

Factors	Levels			Mean values percent reduction
TMP	1			91.3
	2			87.7
MSP	1			89.3
	2			89.7
TMP MSP	1	1		90.9
	1	2		91.6
	2	1		87.6
	2	2		87.8
CNC	1			89.6
	2			89.4
TMP CNC	1	1		90.9
	1	2		91.6
	2	1		88.2
	2	2		87.2
MSP CNC	1	1		89.8
	1	2		88.7
	2	1		89.4
	2	2		90.1
TMP MSP CNC	1	1	1	91.3
	1	1	2	90.5
	1	2	1	90.5
	1	2	2	92.7
	2	1	1	88.3

TABLE 11 (Continued)

Factors	Levels			Mean values percent reduction
TMP MSP CNC	2	1	2	87.0
	2	2	1	88.2
	2	2	2	87.4
DOS	1			89.1
	2			88.8
	3			90.5
TMP DOS	1	1		90.5
	1	2		90.5
	1	3		92.7
	2	1		87.7
	2	2		87.1
	2	3		88.3
MSP DOS	1	1		89.0
	1	2		88.1
	1	3		90.7
	2	1		89.2
	2	2		89.5
	2	3		90.4
TMP MSP DOS	1	1	1	90.4
	1	1	2	89.2
	1	1	3	93.2
	1	2	1	90.7
	1	2	2	91.9
	1	2	3	92.3
	2	1	1	87.6
	2	1	2	87.2
	2	1	3	88.2

TABLE 11 (Continued)

Factors	Levels			Mean values percent reduction
TMP MSP DOS	2	2	1	87.8
	2	2	2	87.1
	2	2	3	88.5
CNC DOS	1	1		89.3
	1	2		88.9
	1	3		90.5
	2	1		88.9
	2	2		88.7
	2	3		90.6
TMP CNC DOS	1	1	1	90.4
	1	1	2	90.4
	1	1	3	92.0
	1	2	1	90.7
	1	2	2	90.6
	1	2	3	93.6
	2	1	1	88.3
	2	1	2	87.5
	2	1	3	89.0
	2	2	1	87.1
	2	2	2	86.8
	2	2	3	87.7
MSP CNC DOS	1	1	1	89.5
	1	1	2	89.0
	1	1	3	90.8
	1	2	1	88.4
	1	2	2	87.3
	1	2	3	90.6

TABLE 11 (Continued)

Factors		Levels			Mean values percent reduction
MSP CNC DOS	2	1	1		89.1
	2	1	2		88.8
	2	1	3		90.2
	2	2	1		89.4
	2	2	2		90.2
	2	2	3		90.6
TMP MSP CNC DOS	1	1	1	1	90.5
	1	1	1	2	90.6
	1	1	1	3	92.9
	1	1	2	1	90.3
	1	1	2	2	87.8
	1	1	2	3	93.5
	1	2	1	1	90.3
	1	2	1	2	90.2
	1	2	1	3	91.1
	1	2	2	1	91.1
	1	2	2	2	93.5
	1	2	2	3	93.5
	2	1	1	1	88.6
	2	1	1	2	87.5
	2	1	1	3	88.7
	2	1	2	1	86.6
	2	1	2	2	86.8
	2	1	2	3	87.6
	2	2	1	1	87.9
	2	2	1	2	87.4
	2	2	1	3	89.3
	2	2	2	1	87.7
	2	2	2	2	86.8
	2	2	2	3	87.7

3. LEVELS OF IRON IN PURIFIED WATER

Preliminary studies had shown that most of the iron added as ferric chloride was removed with the sludge. Iron determinations were performed on all experiments of the factorial design series to measure the variations in iron content of the purified water from different treatments.

The analysis of variance of the results is presented in Table 12. The mean values for different treatments are given in Table 13. Other results used in arriving at Table 12 are given in Appendix II.

The levels of iron are well below the levels found in many natural waters. Some of the fluctuations in the iron content are probably the result of errors involved in measuring very small concentrations. The iron determinations were carried out as this was considered to be a probable contaminant which would be toxic at high levels and could cause discoloration of the product during re-use of the purified water in food processing. Much higher levels of aluminum can be tolerated. Previous research in the Food Science Department had shown that the residual aluminum concentration was of the same order as the residual iron found in the above experiments.

4. RATE OF SETTLING OF SLUDGE

Rate of settling of sludges from conventional treatment of wastewater has been used as one of the measures of

TABLE 12

ANALYSIS OF VARIANCE OF IRON CONTENT OF PURIFIED WATER

Source of Variation	DF	SS	MS	F
Replications	3	0.025	0.008	
TMP	1	0.058	0.058	7.318**
MSP	1	0.102	0.102	12.981**
TMP MSP	1	0.001	0.001	0.180
CNC	1	0.006	0.006	0.747
TMP CNC	1	0.006	0.006	0.825
MSP CNC	1	0.024	0.024	3.019
TMP MSP CNC	1	0.002	0.002	0.294
DOS	2	0.157	0.078	9.976**
TMP DOS	2	0.084	0.042	5.348**
MSP DOS	2	0.097	0.048	6.155**
TMP MSP DOS	2	0.189	0.095	12.020**
CNC DOS	2	0.057	0.029	3.654*
TMP CNC DOS	2	0.105	0.052	6.654**
MSP CNC DOS	2	0.060	0.030	3.788*
TMP MSP CNC DOS	2	0.180	0.090	11.454**
ERROR	69	0.543	0.008	
TOTAL	95	1.696		

STANDARD ERROR = 0.089   COEFFICIENT OF VARIATION = 45.159

*Significant
**Highly significant

TABLE 13

MEAN VALUES OF IRON CONTENT OF PURIFIED WATER
FOR DIFFERENT TREATMENT COMBINATIONS

Treatments	Treatment combinations				Mean value mg/l
TMP MSP CNC DOS	1	1	1	1	0.23
	1	1	1	2	0.17
	1	1	1	3	0.12
	1	1	2	1	0.23
	1	1	2	2	0.32
	1	1	2	3	0.19
	1	2	1	1	0.14
	1	2	1	2	0.15
	1	2	1	3	0.14
	1	2	2	1	0.16
	1	2	2	2	0.13
	1	2	2	3	0.10
	2	1	1	1	0.19
	2	1	1	2	0.18
	2	1	1	3	0.35
	2	1	2	1	0.56
	2	1	2	2	0.00
	2	1	2	3	0.22
	2	2	1	1	0.28
	2	2	1	2	0.25
	2	2	1	3	0.09
	2	2	2	1	0.22
	2	2	2	2	0.24
	2	2	2	3	0.08

the efficiency of the system. A fast rate of settling reduces the load on settling tanks. If settling tanks are not used, it can be used to study the nature of the floc formed. The Jar Test for the determination of coagulant dose is based on the rate of settling of the floc.

Samples of the treated and neutralized waste were promptly placed in a graduated cylinder of 100 ml capacity. The volume of supernatant was measured at regular intervals. The results presented in Figure 12 and 13 show that the lower the temperature, the slower the rate of settling for a given coagulant dose. Also, higher the coagulant dose, the slower the settling for a given temperature.

5. TOTAL, FIXED, VOLATILE RESIDUE AND SETTLEABLE
   MATTER IN PURIFIED AND UNTREATED WASTEWATER
   FOR DIFFERENT COAGULANT DOSAGES AT 10° C AND 50° C

Total, fixed and volatile residue were determined for treatments at higher mixing speed using a solution containing 1 mol each of ferric and aluminium chloride. A batch size of 475 g. wastewater was used at 10° C or 50° C with a dose rate of 260 ml, 280 ml or 300 ml per 9500 g. of wastewater. A sample size of 25 ml of purified water was used. The mean values of the three replicates are presented in Table 14.

Settleable matter was measured in an Imhoff cone. A sample size of 350 ml was used for all the measurements.
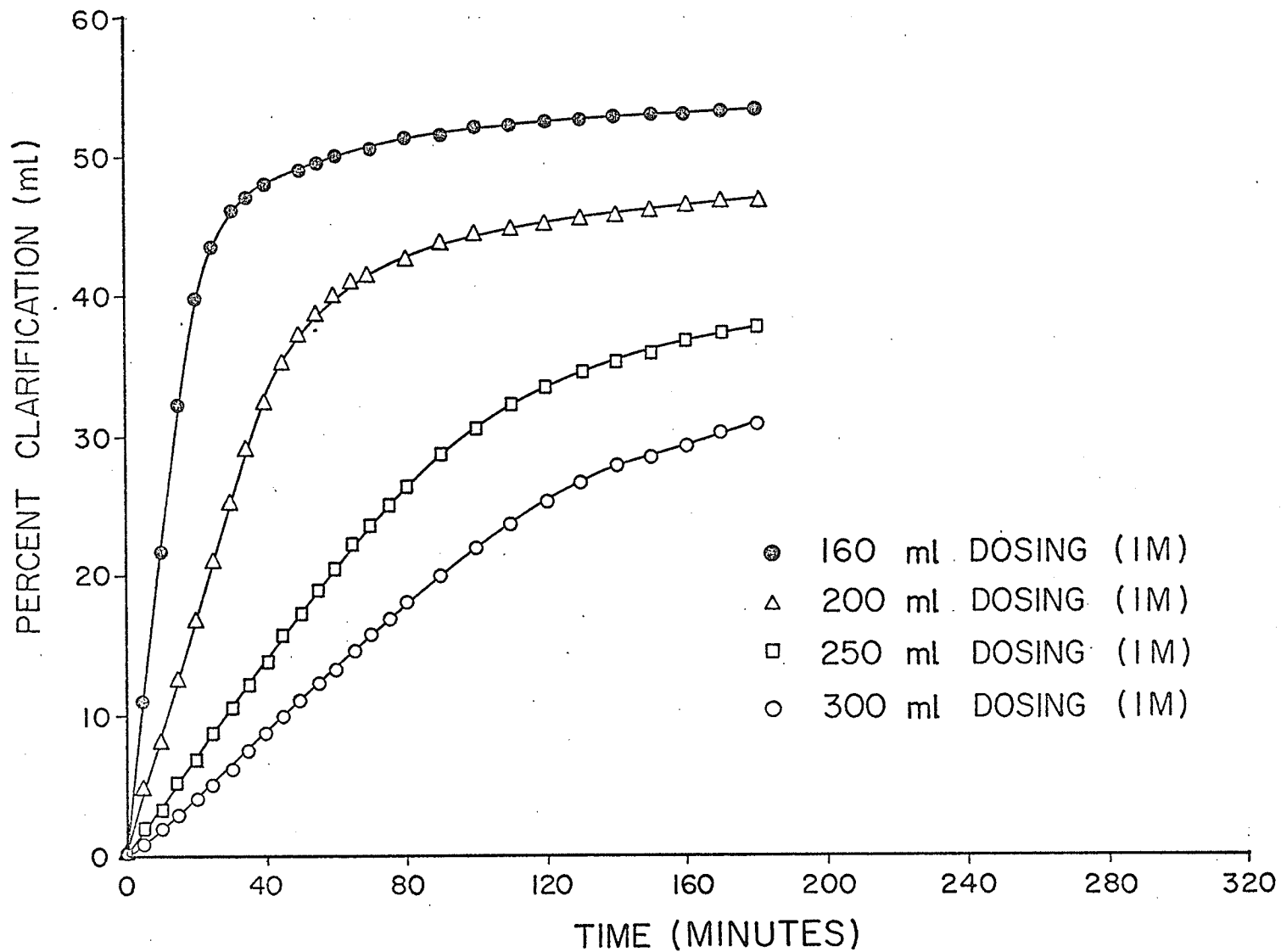
FIGURE 12 RATE OF SETTLING OF SLUDGE AT 10°C
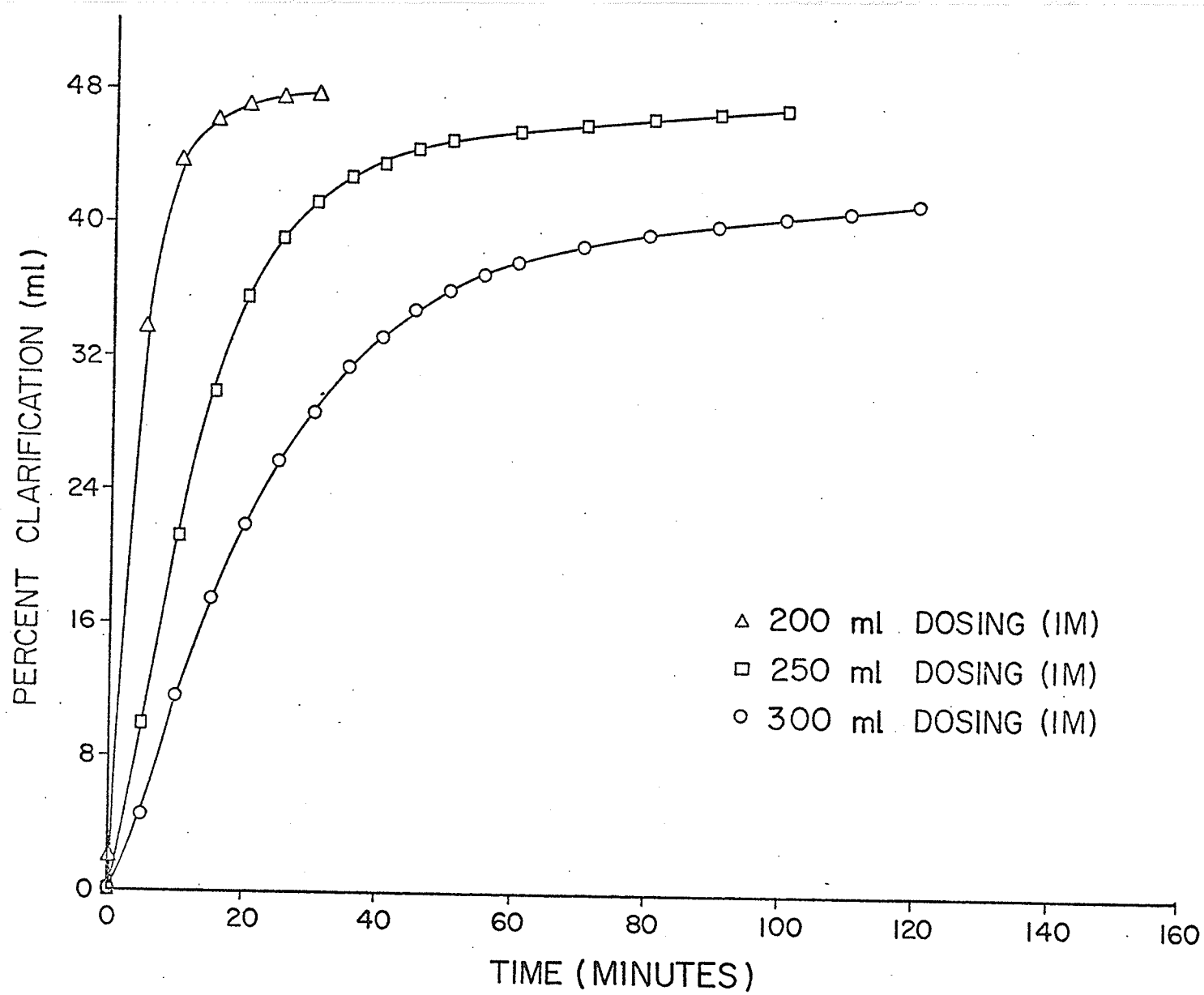
FIGURE 13 RATE OF SETTLING OF SLUDGE AT 50°C

TABLE 14

TOTAL, FIXED, VOLATILE RESIDUE AND SETTLEABLE MATTER
IN PURIFIED AND UNTREATED WASTEWATER FOR DIFFERENT
COAGULANT DOSAGES AT 10° C AND 50° C

Dose (ml)	Tempera-ture	Purified wastewater						
		Total residue g/l	% gain	Total fixed residue g/l	% gain	Total volatile residue g/l	% loss	Settleable matter mg/l
13.0	10° C	9.480	-12.29	8.912	59.71	0.568	89.13	0
14.0	10° C	10.120	- 6.37	9.556	71.25	0.564	89.21	0
15.0	10° C	10.640	- 1.55	10.100	81.00	0.540	89.67	0
13.0	50° C	10.116	- 6.40	9.220	65.23	0.896	82.86	0
14.0	50° C	10.520	- 2.66	9.776	75.20	0.744	85.77	0
15.0	50° C	11.120	+ 2.89	10.392	86.24	0.728	86.07	0
Untreated wastewater		10.808		5.580		5.228		123.0

6. PERCENT COD REDUCTIONS WITH INCREASING
    COAGULANT DOSE RATE

The dose of coagulant was increased from 147 ml (1M)
per 9,500 g. wastewater (COD = 5623 mg/l) to 300 ml (1M) and
the COD of the purified wastewater was determined. The
results are presented in Table 15.

The pH of the wastewater reached 7.0 with a dose of
147 ml and therefore sodium hydroxide was not required.
Treatments at 50° C with doses below 180 ml of one molar
solution did not coagulate satisfactorily. There were four
replicates for each treatment.

For the major part of the investigation dose rates
of 260 ml or more were used. The preliminary studies had
shown that occasionally an unexpectedly high dose rate
(260 ml or more) was required for turbidity removal. This
occurred mainly when the wastewater was stored for more
than a few days.

The object of this experiment was to determine the
effect on COD reductions if the dose rate were progres-
sively increased.

TABLE 15

PERCENT COD REDUCTIONS WITH INCREASING COAGULANT DOSE RATE

Batch size g.	Dose	Strength mol/litre	Reduction in COD %		Turbidity	
			10° C	50° C	10° C	50° C
9500	147	1.0	83.84*	–	over 100	–
9500	160	1.0	89.51	–	56.0	–
9500	180	1.0	89.92	80.90	3.0	31.0
9500	200	1.0	89.95	85.31	1.3	4.0
9500	230	1.0	90.23	85.97	1.3	1.3

*Sodium hydroxide was not required.

DISCUSSION

The rapid growth of the food processing industry has posed the problem of treating large volumes of liquid wastes. Food wastes contain a substantial proportion of organic material of high molecular weight such as polysaccharides, proteins and fats. Also, food wastes can show wide variations in pH e.g., highly alkaline lye-peel wastes from potato processing plants, or acidic wastes from plants processing citrous fruits. The BOD may be as low as 100 ppm, or as high as 100,000 ppm (47). Although there has been considerable research carried out on the treatment of potato wastes, no method of treatment has proven entirely successful and the cost of treatment of these high strength wastes prohibits the construction of plants operating unproven treatment processes (10).

It has been apparent that some method of advanced treatment must be introduced at these plants. Lye-peel waste was chosen for the present research on physicochemical treatment for two main reasons:

1. The high pH (11.0 or more) of this waste would make it relatively more difficult to treat by conventional biological treatment methods.

2. The potato is one of the major crops in many countries of the world including Canada. A major

proportion (70%) of this crop in Manitoba goes to processing plants. About 4000 gallons of water are commonly required to process one ton of potatoes and since an approximately equal volume of wastewater must be produced, purification of the latter is essential.

The major impurity present in the wastewater produced in potato processing plants is starch (a polymer of high molecular weight) which makes it very suitable for physico-chemical treatment.

It was found that a solution containing molecular proportions of ferric chloride and aluminium chloride was more effective than either of them used singly (16). A solution containing hydrated ferric chloride ($FeCl_3 \cdot 6 H_2O$) and hydrated aluminium chloride ($AlCl_3 \cdot 6 H_2O$) in molecular proportions was used as the coagulant for the present research.

Preliminary studies were carried out on the waste-water and coagulation process to determine process parameters. This permitted a reduction in the number of factors considered for the major investigation of COD reductions.

Symons (61) listed mixing as an important factor in the coagulation process. Dlouhy (21) reported that low shear action reduces breakdown of floc during coagulation. The effect of the shape of the impeller showed that a wing type impeller was the best but difficulties were encountered in finding a local supplier who could fabricate one which

was dynamically balanced. The second best was a standard screw impeller, and it was used for all the treatments in this study.

Black and Hannah (5) reported that good coagulation with aluminium sulfate was obtained over a wide pH range. Best turbidity removal occurred between pH 7.5 and pH 8.75. Symons (61) reported that the formation of hydrous oxide floc is best at certain pH values. It was found by Cansfield et al (16) that maximum COD removal was obtained at a final pH of 7.0 when using aluminium and ferric chlorides as coagulants. For alum, the range was 5.5 to 7.4 whereas for ferric salts the range was from 4.0 upwards (61).

The present study showed that adding hydrochloric acid to the coagulant solution did not decrease the coagulant demand.

Moffett and Riddick, as reviewed by Elmwood et al (24), estimated the reaction time with alum to be less than 0.1 sec. Based on the preliminary studies, a two minute reaction time was used for all the treatments.

Correlation between wastewater dilution and coagulant demand was found to be good. The coagulant demand decreased in proportion to dilution. If a correlation could be confirmed for other wastes this might provide a means of controlling coagulant dose.

For the simulated wastewater the refractive index

showed change proportional to dilution. The fact that the coagulant demand also changed directly in proportion to dilution indicated the possibility of using refractive index of the influent as a means of controlling coagulant dose. A refractive index meter, for continuously monitoring the streams is available from Pharmacia Fine Chemicals,* Canada.

The coagulation dose required for raw sewage as reported by Weber et al (66) would appear to be low when compared with high doses required for the purification of simulated lye-peel wastewater. It has been shown that the dose of coagulant required depended on the nature of the turbidity and other impurities, type and concentration of coagulants, the pH and temperature of the wastewater (41). The COD of the simulated wastewater was about 20 times more than that of raw sewage obtained from sewage treatment plant in Winnipeg.

The analysis of variance of COD reductions presented in Table 10 showed that the difference between the mean values of reduction at 10° C and 50° C was highly significant. The main effect of temperature (Table 11) showed that 91% reduction was achieved at 10° C as compared to 88% at 50° C.

The concentration of the coagulants had no significant effect on COD reductions. There would therefore be no undesirable effect if a higher concentration of coagulant were used. Actually this would be beneficial since it would

*Units are also available from other companies.

reduce the volume of added water required to operate the process.

The effect of dose of coagulant used was highly significant. Higher reductions were achieved at higher dose rates. The main effect of dose showed a COD reduction of 89%, 88.8% and 90% for 260 ml, 280 ml and 300 ml doses respectively. The reductions are very close to each other because at high levels of dose, the law of diminishing returns applies. The differences were low, but were found to be significant, indicating the high reproducibility of the treatment processes.

The mixing speed was found to be significant at the 5% level but insignificant at the 1% level. Higher COD reductions were achieved at higher mixing speed.

Interactions showed that low temperature was favoured at high concentration and high dose but the effect of temperature was independent of mixing speed. Low mixing speed was favoured at high levels of dose.

Analysis of variance results for iron content of purified water are presented in Table 12 and 13. The main effect showed that at the lower temperature the higher mixing speed and higher dose rate, the iron content was lower than for other treatments.

Interactions showed that temperature was independent of mixing speed and concentration but was highly dependent on dose level. Lower iron content was obtained for lower

temperature and high   dose levels. Mixing speed was
independent of concentration but was highly dependent on dose
levels were favoured. The effect of concentration on dose
was insignificant at the 1% level but was significant at the
5% level. Higher concentration and higher dose levels were
favoured.

The rate of settling of sludge has been used as a
measure of the effectiveness of coagulation processes. It was
reported by Culp et al (20) that the rate of settling depends
on the floc characteristics. It is possible that the floc
characteristics depend on the conditions used for coagula-
tion.

The rate of settling was found to be a function of
coagulant dose. At the higher doses, settling rate was
lower for a given temperature. Very limited work was done
on settling rates, as we expect to have a Reactor-Clarifier
and a centrifuge installed in our pilot plant for future
work.

Total, fixed, volatile residue and settleable matter
in the purified and untreated wastewater have been presented
in Table 14. Sodium from the alkaline wastewater formed
sodium chloride with chloride ions supplied by ferric and
aluminium chlorides. The salt so formed accounts for the
increased fixed residue in the purified water.

The high total residue of the purified water would
preclude its direct reuse for many food processing operations

without dilution. An additional purification step such as reverse osmosis or electrodialysis would be required to make the water potable.

The COD reductions with increasing coagulant dose rate showed that at the dose rate of 147 ml the turbidity removal is not satisfactory but COD reductions of about 83% can be achieved. This dose rate would be justifiable if activated carbon could be used to remove turbidity with further reduction in COD.

CONCLUSIONS

From this study involving the physicochemical treatment of simulated potato wastewater the following could be concluded:

1. The rate of change of pH and redox values at the minimum dose for coagulation, may provide a method for automatic control of coagulation dose.

2. The coagulant demand as shown by the titration curves with ferric chloride and aluminium chloride decreases directly in proportion to wastewater dilution.

3. The effect of adding acid to the solution of coagulants does not reduce the coagulant demand for good turbidity removal.

4. The selection of mixer is important. It should provide good mixing without causing breakdown of floc.

5. Higher COD reductions may be achieved at lower temperatures, optimum mixing speed and higher coagulant dose. Concentration of the coagulant has no effect. The minimum dose required for coagulation at 10° C is 160 ml per 9500 g. of wastewater of this type and 180 ml at 50° C.

6. The level of iron in the purified water for most of the treatments is well below the levels found in many natural waters.

7. The rate of settling of sludge is directly proportional to temperature and inversely proportional to coagulant dose.

8. Compact treatment plants for batch or continuous treatment of such wastewater are feasible.

9. Special control valves are required. The material of construction should be resistant to corrosion by ferric chloride.

SUMMARY

A pilot plant of 20 gal/h capacity was constructed for the physicochemical treatment of wastewater of a type similar to industrial potato lye-peel effluents. The standard wastewater was prepared by blending potato peels with water and flakes of sodium hydroxide. The mix was heated to 78° C and stored overnight at about 2° C.

Preweighed quantities of simulated wastewater were treated with a solution containing a mixture of ferric chloride and aluminium chloride in molar proportions. The COD, iron content and solids were determined before and after the treatment.

The effect of the following four factors on COD reduction was found to be as follows;

1. Temperature--The COD reduction at 50° C was significantly lower than at 10° C. COD reductions of about 91% were achieved at 10° C as compared to 88% at 50° C.

2. Speed of the mixer--The stirrer with two standard screw impellers was used at two speeds

(i)   400 rpm

(ii)   650 rpm

The difference in COD reduction was found to be insignificant at the 1% level but significant at the 5% level. Higher mixing speeds produced higher COD reductions.

82

3. Concentration of the coagulants--Two concentrations were used:

(a) containing one mol each of aluminium and ferric chloride per litre of solution,

(b) containing 1.74 mol each of the two coagulants per litre of solution.

No significant differences were detected between residual COD values of wastes purified by the two solutions when used in equivalent volumes.

4. Coagulant dose--Three dosage rates, 260 ml, 280 ml and 300 ml of solution (a) (or the equivalent volumes of solution (b)) were used for coagulation. The best results were obtained with the highest dose rates.

Iron content of the purified water was less than 0.3 mg/l for all the runs at the higher stirring speed. At the lower speed it rose to a maximum of 0.56 mg/l, probably because of incomplete mixing.

Fixed residue of the purified water varied from 8.9 g/l to 10.4 g/l depending on the treatment conditions. The fixed residue of untreated wastewater was 5.6 g/l. Volatile residue of the wastewater was 5.2 g/l and decreased to 0.67 g/l after treatment.

The rate of settling of sludge was found to be slowest at the lower temperature and higher chemical dosage. The shape of the impeller also affected the rate of settling.

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APPENDICES

ENGINEERING SPECIFICATION OF MAJOR PILOT
PLANT ITEMS OF EQUIPMENT

Item   Mixer
Make   Lightnin Mixer
Model   10   Ser. No. 8615237

Services   Phase 1   HP   Volt   A   rpm
            Cycles 60-50   1/15   115   2.4   1550

            THERMAL PROTECTION

Shaft   3/8"   /   316   S.S./ 24"

Similar Units Ser. No. 860128   960367
                       860132   861107

Item   Heater
Make   Chromalox
Model   KTLS - 390

Services   Volt   Watts   Phase
             240   9 KW   1

Thermostat AR-2519 60° F to 275° F
            Thermostat D.P.S.T.   125   VAC, 35A/
                                   250   VAC, 25A
            Pilot Duty 125 VAC   125/250 VAC

Item   Mixer
Make   Lightnin Mixer / Type C-3624-A
            NC-4 / Motor Model No.
                / MXT - M56C - VBX-AH-CZ

Services   Phase 1   Volts   A   HP   rpm
            Cycles 60   115/230   4.6/2.3   ¼   1725

Rating   Continuous

Shaft   ½" / 316 S.S./ 40"

Item	Pump
Make	Westinghouse Frame 145
Model	¼ RH Induction Motor Type FJ
Services	Phase 1 Volt 110 rpm 1725
	Cycles 60 A 3.9
Material	White Metal
Pump	Motor mounted--centrifugal
Conn.	Pump Inlet 1½"
	Outlet 1½"
Ser. No.	V 47594 EU

Item	Pressure Switch
Make	Honeywell
Model	L 405 A 1009
Range	0-16 oz.

Item	I/P Transducer
Make	Honeywell
Model	Electric Tel-o-set I/P Transducer
Input	4-20 mA DC
Output	3-15 psi
Accuracy	± ¼% of Span
Speed of	0.5 sec. for 98% response to a 50% step
Response	change in input with output dead-ended.
Internal input Resistance	400 Ohms (Approx.)
Air Supply	20 psi ± 2 psi (Filtered)
Air Consumption (Static)	Less than 0.35 SCFM (Standard cubic feed per minute)
External Connections	Two ¼ " NPT Female connections for output and pneumatic supply lines. See dimension drawings for location.
Adjustments	Fine and coarse span adjustments
Ambient Temperature Range	Weather-proof and explosion-proof: -40° F to 150° F.
	Relay Rack: 40° F to 150° F
Humidity Range	10 to 90% RH

Item	Recorder controller
Make	Honeywell
Model	Currentronik

Chart Width	4 inches

Pen Speed	4 seconds full scale

Line Voltage Requirements — Nominal 115 VAC, Min. 107, Max. 127 VAC, 50/60 cycles. If regulation is necessary to hold these limits, it must be sinusoidal.

Input
Process variable: 4 to 20 mA DC
Set Point: 4 to 20 mA DC
Control Unit: 0 to ± 4 V   3/4 inch per min.

Chart speeds indicating accuracy — ± 0.5 per cent of full scale

Controller Output — 4 to 20 mA DC, into an external load of 600 Ohms

Environmental Limits
Ambient temperature: + 32 to 122° F
Humidity: 10 to 85 per cent RH

Power Consumption — 30 Volt-amperes

Proportional Band Adjustment — 10 to 600% (for flow)

Reset Rate — 1 to 100 repeats/min. (for flow)

Direct-reverse Action — Obtained by reversing the position of a connector.

Item	V/I Transducer
Make	RIS (Rochester Instrument Systems of Canada Limited)
Model	SC - 304 Millivolt Transmitter

Input — -50 to 0 to +50 mV (Zero Centre)

Output — 4 to 20 mA (0-2000 Ohm allowable load variation)

Temperature — 0° to 140° F.

Response Time   Less than 10 milliseconds

Repeatability   ± 0.1% of span

Stability and   ± 0.02% 1° F for an ambient range of 32° to
Drift (at an   ± 20° F maximum: ± 0.01%/$^\circ$ F typical
input span of
100 mV)

Power   117 VAC ± 10%, 60 HZ, 12 watts
Requirements

Line Voltage   ± 0.5% of span maximum ± 0.2% typical at an
Effect   input span of 100 mV

Calibrated   ± 0.1% of full scale
Accuracy

Item   pH Indicator Controller
Make   Radiometer
Model   PHM 28

Range   0 to 14 pH units, -800 to +1600 mV

Temperature   Calibrated in 5° C divisions from 0 to 100° C
                 Accuracy of calibration: ± 3° C

Electrical   8.0 pH
Zero

Output   10 mV/pH and 100 mV/100 mV

Power   115 V ± 15%   50/60 HZ, 0.02 A
Requirements

Repeatability   ± 0.01 pH, ± 1 mV

Relative   ± (0.03 pH + 0.5% of distance from buffer
Accuracy   point) and ± (3 mV + 0.5% of reading)

Amplifier   Less than 0.002 pH/day, noncumulative
Drift   Less than 0.00/pH/$^\circ$ C
                 Less than 0.1 mV/day, noncumulative
                 Less than 0.05 mV/$^\circ$ C

Input   Greater than 10^{13} Ohm
Impedence

Item	Control valve motor
Make	Honeywell
Model	Grad-V-Motor MP 903 A & B
Input	2-15 psi Air pressure
Stroke	3 3/4"

FEED TANK

G.VALVES

3/4"

3/4"

1/2"

CENTRIFUGAL
PUMP

SAND   CARBON   RESIN
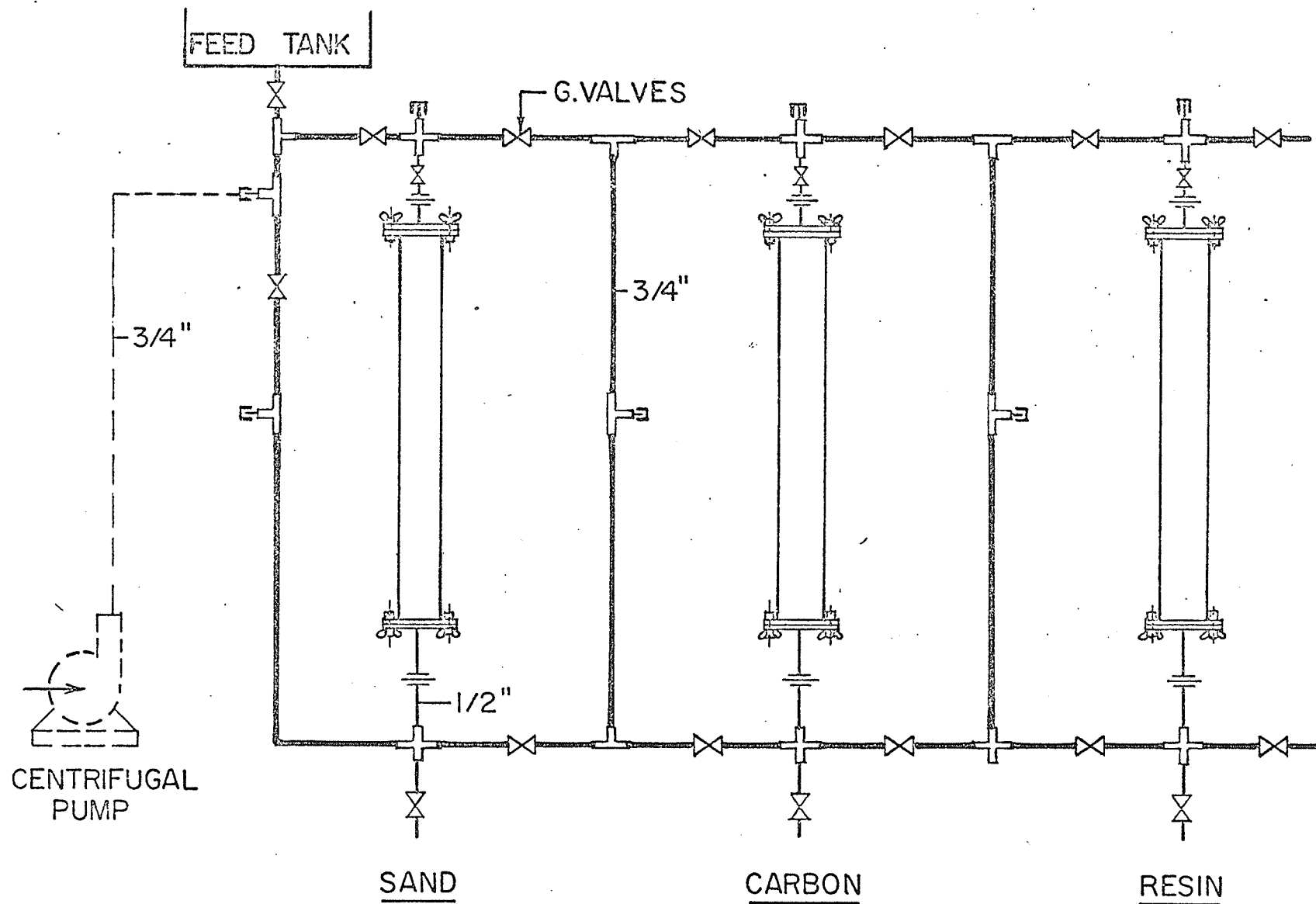
SCHEMATIC : ADSORPTION COLUMNS

DESIGN FEATURES OF ADSORPTION COLUMNS

The column gate valves and monitoring parts have
been arranged in such a way that either chemically clarified
or untreated primary effluent can be fed to any one or more
of the columns, depending on the test conditions desired.
Some of the features are:

1. Columns can be fed from top or bottom.

2. The feed can be under gravity or pressure.

3. Columns can be used in series or parallel.

4. Back-washing can be easily accomplished.

5. Provision has been made for monitoring of
streams and collection of samples.

6. Additional columns can be readily added.

7. All plastic construction makes it suitable for
most effluents.

8. Columns can be by-passed.

9. Conical filters provide large filtering area.

10. Clear transparent acrylic columns can provide
visual inspection.

11. Couplings at both ends providing easy loading
and unloading.

APPENDIX II

TABULATED DATA FOR GRAPHS PRESENTED IN THE TEXT

TABULATED DATA FOR FIGURE 7
CALIBRATION CURVE FOR IRON

µg. Iron	O.D.
10.0	0.050
20.0	0.075
50.0	0.110
100.0	0.235
150.0	0.340
200.0	0.440
250.0	0.535
300.0	0.635
350.0	0.740
400.0	0.820

TABULATED DATA FOR FIGURE 8
THE EFFECT OF THE SHAPE OF IMPELLER ON
THE SETTLING RATE OF SLUDGE

Time (minutes)	Percent Clarification (ml)
(i) Standard Screw Impeller	
1	2.0
2	3.0
3	4.0
4	6.0
5	7.0
6	8.5
7	10.0
8	11.0
9	12.5
10	13.0
(ii) Wing Impeller	
1	2.0
2	5.0
3	8.5
4	13.0
5	20.0
6	25.0
(iii) Paddle of Circular Cross-section	
1	0.5
2	1.5

Time (minutes)	Percent clarification (ml)
3	2.0
4	2.5
5	3.0
6	4.0
7	5.0
8	6.0
9	8.0
10	9.0

TABULATED DATA FOR FIGURE 9
CHANGE IN pH OF WASTEWATER WITH
INCREASING COAGULANT DOSE

ml	pH
Temperature 50° C	
0.0	11.10
10.0	11.10
20.0	11.10
40.0	11.00
60.0	10.80
80.0	10.20
100.0	9.10
120.0	8.05
140.0	6.20
150.0	5.15
160.0	4.40
180.0	4.00
200.0	3.80
220.0	3.70
240.0	3.60
260.0	3.50
280.0	3.35
300.0	3.25
Temperature 10° C	
0.0	12.30
10.0	12.30

ml	pH
20.0	12.30
30.0	12.30
40.0	12.20
60.0	12.00
80.0	11.20
100.0	10.20
120.0	9.20
130.0	7.70
140.0	6.80
160.0	5.35
180.0	4.80
200.0	4.45
220.0	4.20
240.0	4.05
260.0	4.00
280.0	3.90
300.0	3.85

TABULATED DATA FOR FIGURE 10
CHANGE IN REDOX VALUES WITH INCREASING
COAGULANT DOSE AT 50° C

ml	mV
0.0	-140.0
10.0	-140.0
20.0	-140.0
30.0	-135.0
40.0	-130.0
50.0	-120.0
60.0	-100.0
70.0	- 80.0
80.0	- 50.0
90.0	- 20.0
100.0	10.0
110.0	30.0
120.0	70.0
140.0	170.0
150.0	230.0
160.0	340.0
170.0	400.0
180.0	420.0
190.0	440.0
200.0	440.0
210.0	460.0
220.0	460.0
230.0	470.0
240.0	475.0
250.0	480.0
260.0	485.0
270.0	490.0
280.0	510.0
290.0	520.0
300.0	530.0

TABULATED DATA FOR FIGURE 11
CHANGE IN REDOX VALUES OF WASTEWATER WITH
INCREASING COAGULANT DOSE AT 10° C

ml	mV
0.0	-130.0
20.0	-125.0
30.0	-120.0
40.0	-115.0
50.0	-110.0
60.0	- 95.0
70.0	- 75.0
80.0	- 30.0
90.0	20.0
100.0	40.0
110.0	60.0
120.0	90.0
130.0	170.0
140.0	230.0
150.0	280.0
160.0	350.0
180.0	420.0
190.0	450.0
200.0	470.0
220.0	500.0
240.0	510.0
260.0	510.0
280.0	515.0
300.0	520.0

TABULATED DATA FOR FIGURE 12
RATE OF SETTLING OF SLUDGE AT 10° C

Time (minutes)	Percent clarification (ml)
Dose 160 ml	
0.0	0.0
5.0	11.0
10.0	21.7
15.0	32.0
20.0	39.7
25.0	43.5
30.0	46.0
35.0	47.0
40.0	48.0
50.0	49.0
55.0	49.3
60.0	49.8
70.0	50.5
80.0	51.2
90.0	51.5
100.0	52.0
110.0	52.2
120.0	52.5
130.0	52.5
140.0	52.7
150.0	52.8
160.0	53.0
170.0	53.2
180.0	53.3
Dose 200 ml	
0.0	0.0
5.0	4.5
10.0	8.0
15.0	12.5

Time (minutes)	Percent clarification (ml)
20.0	16.5
25.0	21.0
30.0	25.0
35.0	28.8
40.0	32.0
45.0	35.0
50.0	37.0
55.0	38.5
60.0	39.7
65.0	40.8
70.0	41.5
80.0	42.5
90.0	43.5
100.0	44.2
110.0	44.7
120.0	45.0
130.0	45.5
140.0	45.7
150.0	46.0
160.0	46.3
170.0	46.5
180.0	46.7

Dose 250 ml

0.0	0.0
5.0	1.9
10.0	3.2
15.0	5.0
20.0	6.8
25.0	8.6
30.0	10.5
35.0	12.3

Time (minutes)	Percent clarification (ml)
40.0	13.8
45.0	15.6
50.0	17.2
55.0	18.8
60.0	20.5
65.0	22.1
70.0	23.5
75.0	25.0
80.0	26.2
90.0	28.5
100.0	30.5
110.0	32.1
120.0	33.3
130.0	34.5
140.0	35.2
150.0	35.9
160.0	36.8
170.0	37.2
180.0	37.7

Dose 300 ml

0.0	0.0
5.0	0.8
10.0	1.8
15.0	2.8
20.0	4.0
25.0	5.1
30.0	6.2
35.0	7.5
40.0	8.8
45.0	9.9
50.0	11.1

Time (minutes)	Percent clarification (ml)
55.0	12.2
60.0	13.3
65.0	14.6
70.0	15.7
75.0	16.8
80.0	18.0
90.0	19.8
100.0	21.8
110.0	23.5
120.0	25.2
130.0	26.5
140.0	27.7
150.0	28.5
160.0	29.2
170.0	30.0
180.0	30.7

TABULATED DATA FOR FIGURE 13
RATE OF SETTLING OF SLUDGE AT 50° C

Time (minutes)	Percent clarification (ml)
Dose 200 ml	
0.0	2.0
5.0	33.5
10.0	43.5
15.0	46.0
20.0	47.0
25.0	47.5
30.0	47.7
Dose 250 ml	
0.0	0.0
5.0	10.0
10.0	21.2
15.0	29.7
20.0	35.5
25.0	39.0
30.0	41.2
35.0	42.7
40.0	43.7
45.0	44.5
50.0	45.0
60.0	45.7
70.0	46.0
80.0	46.5
90.0	46.7
100.0	47.0

Time (minutes)	Percent clarification (ml)
Dose 300 ml	
0.0	0.0
5.0	4.6
10.0	11.6
15.0	17.5
20.0	21.8
25.0	25.7
30.0	28.7
35.0	31.3
40.0	33.2
45.0	34.8
50.0	36.0
55.0	37.0
60.0	37.7
70.0	38.7
80.0	39.5
90.0	40.0
100.0	40.5
110.0	41.0
120.0	41.5

APPENDIX III

MEAN VALUES OF IRON CONTENT IN PURIFIED WATER

Factors	Levels		Mean values
			Overall mean value 0.20
TMP	1		0.17
	2		0.22
MSP	1		0.23
	2		0.16
TMP MSP	1	1	0.21
	1	2	0.14
	2	1	0.25
	2	2	0.19
CNC	1		0.19
	2		0.20
TMP CNC	1	1	0.16
	1	2	0.19
	2	1	0.22
	2	2	0.22
MSP CNC	1	1	0.21
	1	2	0.25
	2	1	0.17
	2	2	0.16

Factors	Levels			Mean Values
TMP MSP CNC	1	1	1	0.17
	1	1	2	0.25
	1	2	1	0.14
	1	2	2	0.13
	2	1	1	0.24
	2	1	2	0.26
	2	2	1	0.20
	2	2	2	0.18
DOS	1			0.25
	2			0.18
	3			0.16
TMP DOS	1	1		0.19
	1	2		0.19
	1	3		0.13
	2	1		0.31
	2	2		0.17
	2	3		0.18
MSP DOS	1	1		0.30
	1	2		0.17
	1	3		0.22
	2	1		0.20
	2	2		0.19
	2	3		0.10
TMP MSP DOS	1	1	1	0.23
	1	1	2	0.24
	1	1	3	0.15

Factors	Levels			Mean values
TMP MSP DOS	1	2	1	0.15
	1	2	2	0.14
	1	2	3	0.12
	2	1	1	0.38
	2	1	2	0.09
	2	1	3	0.28
	2	2	1	0.25
	2	2	2	0.24
	2	2	3	0.08
CNC DOS	1	1		0.21
	1	2		0.18
	1	3		0.17
	2	1		0.29
	2	2		0.17
	2	3		0.14
TMP CNC DOS	1	1	1	0.19
	1	1	2	0.17
	1	1	3	0.12
	1	2	1	0.20
	1	2	2	0.22
	1	2	3	0.14
	2	1	1	0.23
	2	1	2	0.21
	2	1	3	0.22
	2	2	1	0.39
	2	2	2	0.12
	2	2	3	0.15
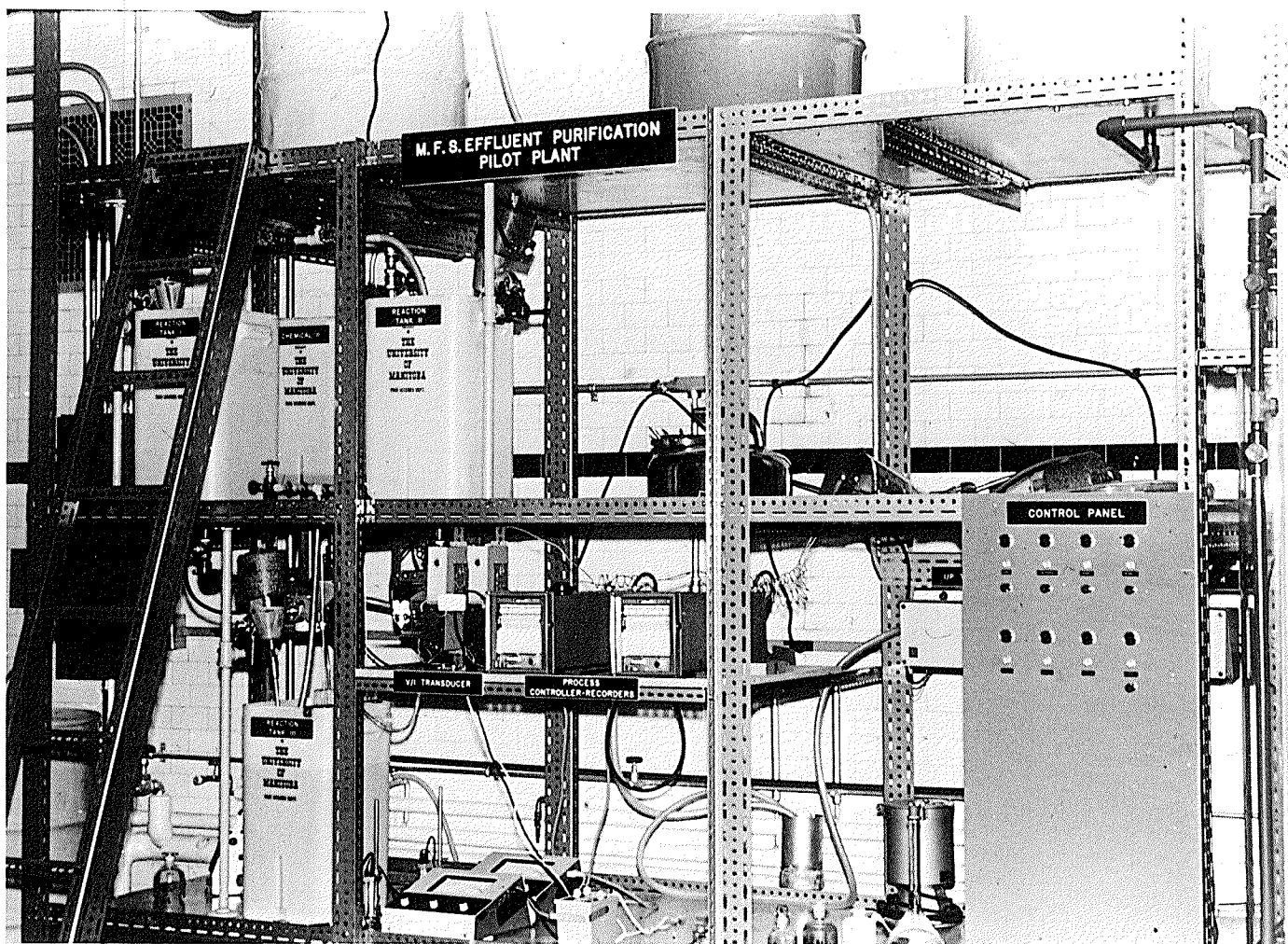
A PHOTOGRAPH OF THE PILOT PLANT