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Arkansas Water Resources Research Center
University of Arkansas
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ABSTRACT

FACTORS AFFECTING THE REMOVAL OF SUSPENDED AND DISSOLVED SOLIDS IN HIGH STRENGTH WASTEWATER FROM VEGETABLE PROCESSING

Fifty or more individual factorial experiments were designed to study the effectiveness of physical-chemical and micro-biological treatments in removal of suspended and dissolved solids in effluent from potatoes, hominy, dry beans and other vegetables. The wastewaters were obtained from local processing plants and treated with 3 to 5 inorganic salts, 13 polymers, and 3 or more pH levels during 12 months. Also, selected strains of yeast and fungi were used to assimilate the effluent. Individual inorganic salts were more effective on a certain vegetable effluent than others. Polymers (anionic and cationic) were more effective in coagulating suspended solids in combination with salts than either alone. Different polymers and concentrations of polymers in combination with salts were required for each effluent tested. *Saccharonyces fibuliger* was the most effective yeast for reducing total solids and chemical oxygen demand in potatoes. Actively fermenting systems were capable of 90% or more reduction after centrifugation. The fungi *Neurospora sitophila* and *Trichoderma viride* assimilated the total and dissolved solids more rapidly in effluents from potato and hominy processing than any of the other fungi studied.

Sistrunk, William A.

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KEYWORDS-suspended solids/dissolved solids/total dissolved solids/effluent/wastewater/wastewater strength/treatment systems/physical-chemical/turbidity/polymers/inorganic salts/flocculating agents/coagulating

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INTRODUCTION

The Ozark region is one of the major processing regions in the U.S. These industries discharge large volumes of effluent characterized by high Chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total suspended solids (TSS) and various inorganic constituents. The 12 vegetable processing plants in the region operate throughout the year in producing a wide variety of vegetable products, and discharge 5 to 10 million gallons (19 to 38 million liters) of wastewater daily. Nine of these plants discharge effluent into municipal systems after screening. Other food processing plants in the region discharge an additional 20 million or more gallons (76 million liters) of treatable wastewater daily.

The expansion of volume of processed products, diversification of products, increase in population and increasing costs of building adequate municipal waste treatment facilities in the region make it mandatory that primary and/or secondary treatment be applied to the effluent from the processing plants.

Lye, abrasive and steam-peeling wastes from potatoes, sweet potatoes, beets, carrots and corn are extremely high in COD. These products require large volumes of water to wash, peel, clean, flume and blanch during the processing operation. Much progress has been made in the region in altering processing methodology to reduce water usage and strength of the effluent, but more progress is needed in applying physical-chemical and biological methods to further reduce TSS and total dissolved solids (TDS).

A. Purpose and Objectives

1. To develop a broad set of data on inorganic salts and/or organic polymers that provide optimum reduction in TSS and floc size.
2. To establish the optimum pH, waste concentration, aeration and temperature for maximum separation of TSS.
3. To determine the types of microorganisms and optimum conditions for reduction of TDS in the residual wastewater.

B. Related Research or Activities

Plain sedimentation is the most common primary treatment used to remove suspended or settleable solids from fruit and vegetable processing effluent after screening (44). Separation or settling of solids from the effluent can be accomplished in settling basins or tanks prior to discharge of effluent to other treatment systems. In potato processing plants plain sedimentation can remove 41 to 71% of the BOD and 73 to 93% of the TSS (17,28). A limiting factor is the efficiency of sedimentation or fine screening. High strength effluent from processing potatoes, sweet potatoes, pickles, poultry and other types of processing and industrial wastes has been treated by primary treatment to remove TSS by screening, filtration, centrifugation and other methods (3, 5, 6, 7, 8, 16, 19, 20, 21, 27, 33, 51, 52, 53). Effluent from processing poultry was treated with inorganic flocculants after screening, then filtered and reused in the operation (16, 53). By the use of appropriate levels of polymeric flocculating agents and inorganic salts, TSS and turbidity of pimiento wastes were reduced by 74 to 95%, and COD by 8 to 19%. Bough (7, 8) successfully removed most of the TSS in effluent from leafy greens by the use of inorganic salts and chitosan. Source of effluent and type of greens influenced the levels of chemicals required.

Chemical coagulation normally involves the process of destabilization, aggregation and binding together of colloids by flocculants such as $CA(OH)_2$, $Al_2(SO_4)_3$, $FeSo_4$ and $FeCl_3$ to coagulate TSS (2, 35,39, 45). Ismail (33) demonstrated that $FeCl_3$ was the most effective for coagulation of citrus wastewater, inducing greater than 90% reduction in turbidity (NTU) and mg/l TSS. Eldridge (23) reported that 33 to 75% of BOD could be removed from effluents from beets, tomatoes, peas, corn and kraut by treatment with 700 to 2520 mg/l of $CA(OH)_2$, $Al_2(SO_4)_3$, $FeSo_4$ and $FeCl_3$

Both inorganic salts and organic polymers have been applied to wastewaters from different food processing sources. Lamer and Healy (38) described the action of polymeric flocculuting agents whereby the polymer destabilizes a colloidal suspension by adsorption of particles and subsequent formation of particle-polymer-particle bridges by both cationic and anionic polyelectrolytes, depending on the electrical charge of the wastewater. The organic cationic polymer chitosan has been shown to be effective for coagulation of TSS in certain food processing wastes such as poultry egg, meat, shrimp, cheese and vegetables(7, 8, 9, 10, 11, 54). Other polyelectrolytes were effective in treatment of vegetable wastes for reducing TSS at low concentrations of 10 to 100 mg/l (6, 10). Studies on pickle brines showed that the addition of 6 mg/l of anionic polyelectrolyte to the spent curing and pickling brines formed large floc and removed up to 100% of TSS (26, 27).

The long soaking times commonly used for dry beans for processing generates approximately 3 times as much COD in effluent as shorter soaking times (46, 49). Also, bean types and style of canned pack have a significant effect on TSS and COD of the effluent.

Pure strains of microorganisms have been utilized for reducing the COD in wastewater from potato wastes (34, 40, 41, 43). Some of these microorganisms produce high concentration of amylolytic enzymes that hydrolyze starchy water from many vegetable products (18). The resulting sugars can be rapidly converted to alcohol by yeasts or single-cell protein. The conversion of dissolved solids into useful by products is attractive since disposal costs are alleviated and a financial return from the sale of these products could offset the cost of effluent treatment.

Bough et al. (12) have estimated that 322 million lb (146.4 million kg) of dried activated sludge per year with a protein content of 28 to 36% could be produced from food processing and brewery wastes. The BOD of potato processing effluent was reduced by as much as 90% by the use of a yeast fermentation step before treatment in which the yeast cells were recovered (40, 41, 50). Sweet potato effluent was treated by Skogman (50) with a symbiotic culture of *Endomycopsis fibuliger* (*E. fibuliger*) and *Candida utilis* (*C. utilis*). The lactic acid in sauerkraut effluent was treated successfully by a flocculant strain of *Kluyveromyces fragilis* (*K. fragilis*) yeast in which the lactic acid was reduced 95 to 97% in 4 hours and 99% of the yeast cells settled in 1 hour (32). Yeast cells containing 45% protein and rich in B vitamins were produced from sauerkraut brine by *C. utilis* (30). The use of *C. utilis* and *K. fragilis* for the treatment of lemonade processing effluent produced cell yields of 2.5 g/l in 32 hours and reduced approximately 87% of BOD when 0.05% $(NH_4)_2\ SO_4$ and 0.01% K_2PO_4 were added to the effluent (29).

One means of reducing the organic load of wastes to streams and municipal treatment systems is by the use of Fungi Imperfecti in a continuous oxidation system. Church et al. (14) showed that the fungus Trichoderma viride reduced the COD of corn and pea canning wastes by 95% in an aerated lagoon and an oxidation ditch. In addition to reducing COD of corn whey by 98%, 50 to 60 g of dry fungal biomass was produced per 100 g of COD utilized.

Neurospora sitophila (N. sitophila) NRRL 2884 has been shown to ferment alkaline rutabaga and potato wastes after pH adjustment 5.6 (4). There was a decrease in COD of 42 to 68% in 4 days with a four fold increase in total amino acids of the biomass recovered.

Aspergillus foetidus (A. foetidus) NRRL 337 has been used effectively for assimulating baked bean effluent (31). In 24 hours at pH 3.3, the fungus utilized 80% of the BOD and produced a biomass that was 50% protein on a dry basis.

Most fruit and vegetable wastes are low in nitrogen and phosphorus, and therefore require the addition of these nutrients in biological oxidation systems. Esvelt and Hart (24) suggested a COD/nitrogen/phosphorus ratio of 100/4-5/0.5-1.0 for nutrient supplementation to attain optimum utilization of COD. In addition to nutrients, air or oxygen at a rate to supply 0.8 mg/l to 4 mg/l of dissolved oxygen was supplied.

METHODS AND PROCEDURES

Effluent samples

Composite samples of vegetable processing wastewater including effluent from canning abrasive-peeled, steam-peeled and lye-peeled potatoes, pork and beans, pinto beans,hominy, green beans, sweet potatoes and leafy greens were collected from Allen Canning Co. at Alma, Johnson, Siloam Springs, Springdale and Van Buren, Arkansas. The samples were stored in a cold room at $2^{o}C \pm 2^{o}$ and used within 1 week. Samples of fresh wastewater were taken repetitively throughout the year during the periods for processing individual vegetables.

Physical-chemical treatment of the wastewater

The experiments to determine the optimum physical-chemical treatment for removing TSS and developing large floc were designed as factorial experiments as follows: 3 to 4 pH levels (5, 7, 9, 11.3); 3 to 5 inorganic salts, Alum ($Al_2(SO_4)_3$, ferric chloride ($FeCl_3.6H_2O$), ferric sulfate ($Fe_2(SO_4)_3$, ferrous sulphate ($FeSO_4$), and calcium chloride ($CACl_2$); and 7 concentrations (0, 100, 200, 300, 400, 500 and 1000 mg/l). In the inorganic salt plus polymer combinations only the most effective salt for the individual effluent was tested with 12 polymers, nonionic polymer Hercofloc 827, Anionic polymers purifloc #23, Hercofloc 1031 and 1018, Cationic polymers, Magnifloc 2535 CH and 2540C, Dubois GWP-25, Nalco 7120 and 7122, and Varcofloc, and Purifloc #43 and Chitosan; 7 concentrations of polymer (0, 5, 10, 20, 40, 60 and 80 mg/l);and 6 concentrations of salt (0, 100, 150, 200, 250 and 300 mg/l).

The pH 11.3 was used only for the effluent from lye-peeled potatoes and corn for hominy. The appropriate dosages of inorganic salts and polymers were added to 100 to 200 ml of the effluent after pH adjustment with NAOH or H_2SO_4 in a 150 or 250 ml beaker. The mixtures were stirred for 3 minutes at approximately 100 rpm at room temperature (25^oc) using a 6-position stirrer. The contents of the beaker were allowed to settle for 30 minutes before samples of the supernatant were withdrawn for turbidity measurement by using a nephelometer as described by the procedure in standard methods. Turbidity values which are indicative of the suspended solids were expressed as nephelometric units (NTU). The nephelometer measures the amount of light scattered at a 90^o angle to the beam, and values are proportional to suspended particulate matter in wastewater. The sequence of adding inorganic salts, cationic polymers and anionic polymers to the effluent during agitation were the same as those described earlier (10,22).

After the optimum conditions were found for each wastewater as indicated by low NTU values and larger floc, separate experiments were designed to measure NTU, TSS, and COD of the supernatant. Not all salts and polymers were used on each wastewater because of the composition and source of the water in the processing plant. However, in every instance the optimum conditions were attained for removing TSS and decreasing COD.

Microbiological methods of wastewater treatment

Organisms: The yeast *S. fibuliger* ATCC 9947 and the fungus *Aspergillus oryzae* (*A. oryzae*) ATCC 9362 were obtained from American Type Culture Collection, Parklawn Drive, Rockville, MD. The yeast culture *C. utilis* IFO-1086 was obtained from the Biomass, Research Center, University of Arkansas, Fayetteville. The yeast cultures *K. fragilis* NRRL-Y1109 and NRRL-Y2415 and the fungi *A. foetidus* NRRL-337, *Neurospora sitophila* (*N. sitophila*) NRRL-2884, *A. oryzae* NRRL-697, *A. oryzae* NRRL-1808, *A. oryzae* NRRL-9362, *Gliocladium deliquescens* (*G. deliquescens*) NRRL-1806, *Trichoderma viride* (*T. viride*) NRRL-6418 and *T. reesei* QM-9414 were obtained from the Northern Regional Research Laboratory, Peoria, IL. and the Biomass Research Center, University of Arkansas, Fayetteville.

The yeast cultures were inoculated on dextrose agar and yeast extract-peptone glucose (YEPG) and fungi cultures on potato dextrose agar (PDA) incubated at 30°c until the organisms were growing actively, then held at 2°c until the experiments were conducted. Further details of the preparation of cultures are described in detail in other reports (36, 37).

Fermentation studies

The yeast cells were harvested from actively growing cultures in YEPG medium aseptically by centrifugation at 4000 rpm for 10 minutes, then resuspended in 0.85% saline solution. A 3%

suspension (v/v) was used as an inoculum in the wastewater. Details on the size of sample, aeration, time of incubation, etc. have been described (36).

The fungi were grown on 100 ml aliquots of wastewater in 300 ml round-bottom flasks which was adjusted to the optimum pH of each culture by 0.1NHCl. The wastewater was then inoculated with spores of fungi from the PDA plates. Flasks were placed on a mechanical shaker (180 rpm) and incubated at 28°c for 24 to 48 hours or until sufficient active mycelium was produced in each flask of each organism. The actively growing myceliam were then used as stock cultures for further inoculation in the factorial experiments. Details of individual fermentation experiments have been described (36, 37). Fungal mycelia were harvested by screening and filtering, and recorded as mg/l of fermentation liquid (13). Protein content of dried yeast cells and fungal mycelia was determined by the procedure described in standard methods (1).

Total suspended solids (TSS), total solids (TS),total dissolved solids (DS), total phosphorus, and turbidity were determined by the methods described in standard methods for the examination of water and wastewater (1). COD was measured by the method of Mercer and Rose (42). The data were analyzed as factorials by the analysis of variance by the Statistical Analysis System (SAS) of the University of Arkansas Computing Center.

Means of the main effects were separated by Duncan's Multiple Range Test, and means of interactive effects by the Least Significant Difference at the 5% level.

PRINCIPAL FINDINGS AND THEIR SIGNIFICANCE

Physical-chemical Treatment of Vegetable Processing Wastewater

1. The reduction in turbidity expressed as nephelometric turbidity units (NTU) of effluent from abrasive-peeled potatoes at pH 5 was greater with $FeCl_3$ and $Fe_2(SO_4)_3$ than with $CACl_2$ and $Al_2(SO_4)_3$ (Fig. 1). The NTU values were reduced from 200 to 12 and 8 with 300 and 400 mg/l, respectively. This represented a turbidity reduction of 94 and 96% for the two inorganic salts. Other workers have used NTU measurements as a means of analyzing TSS and COD in wastewater (5, 10). Sedimentation alone without added chemicals reduced NTU values approximately 25% but the TSS were not flocculated (Fig. 1).

In abrasive-peeled potato wastewater adjusted to pH 7 and 9, $FeCl_3$ resulted in the greatest reduction in NTU values as compared to the other salts. Calcium chloride was more effective in reducing NTU at pH 7 and 9 than at 5, and results were similar to $Al_2(SO_4)_3$ and $Fe_2(SO_4)_3$.

Eleven polymers were used singly to determine the ones that were most effective in reducing NTU of abrasive-peeled potato effluent at pH 5 (Table 1). Varcofloc was the least effective, while GWP-25 and PA #23 were the most effective in reducing turbidity. A concentration of 40 mg/l of polymer reduced NTU more than the other levels (Table 2). Also, 300 mg/l of $FeCl_3$ was the optimum concentration for reducing turbidity.

When the most effective polymer was combined with $FeCl_3$ at different concentrations, the optimum treatment for effluent from abrasive-peeled potatoes was 150 mg/l of $FeCl_3$ amd 20 mg/l of PA #23 polymer in which the NTU was reduced from 170 to 4 (Table 3). The TSS was coagulated immediately into large floc that settled rapidly, and was removed by screening through an 80-mesh screen.

Since effluent from abrasive-peeled potatoes contains peel residue, soluble sugars, organic acids and non-gelatinized starch, most of the COD was removed along with TSS. Similar results were obtained at the other pH levels tested although the reductions of COD and TSS were significantly greater at pH 5.

2. Effluent from steam-peeled potatoes, characterized by peel residue and gelatinized starch, was much higher in TSS and COD. $CaCl_2$ was superior to the other inorganic salts in coagulation-flocculation of TSS of the effluent at pH 5 as measured by NTU (Fig. 2). Concentrations of 400 and 500 mg/l of $CaCl_2$ reduced NTU from 960 to 70 and 60, respectively. Similar results were obtained at pH 7 and 9 in that turbidity was decreased significantly as the concentration of salt was increased up to a concentration of 500 mg/l.

The polymers N-7122 and PA #23 were the most effective among the polymers in reducing TSS at all pH levels, as measured by NTU (Table 4). In combinations of $CaCl_2$, the most effective inorganic salt, with polymers concentrations of 350 mg/l of $CaCl_2$ + 35 mg/l of polymer resulted in a maximum decrease in NTU at pH 5. Similar reductions in TSS were achieved at pH 7 and 9. Higher concentrations of polymer in combination with $CaCl_2$ increased NTU values significantly.

The reductions in turbidity COD and TSS of effluent from steam-peeled potatoes by a combination of 350 mg/l of $CaCl_2$ with 25 mg/l of the polymers N-7122 and PA #23 are shown in Table 5. In the raw effluent (pH 5), treatments of 350 mg/l of $CaCl_2$, 350 mg/l of $CaCl_2$ + 25 mg/l of N-7122 and 350 mg/l of $CaCl_2$ + 25 mg/l of PA #23 reduced COD levels by 56, 60 and 54% and TSS by 88, 90 and 89%, respectively. The high COD remaining in the treated effluent indicates that there is a large percentage of the total solids of effluent present as dissolved solids in steam-peeled potato wastewater. While TSS was decreased by 80 to 90%, the COD was reduced only by approximately 50% regardless of treatment and pH.

3. The turbidity of effluent from lye-peeled potatoes was decreased more by 400 to 500 mg/l of $CaCl_2$ than either of the other salts used for flocculation at pH 11.3 and 7. However, at pH 5 $FeCl_3$ and $Fe_2(SO_4)_3$ were more effective in reducing NTU. The

maximum reduction of turbidity in effluent from lye-peeled potatoes was accomplished by treatment with the polymers GWP-25 and PA #23 at pH 11.3. At the lower pH values (7 and 5), the polymer H-1018 reduced NTU significantly, but not as much as at pH 11.3 by the other two polymers. The most suitable concentrations of polymer and $CaCl_2$ were 45 mg/l and 400 mg/l, respectively at pH 11.3. Greater reductions in NTU were accomplished with 45 mg/l of the polymer H-1018 in combination with 300 to 500 mg/l of $FeCl_3$ and $Fe_2(SO_4)_3$ at pH 5.

The combined effect of using various optimum chemical treatments on reducing turbidity, COD and TSS of the effluent from lye-peeled potatoes at pH levels of 11.3, 7 and 5 are shown in Table 6. Treatments of 300 mg/l of $CaCl_2$ + 25 mg/l of PA #23 and 300 mg/l of $CaCl_2$ + 25 mg/l of GWP-25 reduced COD levels by 69 and 63% and TSS by 76 and 75%, respectively. This corresponds to reductions in COD from 3600 mg/l to 1113 and 1346 mg/l, and TSS from 1900 mg/l to 450 and 480 mg/l, respectively. When the effluent was adjusted to pH 7, treatments of 350 mg/l of $CaCl_2$ + 25 mg/l of H-1018 polymer reduced COD by 67% and TSS by 72% of the concentrations in raw wastewater. In effluent adjusted to pH 5, the use of 300 mg/l of $FeCl_3$ + 25 mg/l of H-1018, and 300 mg/l of $Fe_2(SO_4)_3$ + 25 mg/l of H-1018 decreased COD by 70 and 72% and TSS by 75 and 78%, respectively from the original values.

4. Wastewater from lye-peeling and processing of corn for canned hominy.

The wastewater generated from the lye-peeling of corn for hominy is the most concentrated effluent and the lowest volume among other hominy wastewaters. The high pH (11.0 to 12.4) and high total solids (1.5 to 5%) creates major problems in treatment systems. Plain sedimentation can be used to separate part of the heavy solids from the supernatant, but this process is slow and inefficient. Another method is by dilution with other low strength effluent in the plant. When the pH was adjusted to 9 and the heavy waste diluted with 2 parts of water, the turbidity decreased significantly in 30 minutes.

The interactive effects of settling time, pH and dilution on COD were significant (Table 7). The interaction on TSS was caused by a large decrease in TSS in the control between 30 and 120 minutes of setting, whereas in the diluted effluent most of the settling occurred in 30 minutes. Also, at the high pH level (11.4), less change occurred in the control and 1:1 dilution, yet the decrease in TSS was significant between 30 and 120 minutes. The interactive effects on COD were influenced by the large decrease in COD between 30 and 120 minutes of settling, especially at pH 7 and 9. However, in the effluent diluted 1:1 and 1:2 with low strength water no significant changes occurred during the same period.

It seemed to be impractical to remove the TSS and COD by pH adjustment alone because of the long settling time required for separation. However, the heavy peel wastes could either be isolated and treated separately or diluted with other low strength wastewater before further treatment.

Wastewater from cooking hominy

The main effects of inorganic salts indicate that $FeCl_3$ and $Al_2(SO_4)_3$ decreased the turbidity of cooking water more than $CaCl_2$, $FeSO_4$ and $Fe_2(SO_4)_3$ (Table 8). A concentration of 150 mg/l of salts was the most effective level, and pH 9 was the better pH for reduction of turbidity.

Anionic and nonionic polymers added individually did not reduce turbidity when added to cooking water. Cationic polymers at 20 mg/l decreased turbidity, but did not flocculate the TSS. Combinations of either $FeCl_3$ or $Al_2(SO_4)_3$ with 10 to 20 mg/l of the polymers H-1018, F-627 and PA #23 at pH levels of 5, 7 and 9 flocculated the TSS of the cooking water. Larger floc was produced at pH 6, 7 and 9, but only small floc formed at pH 5 which was probably due to the decrease in pH when $Al_2(SO_4)_3$ was added at pH 5. The maximum % reduction in COD and SS (98.5 and 98.1%, respectively) were obtained when cooking water was treated with 100 mg/l of $Al_2(SO_4)_3$ and 10 mg/l of H-1018 at the initial pH of 6. Similar results were obtained in the same experiment when $FeCl_3$ was used as the inorganic salt. This suggests that the TSS and COD can be removed effectively from hominy cooking water and recycled to reduce the cost of operation.

The main effects of different initial pH levels, treatments and inorganic salts on turbidity, COD and TSS of cooking water indicate that either 6, 7 or 9 pH was suitable for flocculation of TSS and removal of COD (Table 9). The combination treatment of inorganic salt and H-1018 was the most effective in decreasing turbidity, COD and TSS. When $Al_2(SO_4)_3$ was combined with the treatments, a greater reduction in turbidity occurred than with $FeCl_3$; however, $FeCl_3$ was superior for reducing COD. This was probably caused by the tinting of the effluent by $FeCl_3$ which affected NTU values.

The effectiveness of removal of flocculated TSS by the chemical treatments was tested by screening the samples over a series of U.S. standard screens. A combination of $Al_2(SO_4)_3$ and H-1018 produced larger and more stable floc at both 5 and 10 mg/l levels of polymer at pH levels of 6, 7 and 9. This floc was effectively removed by screening even with the larger diameter screen (No. 32). At a pH of 5 the floc was small and could not be efficiently removed by even the smallest screen (No. 140).

Wastewater from bleaching hominy

A periodic batch dumping of bleaching water in which SO_2 is added at a temperature of 80 to 90^{o}c produces effluent with different levels of TSS and COD. Bleaching water is composed largely of starch and dextrins. At the beginning of dumping of a completed bleaching tank of hominy the turbidity was lower than that of hominy cooking water.

Because of the high buffering capacity of the bleaching water, higher concentrations of $Al_2(SO_4)_3$ were required to coagulate TSS and reduce turbidity. The initial bleaching water at the beginning of dumping required almost 600 mg/l of $Al_2(SO_4)_3$ and 10 mg/l of H-1018 to flocculate the TSS into large floc, but at subsequent collection times much less $Al_2(SO_4)_3$ was required to form large floc in the more diluted water; that is, 250, 150, and 50 mg/l at collection times 30, 60 and 120 min, respectively.

Hominy total effluent

Among the 5 salts tested on total effluent, $FeSO_4$ was the most effective coagulant for reducing turbidity (Fig. 3). The maximum reduction was obtained at 400 mg/l when averaged over pH levels of 7, 9 and 11.4. However, the largest decrease in turbidity occurred at pH 9 and a concentration of 300 mg/l of $FeSO_4$.

The interactive effects of organic polymers and concentrations on turbidity of total effluent was caused by the large decrease in NTU of the effluent as the concentration was increased when F-250 was applied, while in most of the other polymers there was either no change or an increase in NTU (Table 10). The polymer F-250 decreased NTU at all pH levels. Comparable changes in NTU were induced by Chitosan at pH 11.4, although it was not effective in reducing NTU at the other pH levels.

Flocculation of TSS in total effluent from hominy processing was accomplished by applying first a cationic polymer followed by an anionic polymer. The interactive effects of cationic and anionic polymer concentrations and pH revealed that Chitosan flocculated TSS and reduced turbidity at levels of 40 and 60 mg/l in combination with 10, 20 and 40 mg/l of PA #23 at pH 9 (Table 11). Also, F-250 at 20 mg/l was effective in flocculating TSS at pH 9, and 60 mg/l at pH 11.4 in combination with PA #23, resulting in small floc that could be removed by a 140 mesh screen. Although a combination of polymers (cationic and anionic) were effective for removing TSS from hominy total effluent, the use of $Al_2(SO_4)_3$ as a primary flocculant increased the size of floc and reduced the TSS up to 89%.

<u>Wastewater from dry beans</u>

The interactive effects of inorganic salts and concentrations on turbidity indicated that $Al_2(SO_4)_3$ was the most effective salt for reducing NTU at 500 mg/l (Fig. 4). The drastic decrease in NTU value at 1000 mg/l when the effluent was treated with $Fe_2(SO_4)_3$, $FeCl_3$ and $Al_2(SO_4)_3$ was responsible for the interaction.

By preliminary tests it was found that a combination of anionic and cationic polymers decreased turbidity significantly (Table 12). The interactive effects of pH anionic polymer and cationic polymer demonstrated that Chitosan flocculated TSS at all pH levels, while the other cationic polymers had no effect at pH 5 and 6. Anionic polymer F-627 in combination with PC-43 and GWS-5 formed small floc at pH 7. Likewise, PA #23 formed floc with PC-43 at pH 7.

All combinations of anionic polymers and concentrations of polymers produced a screenable floc with $Al_2(SO_4)_3$ and Chitosan. The effluent with higher initial turbidity and TSS required a higher dosage of Chitosan to flocculate. The combination of 10 mg/l of PA #23 and Chitosan resulted in significant reductions in turbidity and formation into large floc.

The interactive effects of inorganic salts, organic polymers and pH on components of navy bean wastewater were due in part to the differences in the reductions at the 3 pH levels (Table 13).

The TSS was reduced by approximately 95% and COD by 13% when 25 mg/l of $Al_2(SO_4)_3$ was added followed by 30 mg/l Chitosan and 10 mg/l anionic polymer PA #23 at different pH levels.
Flocculite-250 coagulated the TSS fairly well but the floc was not screenable. In some instances, the reduction in TSS was the same as the control (F-250) and less than the control (GWS-5 and PC-43), indicating that the addition of the latter two polymers caused resuspension of the dispersed solids.

In additional studies on effluent from pinto beans the results were similar to those on navy beans. Therefore, Chitosan can be successfully applied to the wastewater from processing of other dry bean products to remove TSS.

Microbiological methods of treatment

1. Inoculation with yeasts

Physical-chemical treatment of effluent from processing potatoes removes a large percentage of the TSS. Another method of removing TSS and dissolved solids from wastewater is by the use of yeasts. Two yeasts, *S. fibuliger* and *C. utilis* have been used frequently for utilization of total solids in wastewater from lye-peeled potatoes.

Greater COD potatoes removal was obained in samples inoculated with *S. fibuliger* over a 72 hours incubation period than in the other treatments (Table 14). An original COD of 4080 mg/l was decreased to 1600 and 1150 mg/l in the supernatant after 48 and 72 hr of fermentation. By centrifugation at 400 rpm the COD was reduced to 750 mg/l. C. utilis was not effective in decreasing COD. Although a combination of the two yeasts resulted in a slightly greater decrease in COD than *C. utilis* alone. However, apparently the growth of these two yeasts together reaches a stage whereby *C. utilis* removes glucose at a faster rate than the *S. fibuliger* can hydrolyze starch thereby suppressing the growth of *S. fibuliger* (34, 36, 40, 43).

In further studies in which the actively fermenting wastewater was replaced by half of the effluent volume daily to simulate an actual plant condition the COD decreased in the system inoculated with _S_. _fibuliger_ by 71, 78%, respectively in 24, 48 and 72 hours. Further reductions were achieved by centrifugation to remove yeast cells.

In effluent from steam-peeled potatoes in which the system was kept actively fermenting with _S_. _fibuliger_, and other yeasts (Table 15), _S_. _fibuliger_ was superior for reducing COD of the effluent. The COD was reduced from 6300 to 1700, 1540 and 1500 mg/l, respectively after 24, 48 and 72 hours of fermentation. After centrifugation, the decrease in COD was 89, 90 and 92%, respectively of the initial value. Other strains of yeast were less effective in assimilating the total solids of potato effluent.

Comparisons were made to evaluate the effectiveness of _S_. _fibuliger_ in reducing the COD of fresh, boiled and activated wastewater from steam-peeled potatoes. Eighty-five percent of the initial COD of wastewater was reduced after 24 hours of fermentation in the activated system (36). Greater reductions exceeding 90% in 18 hr were achieved by centrifugation. Changes in pH, total sugars and starch occurred during fermentation. The pH increased approximately by a pH of 1 from the initial pH of 4.7.

Total sugars and starch decreased to zero in 28 hr of fermentation. The % protein of the dried yeast solids was 31% with a net dry weight of 1.6 g/l.

2. Inoculation with fungi

Studies were conducted on the use of _A_. _oryzae_ ATCC 9362 _A_. _foetidus_ NRRL 337 and _N_. _sitofila_ NRRL 2884 for reducing COD of effluent from steam-peeled potatoes. Greater reductions in COD were obtained when the effluent was inoculated with _N_. _sitofila_ (Table 16). The COD was reduced from 5400 to 750 mg/l in 48 hours at pH 5. Lower pH levels of 3.0 to 4.5 resulted in poor growth of the fungus. The addition of 0.1% $(NH_4)_2HPO_4$ to the effluent resulted in higher % reductions of COD, over 90 % in 48 hours. The biomass recovered from the wastewater contained 1.65 g/l (dry wt.) of mycelium, and contained 3.9% protein. Repetitive transfers of the mycelium to fresh wastewater produced a more actively growing biomass in which higher reductions of COD and higher yields of dry fungal biomass were recovered.

Most of the pollution loads in effluent from processing hominy originated from the lye-peeler and cooking tanks. A number fungi imperfecti strains were tested for their ability to grow and assimilate the total effluent of hominy. _N_. _sitophila_ was the most effective organism in reducing the COD level up to 76% at an initial pH of 5.0. It also grew well under alkaline conditions at pH

10, yet it failed to grow at an initial pH below 4.0. The mold *T. viride* NRRL 6418 reduced COD up to 74% at pH 4.0, but it did not grow at pH 10.0. Also, *G. deliquescens* was the least effective for reducing COD, followed by *A. oryzae* NRRL 1808 and *T. reesei* QM 9414. The fungi *A. foetidus* NRRL 337, *A. oryzae* NRRL 697 and *A. oryzae* NRRL 9362 were intermediate in utilizing total effluent from hominy and reducing COD under the conditions that were tested.

The fungi *N. sitophila* and *T. viride* were selected for more detailed studies since these two fungi grew best among those tested. The mold *N. sitophila* decreased the COD almost 90% in 24 hours and it grew well at pH levels ranging from 4 to 10 (Fig. 5). Prolonging the fermentation beyond 48 hours did not reduce the COD further. This might have been caused by either (a) presence of compounds not readily metabolized by the organism, (b) exhaustion of essential nutrients, or (c) accumulation of metabolic inhibitors (31).

Poor growth occurred at pH levels of 3 and 11.4, the original pH of the effluent (Fig. 5). The yield of dried mycelium was 2.8 g/l (dry wt), containing a protein content of 38%. In a separate experiment using *N. sitophila*, the addition of $(NH_4)_2SO_4$ and/or NaH_2PO_4 as sources of N and P did not improve assimilation of COD in the effluent except when 20% inoculum was used as compared to 5%.

The inhibition of growth of _N_. _sitophila_ when $(NH_4)SO_4$ was applied at pH 10.0 was alleviated by delaying the addition of the nutrient for 24 hours (Fig. 6). The COD was significantly reduced at 48 and 72 hours of fermentation as compared to the control.

The interactive effects of pH and fermentation time indicated that _T_. _viride_ grew more rapidly at certain pH levels than others (Fig. 7). The COD was decreased rapidly during the first 24 hours at pH 4.0. The reduction was greater at 72 hr when the pH was 3.0 to 3.5.

In other studies with _T_. _viride_, inoculum levels of 5 to 20% had no effect on reduction of COD possibly due to the rapid growth of the fungus in hominy effluent. Most of the growth occurred during the first 24 hours. The addition of 1.5 g/l of $(NH_4)_2SO_4$ + 0.4 g/l of NaH_2PO_4 accelerated the decrease in COD to 84% at pH 3.3 where pH was controlled. Similar results were obtained by Church and Nash (13) when N and P were added to corn waste.

In other factorial experiments conducted on effluent from sweet potatoes, green beans, spinach and leafy greens, each individual vegetable exhibited different optimum conditions for removal of TSS by chemicals in order to attain clear water. The flocculated TSS was aggregated into large floc particles capable of being recycled in spinach, leafy greens and green beans. After the floc was removed by screening the COD was reduced to low levels. In addition, the total and coliform bacterial counts were significantly reduced as shown in the data for green beans(Table 17). The total and coliform counts were reduced by approximately 2 log cycles. Similar results in reduction of bacteria were obtained in the other three vegetables. Over 90% in reductions in TSS and 75% in COD were obtained in effluent from green beans by a combination of $Al_2(SO_4)_3$, Chitosan and F-627. Other polymers were with $Al_2(SO_4)_3$ were equally effective in improving the quality of the wastewaters.

CONCLUSIONS

Physical-chemical treatment

The TSS and COD in effluent from processing potatoes by lye, abrasive, and steam-peeling methods can be significantly decreased by the addition of inorganic salts and/or polymeric flocculating agents. The nature of the individual wastewaters such as source, pH and concentration of TSS and TDS played an important role in determining the type and concentration of chemicals required for optimum coagulation-flocculation of TSS.

In effluent from abrasive-peeled potatoes, the addition of 150 mg/l of $FeCl_3$ +20 mg/l of PA #23 polymer resulted in optimum flocculation of TSS. The COD and TSS were reduced by 97 and 99%, respectively as compared to the control. The use of 350 mg/l of $CaCl_2$ in combination with 25 mg/l of either N-7122 or PA #23 polymers produced large floc particles at pH 5 in effluent from steam-peeled potatoes that could be removed by screening. Although TSS in the effluent was reduced by approximately 90%, high concentrations of TDS remained in steam-peeled potato effluent. In high alkalinity effluent (11.3) from lye-peeled potatoes, the addition of 300 mg/l of $CaCl_2$ + 25 mg/l of PA #23 polymer reduced COD and TSS by 69 and 76%, respectively. At lower pH levels (5 and 7), $CaCl_2$ and $FeCl_3$ in combination with H-1018 polymer decreased COD and TSS by 70 and 80%, respectively.

Wastewater from cooking hominy was treated effectively by adding a combination of either $Al_2(SO_4)_3$ or $FeCl_3$ at concentrations from 50 to 150 mg/l and 10 to 20 mg/l of anionic poylmers H-1018, H-1031, PA #23 or F-627 at a range of pH levels of 5 to 9. The TSS were flocculated into large floc that can be removed by an 80-mesh screen. After more than 98% reduction in TSS, the treated water could be recycled for cooking additional batches of hominy.

The total effluent from bleaching hominy was flocculated by concentrations of $Al_2(SO_4)_3$ ranging from 50 to 500 mg/l in combination with anionic polymers H-1018, H-1031, PA #23 or F-627. Concentration and pH of the effluent affected the level of chemicals required to produce large floc particles. In total effluent from hominy, the inorganic salt $Al_2(SO_4)_3$ combined with 40 mg/l of either H-1018 or PA #23 at pH 7 and 9, respectively flocculated 89% of TSS and removed 73% of the COD.

The effluent from soaking and processing pork and beans from navy beans was flocculated by cationic polymer Chitosan when combined with 5 to 15 mg/l of anionic polymers H-1018, PA #23 or F-627 at pH levels of 5 and 7. When large floc particles were formed by the chemical treatments, total plate and coliform counts were reduced by 1 to 2 log cycles, indicating that minimal chlorination would be required during recycling of the treated water.

Microbiological treatment

Among the strains of yeasts tested for effectiveness in reducing COD and TDS, *S. fibuliger* fermented effluent from lye-and steam-peeled potatoes at an initial pH of 4.7 in 24 to 72 hours, decreasing COD and TDS by 70 to 93% in the centrifuged supernatant. The centrifuged yeast solids contained 2.20 g/l of dried product with a protein content of 32% after 28 hours of fermentation.

The fungus *N. sitophila* significantly reduced COD by 69 and 94% after 24 and 48 hours, respectively in effluent from steam-peeled potatoes at a pH of 5.0 to 6.5. A fungal biomass of 1.65 g/l(dry wt.) that contained 39% protein was recovered after 48 hours of fermentation in the actively growing system.

The fungi *N. sitophila* and *T. viride* assimilated the TSS and TDS in total effluent from hominy in 24 to 72 hours. *N. sitophila* had the advantage of growing at a wide range of pH from 4 to 10 , while T. viride grew best at pH levels of 3 to 4. Reductions in COD as high as 78% were attained with 5% or more of inoculum. Nutrient supplementation with $(NH_4)_2SO_4$ and NaH_2PO_4 enhanced growth of T. viride at a controlled pH of 3.3 and a temperature of 38°C, while reducing COD by 85%. The fungal biomass, containing 38% (N. sitophila to 48% (T. viride) protein, was easily recovered by screening.

At the present time, food processors in the Ozark region of Arkansas are still faced with the problems of heavy pollution of effluent from processing potatoes, hominy, dry beans and other vegetables. The application of the information gained on individual wastewaters in these studies could alleviate most of the present problems. By selecting the appropriate methods of either physical- chemical or microbiological treatment or both that would adapt to the processing plant facilities and volume, pH and concentration of effluent, the processor could reduce pollution at an economical cost. The alternatives suggested by this research for effluent treatment would greatly benefit the Ozark region or other regions in improving water quality.

Table 1. Effect of different polymers on reduction of turbidity of wastewater from abrasive-peeled potatoes at pH 5.

Type of polymers	Turbidity Value (NTU)[a]	Type of polymers	Turbidity Value (NTU)
Control[b]	35.83	Dubois GWP-25	26.47
H 827	35.56	N 7122	29.94
H 1031	36.17	N 7120	31.50
H 1018	33.50	Varcofloc	37.14
M 2535CH	33.19	PC #43	32.58
M 2540C	33.61	PA #23	23.64
LSD .05[c]		0.36	

[a] Nephelometric Turbidity Units.

[b] Supernatant wastewater settled for 30 min.

[c] Least Significant Difference at 5% level.

Table 2. Effect of concentration of polymers and $FeCl_3$ on reduction of wastewater turbidity from abrasive-peeled potatoes at pH 5.

Concentration of polymers (mg/l)	Turbidity Value (NTU)[a]	Concentration of $FeCl_3$ (mg/l)	Turbidity Value (NTU)
5	34.19	0	81.69
10	32.38	100	64.78
20	32.31	150	14.44
40	30.25	200	13.44
60	31.81	250	10.47
80	33.64	300	9.74
LSD .05[b]	0.30		0.73

[a] Nephelometric Turbidity Units.

[b] Least Significant Difference at 5% level.

Table 3. Effect of concentration of polymer and FeCl$_3$ on reduction of wastewater turbidity from abrasive-peeled potatoes at pH 5.

	Concentration FeCl$_3$ (mg/l)					
	0	100	150	200	250	300
	Turbidity (NTU)[a] Value					
Raw Wastewater	170					
Control[b]	90	75	16	14	10	10
Added PA #23 Polymer (mg/l)						
5	80	60	10	10	8	6
10	78	45	4*	4	4	4
20	75	40	4**	4	4	4
40	75	30	4	4	4	4
60	70	35	8	8	8	8
80	70	35	14	10	10	10
LSD .05[c]			2.8			

[a] Nephelometric Turbidity Units.

[b] Supernatant wastewater settled for 30 min.

[c] Least Significant Difference at 5% level.

* Small Flocs found in wastewater (not removable on 80-mesh screen).

** Large flocs found in wastewater (removable on 80-mesh screen).

Table 4. Effect of different polymers on reduction of the wastewater turbidity from steam-peeled potatoes at pH 5, 7, and 9.

pH	Type of polymers	Turbidity Value (NTU)[a]	Type of polymers	Turbidity Value (NTU)
5	Control	115.5	N 7120	101.2
	H 827	112.0	Varcofloc	111.3
	H 1031	114.6	PC #43	110.1
	H 1018	112.2	Dubois GWP-25	94.5
	M 2535CH	111.2	N 7122	90.7
	M 2540C	111.3	PA #23	107.8
LSD .05[c]			0.36	
7	Control	124.8	N 7120	103.2
	H 827	119.5	Varcofloc	118.9
	H 1031	119.4	PC #43	117.2
	H 1018	116.5	Dubois GWP-25	100.8
	M 2535CH	117.3	N 7122	98.9
	M 2540C	115.3	PA #23	97.3
LSD .05			0.87	
9	Control	125.0	N 7120	103.7
	H 827	117.2	Varcofloc	111.1
	H 1031	116.8	PC #43	106.6
	H 1018	113.6	Dubois GWP-25	98.7
	M 2535CH	114.2	N 7122	101.7
	M 2540C	115.9	PA #23	83.5
LSD .05			0.83	

[a] Nephelometric Turbidity Units.

[b] Supernatant wastewater settled for 30 min.

[c] Least Significant Difference at 5% level.

Table 5. Main effects of coagulating and flocculating agents on turbidity (NTU), COD and total suspended solids (TSS) levels of steam-peeled potato processing wastewater at pH 5, 7, and 9.

	pH 5					pH 7					pH 9				
Treatment	NTU	COD ppm	% COD reduction	TSS mg/l	% TSS reduction	NTU	COD ppm	% COD reduction	TSS mg/l	% TSS reduction	NTU	COD ppm	% COD reduction	TSS mg/l	% TSS reduction
Raw wastewater	900	8230		4417		750	7220		4000		850	7325		4250	
Control[a]	140	4218	49	727	84	150	4547	37	803	80	140	4092	44	706	83
350 mg/l $CaCl_2$	90	3603	56	513	88	95	3620	50	576	86	65	3365	54	545	87
350 mg/l $CaCl_2$ + 25 mg/l N7122	65	3317	60	433	90	75	3708	49	600	85	85	3808	48	604	86
350 mg/l $CaCl_2$ + 25 mg/l PA #23	90	3750	54	493	89	70	3420	53	487	88	50	3202	56	408	90
LSD .05[b]		140		7.89			9.19		11.87			11.76		9.52	
% CV[c]		1.7		0.33			0.11		0.5			0.2		0.4	

[a] Supernatant wastewater settled for 30 min.

[b] LSD .05 Least Significant Difference at 5% level.

[c] %CV Percentage Coefficient of Variation.

Table 6. Main effects of coagulating and flocculating agents on turbidity (NTU), COD and total suspended solids (TSS) levels of lye-peeled potato processing wastewater at pH 5, 7, and 11.3.

	pH 5					pH 7					pH 11.3				
Treatment	NTU	COD mg/l	% COD reduction	TSS mg/l	% TSS reduction	NTU	COD mg/l	% COD reduction	TSS mg/l	% TSS reduction	NTU	COD mg/l	% COD reduction	TSS mg/l	% TSS reduction
Raw wastewater	280	3710		1920		220	3650		1880		210	3600		1900	
Control[a]	210	1675	55	695	64	160	1650	55	665	65	130	1500	58	600	68
300 mg/l $CaCl_2$ + 25 mg/l PA #23 polymer	150		ND			110		ND			70*	1113	69	450	76
300 mg/l $CaCl_2$ + 25 mg/l Dubois-GWP25	160		ND			120		ND			75	1346	63	480	75
350 mg/l $CaCl_2$ + 25 mg/l H1018	120		ND			90	1200	67	520	72	100		ND		
300 mg/l $FeCl_3$ + 25 mg/l H1018	70*	1100	70	475	75	160		ND			110		ND		
300 mg/l $Fe_2(SO_4)_3$ + 25 mg/l H1018	65*	1058	72	427	78	160		ND			120		ND		
LSD .05[b]		70.0		21.73			60.1		13.3			15.45		15.9	
% CV[c]		2		1.3			1.8		0.9			0.4		1.0	

[a] Supernatant wastewater settled for 30 min.

[b] LSD .05 Least Significant Differenct at 5% level.

[c] %CV Percentage Coefficient of Variation

* Large flocs found in wastewater.

ND No data available.

Table 7. Interactive effects of settling time, pH and dilution on COD of lye-peel wastewater from hominy.

		Settling Time (min.)						
		0	30		60		120	
Dilution	pH	COD (mg/l)						
				% Reduction[a]		% Reduction		% Reduction
Control	7	16626.7	10943.3	34.2	5936.7	64.3	5371.7	67.7
	9	16516.7	10973.3	33.6	5720.0	65.4	5220.0	68.4
	11.4	16640.0	7833.3	52.9	7596.7	54.3	7140.0	57.1
1:1	7	9313.3	4281.3	54.0	4056.7	56.4	3943.3	57.7
	9	9276.7	4432.7	52.2	4063.3	56.2	3976.7	57.1
	11.4	9233.3	5018.0	45.7	4430.0	52.0	4536.7	50.9
1:2	7	6276.7	2980.0	52.5	3036.7	51.6	3063.3	51.2
	9	6326.7	2986.7	52.8	2876.7	54.5	2770.0	56.2
	11.4	6283.3	3253.3	48.2	3053.3	51.4	3093.3	50.8
LSD .05[b]					670.4			

[a] % reduction from the original COD at zero time.

[b] Least significant difference at 5% level. (COD).

Table 8. Main effects of inorganic salts and concentration on turbidity of cooking wastewater from hominy at different initial pH levels.

Inorganic salts	Turbidity (NTU)	Salt Conc. mg/l	Turbidity (NTU)	Initial pH	Turbidity (NTU)
$CaCl_2$	24.6c[b]	0	31.5a	5	33.6a
$FeSO_4$	29.5b	25	26.7cd	6	26.4b
$Fe_2(SO_4)_3$	36.4a	50	27.4bc	7	26.2b
		100	27.3bc	9	20.9c
$FeCl_3$	23.6d	150	24.1f		
		200	24.1f		
$Al_2(SO_4)_3$	19.8e	250	25.7e		
		300	26.4de		
		350	28.1b		

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[a] Raw wastewater turbidity=365.3 NTU.

[b] Means of the main effects within inorganic salts, inorganic salts concentration and initial pH levels are separated by Duncan's Multiple Range at 5% level. Means having any letter in common are not different ($P \geq .05$).

Table 9. Main effects of initial pH levels, treatments and salts on turbidity, COD, and suspended solids in hominy cooking wastewater.

Variables	Turbidity Value (NTU)	COD mg/l	Suspended Solids mg/l
pH			
5	112.3a[a]	1579.1a	887.2a
6	108.4b	1517.5b	857.7b
7	108.3b	1514.4b	851.3b
9	110.1ab	1510.8b	844.5b
Treatments			
Raw Wastewater	365.3a	6156.7a	3337.7a
Control[b]	114.2b	865.2b	567.5b
Salts + Hercofloc 1018	16.6e	161.6d	97.3d
Salts + Floculite 627	29.1c	239.8c	153.6c
Salts + Purifloc A23	23.8d	229.0c	144.9c
Inorganic Salts			
$Al_2(SO_4)_3$	108.2b	1545.3a	868.9a
$FeCl_3$	111.4a	1515.6b	851.5a

[a] Means of the main effects within initial pH, treatments, and inorganic salts are separated in columns by Duncan's Multiple Range Test at 5%. Means within a variable category having any letter in common are not different ($P \geq .05$).

[b] Raw wastewater settled for 30 minutes.

Table 10. Interactive effects of organic polymers and concentrations on turbidity of total effluents from hominy.[a]

	Conc. (mg/l)					
	10	20	40	60	80	100
Polymers	Turbidity Value (NTU)					
Control	54.4					
Cationic						
Chitosan	51.1	50.9	74.7	84.9	99.1	110.7
F-250	48.0	41.8	32.4	25.1	21.1	22.2
N-7122	53.5	55.1	59.1	66.0	63.3	69.8
GWS-5	50.4	51.1	54.4	53.6	54.4	53.7
P-C43	54.2	51.1	55.1	53.3	55.6	55.1
Anionic						
H-1018	69.6	74.4	87.8	80.2	85.6	88.0
H-1031	67.1	70.2	78.6	78.6	81.8	80.7
F-627	53.3	55.1	52.0	52.9	54.7	51.1
F-551	55.8	55.1	56.2	55.6	52.0	49.7
P-A23	57.8	62.0	64.9	68.2	70.2	72.9
Nonionic						
F-555	64.4	64.7	67.3	67.8	66.4	67.8
LSD .05[b]	3.0					

[a] Raw wastewater turbidity = 238.7 NTU.

[b] Least significant difference at 5% level.

Table 11. Interactive effects of cationic and anionic polymers at different concentrations on reduction in turbidity of total effluent from hominy at different initial pH levels.

pH	Anionic Polymer purifloc A23 mg/l	Cationic Polymer							
		Chitosan mg/l				Floculite 250 mg/l			
		0	20	40	60	0	20	40	60
		Turbidity Value (NTU)							
7.0	0	50.7	96.0	113.3	153.3	50.7	42.7	38.7	28.7
	10	56.7	78.7	84.0	108.7	56.7	43.3	40.7	37.7
	20	61.3	83.3	84.7	104.0	61.3	46.7	41.3	38.7
	40	65.3	74.0	89.3	109.3	65.3	52.7	41.3	39.3
9.0	0	46.7	33.3	84.0	114.0	46.7	42.0	38.7	29.3
	10	50.7	51.3	42.7*	64.0*[b]	50.7	35.3*	22.7*	22.0*
	20	57.3	52.7	39.3*	54.7*	57.3	31.3*	23.3*	20.7*
	40	56.7	48.7	41.3*	54.7*	56.7	40.0	29.3*	22.7*
11.4	0	71.3	48.7	39.3	33.3	71.3	46.0	44.7	44.0
	10	64.7	48.7	37.3	32.7	64.7	41.3	35.3	79.3*
	20	65.3	52.7	48.0	40.7	65.3	43.3	39.3	31.3*
	40	72.7	49.3	44.7	40.0	72.7	45.3	35.3	30.7*
LSD .05[c]		5.3							

[a] Raw wastewater turbidity = 238.7 NTU.

[b] * Small floc removable by 140 mesh screen.

[c] Least significant difference at 5% level.

Table 12. Interactive effects of cationic polymers and concentrations on turbidity of total effluent from navy beans at different initial pH levels.[a]

		Cationic Polymers			
Initial pH	Polymer conc. mg/l	Chitosan	Floculite 250	Purifloc C43	GWS-5
		Turbidity Value (NTU)			
5	0	45.3			
	10	40.7	24.0	62.7	60.7
	20	14.7	25.3	97.3	92.0
	30	6.7*[b]	28.7	95.3	94.7
	40	26.7	33.3	93.3	92.7
	60	73.3	42.7	85.3	97.3
6	0	39.3			
	10	19.3	32.0	39.3	42.7
	20	10.7	29.3	41.3	41.0
	30	5.3*	20.7	40.7	43.3
	40	25.3	24.0	42.0	42.7
	60	65.3	23.3	41.3	42.7
7	0	40.7			
	10	15.3	15.3	24.7	26.0
	20	9.3	7.3	28.7	23.3
	30	3.7*	8.0	29.3	29.3
	40	5.3	7.7	25.3	36.7
	60	48.0	11.0	24.0	32.7
LSD .05[c]		3.5			

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[a] Raw wastewater turbidity = 88.3 NTU.

[b] * Small floc removable by 200 mesh screen.

[c] Least significant difference at 5% level.

Table 13. Effects of inorganic salt and organic polymers on reduction of turbidity, COD, and suspended solids in total effluent from navy beans at different initial pH levels.

Initial pH	Treatments	Turbidity (NTU)	COD (mg/l)	% reduction	SS (mg/l)	% reduction
	Raw Wastewater	87.3	2566.7	----	297.3	----
	Control[a]	61.3	2450.0	4.5	137.7	53.7
5	Chitosan[b]	1.7**[c]	2245.7	12.5	15.3	94.9
	Floculite 250	21.3	2406.7	6.2	121.7	59.1
	GWS-5	84.0	2496.0	2.8	255.7	14.0
	Purifloc C43	82.7	2459.0	4.2	250.0	16.0
	Control	40.7	2429.3	5.4	120.7	59.4
6	Chitosan	2.0**	2238.0	12.8	17.0	94.3
	Floculite 250	15.7	2403.3	6.4	99.3	66.6
	GWS-5	76.0	2460.0	4.2	260.3	12.4
	Purifloc C43	79.3	2480.0	3.4	257.7	13.3
	Control	29.3	2412.7	6.0	119.3	59.9
7	Chitosan	1.3**	2222.3	13.4	13.3	95.5
	Floculite 250	31.3	2390.0	6.9	124.7	58.1
	GWS-5	77.3	2466.7	3.9	257.3	13.5
	Purifloc C43	66.7	2443.3	4.8	252.3	15.1
LSD .05[d]		4.9	89.7		15.4	

[a] Raw waste settled for 30 minutes.

[b] 25 mg/l $Al_2(SO_4)_3$ added followed by 30 mg/l cationic polymers (chitosan, F-250, GWS-5 and P-C43), then 10 mg/l anionic polymer Purifloc A23.

[c] ** Large floc removable by 80 mesh screen.

[d] Least significant difference at 5% level.

Table 14. Removal of COD from lye-peeled potato effluent (pH 4.7) inoculated with *S fibuliger*, *C. utilis* and a mixture of *S. fibuliger* + *C. utilis* yeasts over a 72 hr period of fermentation.

Wastewater treatment	Fermentation Period (HR)							
	0	24	48	72	0	24	48	72
	Wastewater COD (mg/l)				Centrifuged Wastewater COD (mg/l)			
Control[a]	4080	3990	3820	3700	3900	3500	3400	3310
Wastewater + *S. fibuliger*		2900	1600	1150		2520	1150	750
Wastewater + *C. utilis*		3600	1950	1500		2950	1450	980
Wastewater + Mixture of *S. fibuliger* and *C. utilis*		3200	1750	1350		2700	1260	876
LSD .05[b]					8.76			

[a] Wastewater not inoculated with yeasts.

[b] Least Significant Difference at 5% level.

Table 15. Removal of COD from activated wastewater (pH 4.7) of steam-peeled potatoes inoculated with different yeast cultures over a 72 hr fermentation period.

Wastewater treatment	Fermentation Period (HR)							
	0	24	48	72	0	24	48	72
	Wastewater COD (mg/l)				Centrifuged Wastewater COD (mg/l)			
Control Wastewater[a]	6300	5760	5250	4300	5700	5310	4650	4210
Wastewater + *S. fibuliger*		1700	1540	1400		720	625	510
Wastewater + *C. utilis*		4210	3818	3600		3665	3250	3115
Wastewater + Mixture of *C. utilis* and *S. fibuliger*		3110	2630	2160		2280	1742	1205
Wastewater + *K. fragilis* NRRL Y-1109		4000	3620	3410		3300	2900	2580
Wastewater + *K. fragilis* NRRL Y-2415		4100	3680	3460		3440	3050	2670
LSD .05[b]					7.45			

[a] Wastewater not inoculated with yeasts.

[b] Least Significant Difference at 5% level.

Table 16. Removal of COD from steam-peeled potato processing wastewater with different fungi over a 48 hr fermentation period.

Wastewater Treatment	Fermentation Period (HR)				
	0	12	24	36	48
Control Wastewater[a]	5400	5345	5280	5168	5108
Wastewater + *A. oryzae* ATCC 9362	5400	4310	3700	3165	2400
Wastewater + *A. foetidus* NRRL 337	5400	3710	1876	1650	1467
Wastewater + *N. sitophila* NRRL 2884	5400	2800	1333	1050	750
LSD .05[b]			5.67		

[a] Wastewater not inoculated with fungi.

[b] Least Significant Difference at 5% level.

Table 17. Effects of inorganic salt ($Al_2(SO_4)_3$ and organic polymers on reduction in turbidity, total suspended solids, chemical oxygen demand and bacterial counts of effluent from processing green beans (Initial pH 6.2).

Treatment	Turbidity (NTU)	Total suspended solids (mg/l)	% reduction	Chemical oxygen demand (Mg/l)	% Reduction	Total plate counts	Total coliforms
Raw wastewater	72.0	278.0	------	385.0	------	$4.0x10^{7}$a	$3.3x10^{5}$a
Cationic polymers[a]							
Chitosan	2.8**	18.0b	93.6a	88.0c	75.9a	$3.9x10^{5}$b	$1.5x10^{3}$c
Flocculite-250	4.2**	21.0b	92.5a	105.0a	71.3b	$3.0x10^{5}$b	$3.8x10^{3}$b
Nalco 7122	4.5**	26.0a	89.2b	98.0b	68.3c	$3.3x10^{5}$b	$3.1x10^{3}$b

[a] 50 mg/l of $Al_2(SO_4)_3$ added, then followed by 20 mg/l of cationic polymer, and 10 mg/l of anionic polymer Floculite 627.

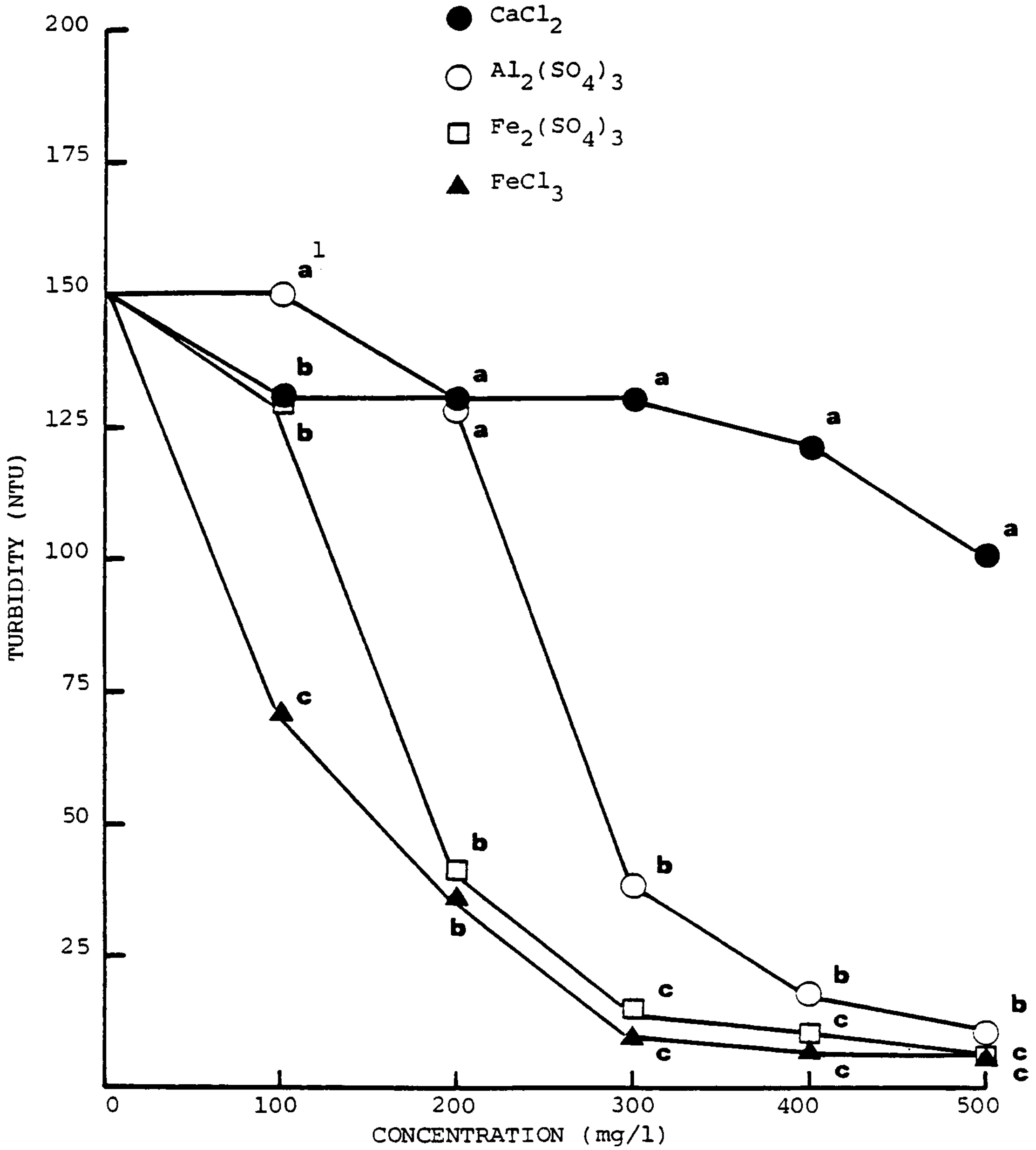

Fig. 1 - Effect of concentrations of different inorganic salts on reduction of turbidity in abrasive-peeled potato wastewater at pH 5.0. Raw wastewater turbidity=200 NTU. [1]Values followed by the same letter within concentrations do not differ significantly at the 5% level using Duncan's multiple range test.

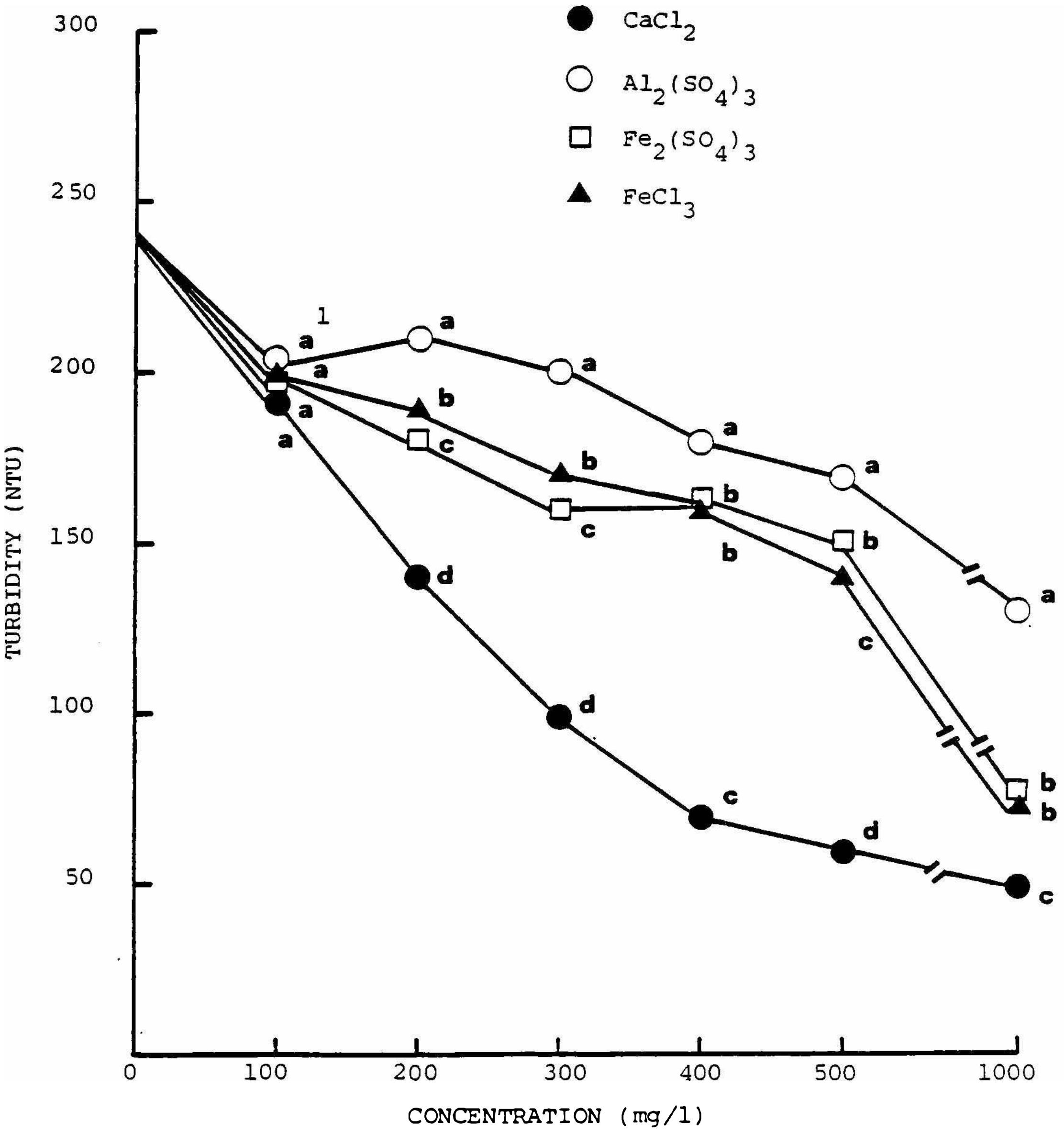

Fig. 2 - Effect of concentrations of different inorganic salts on reduction of turbidity in steam-peeled potato wastewater at pH 5.0. Raw wastewater turbidity=960 NTU. [1]Values followed by the same letter within concentrations do not differ significantly at the 5% level using Duncan's multiple range test.

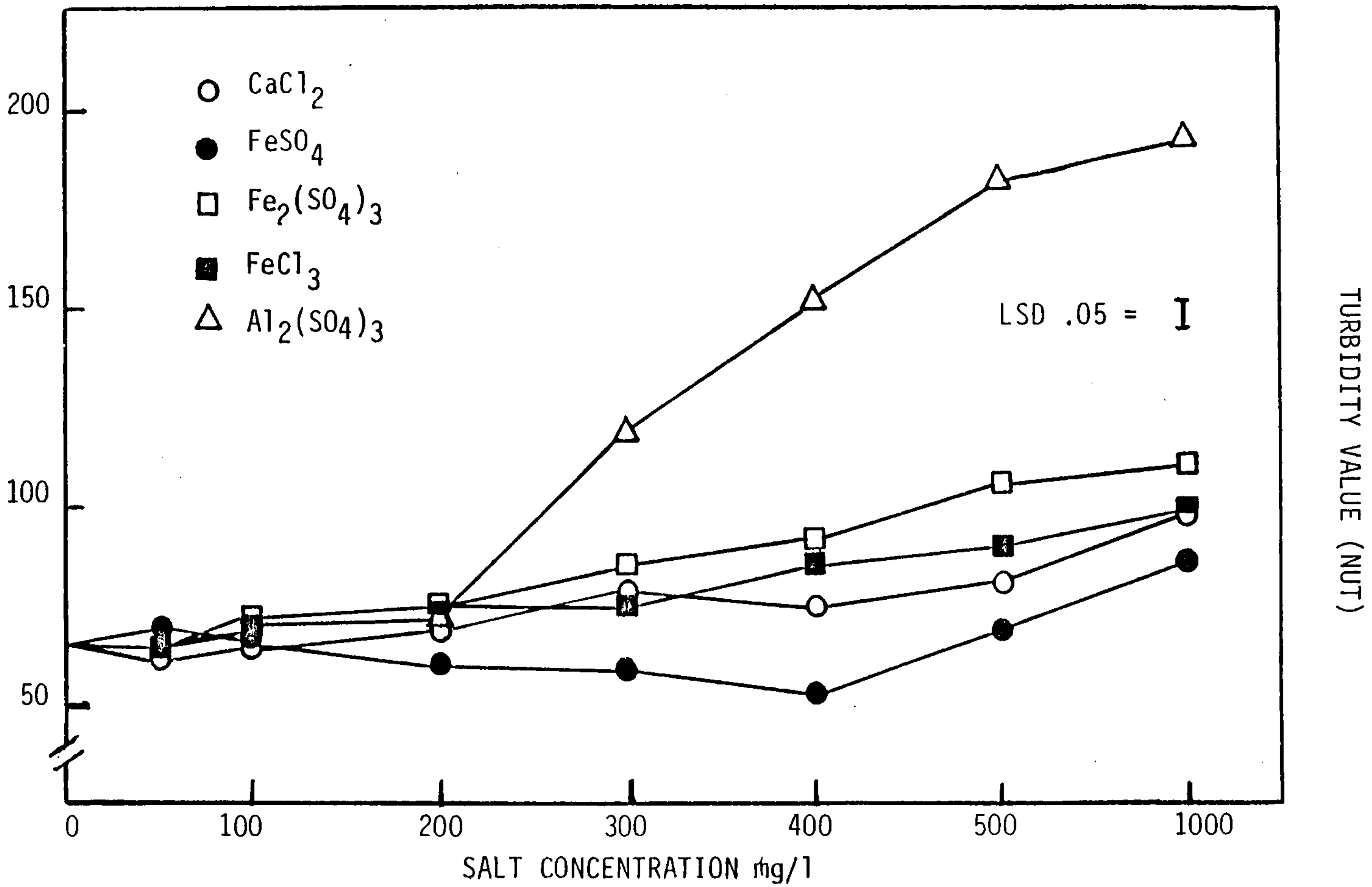

Fig. 3. Interactive effects of inorganic salts and salt concentrations on turbidity of total effluent from hominy.

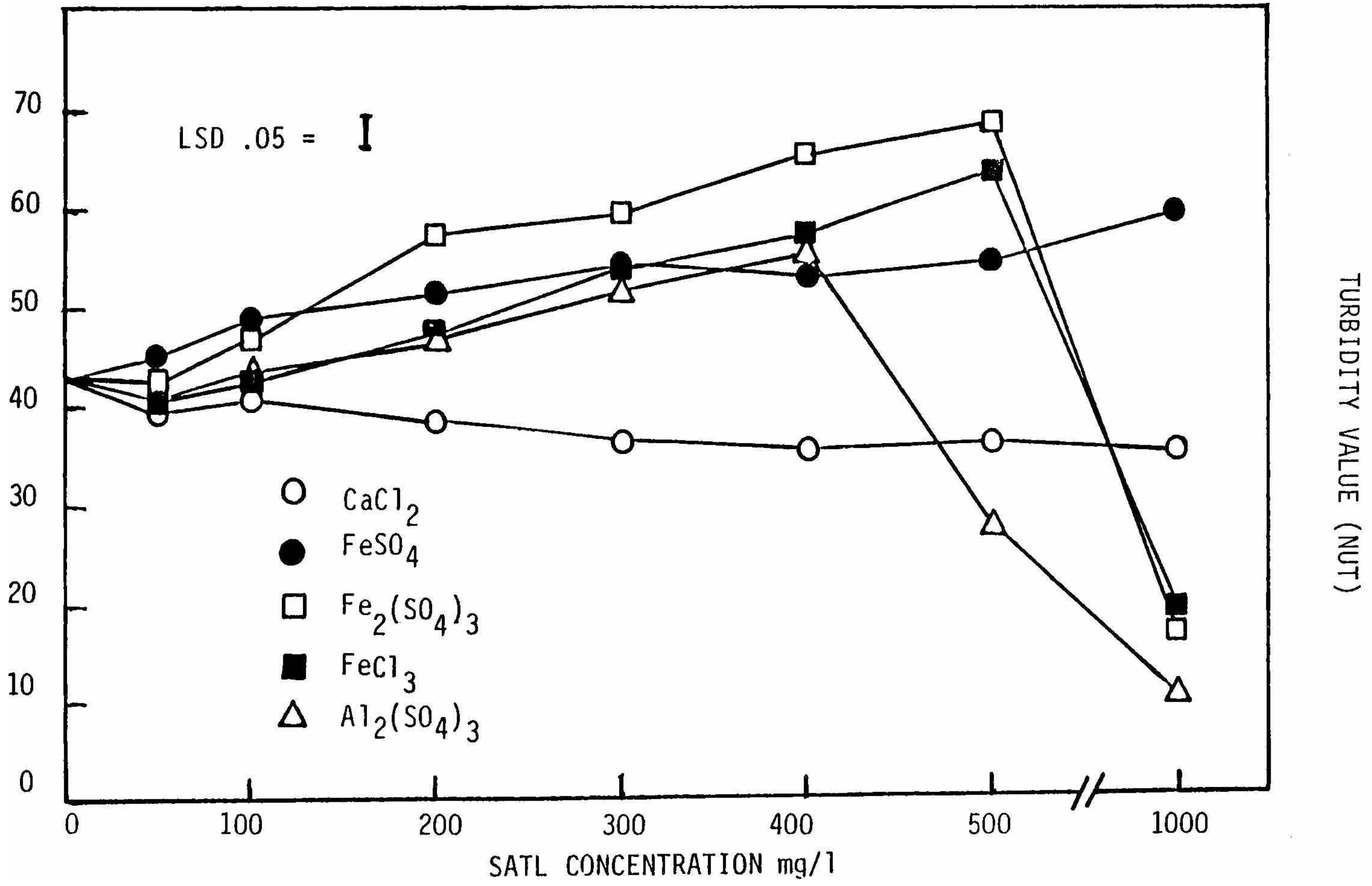

Fig. 4. Interactive effects of inorganic salts and concentration on turbidity of wastewater from navy beans.

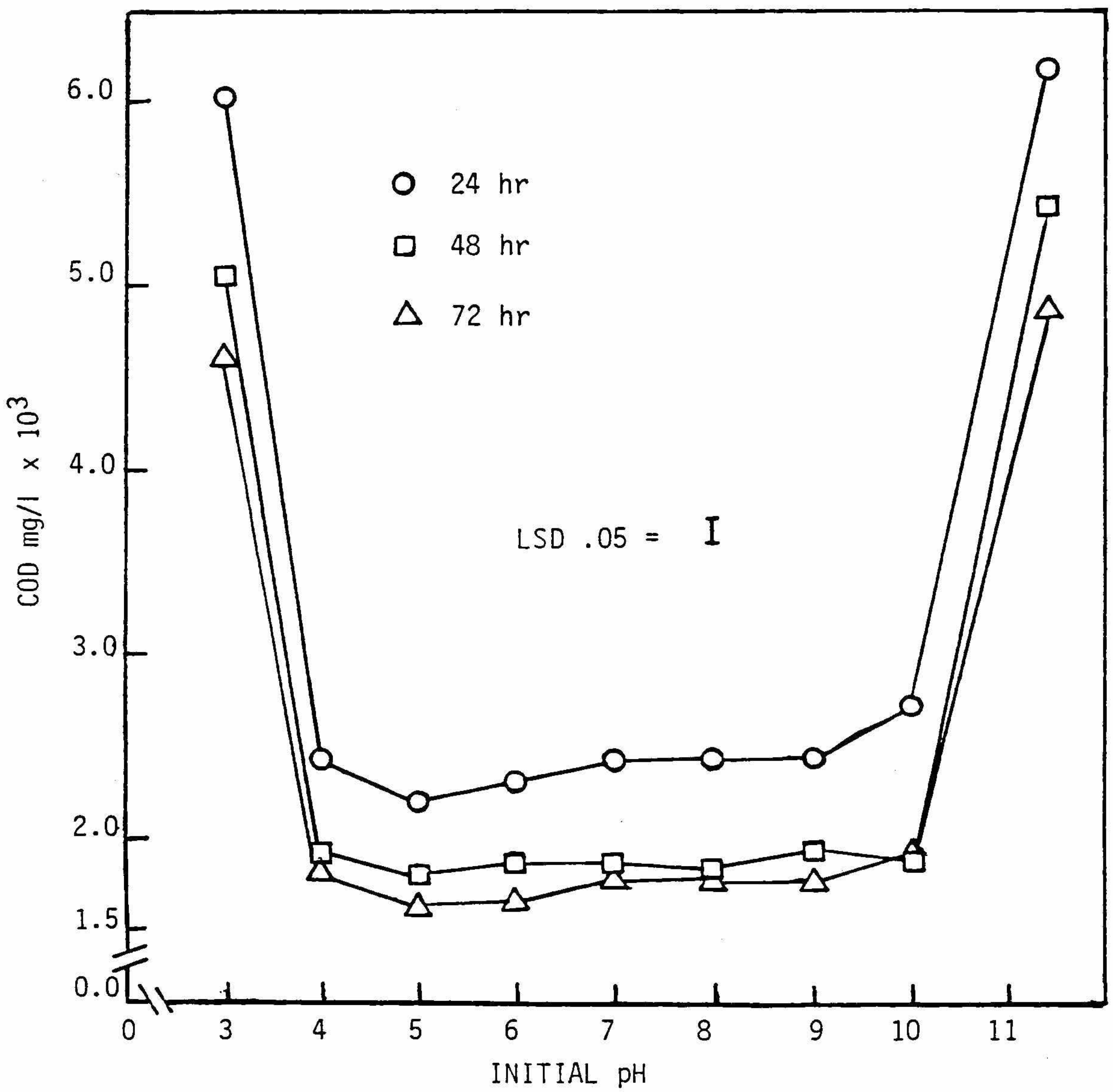

Fig. 5 . Interactive effects of initial pH and fermentation time on reduction of COD by the growth of _N. sitophila_ NRRL 2884 in total effluent from hominy.

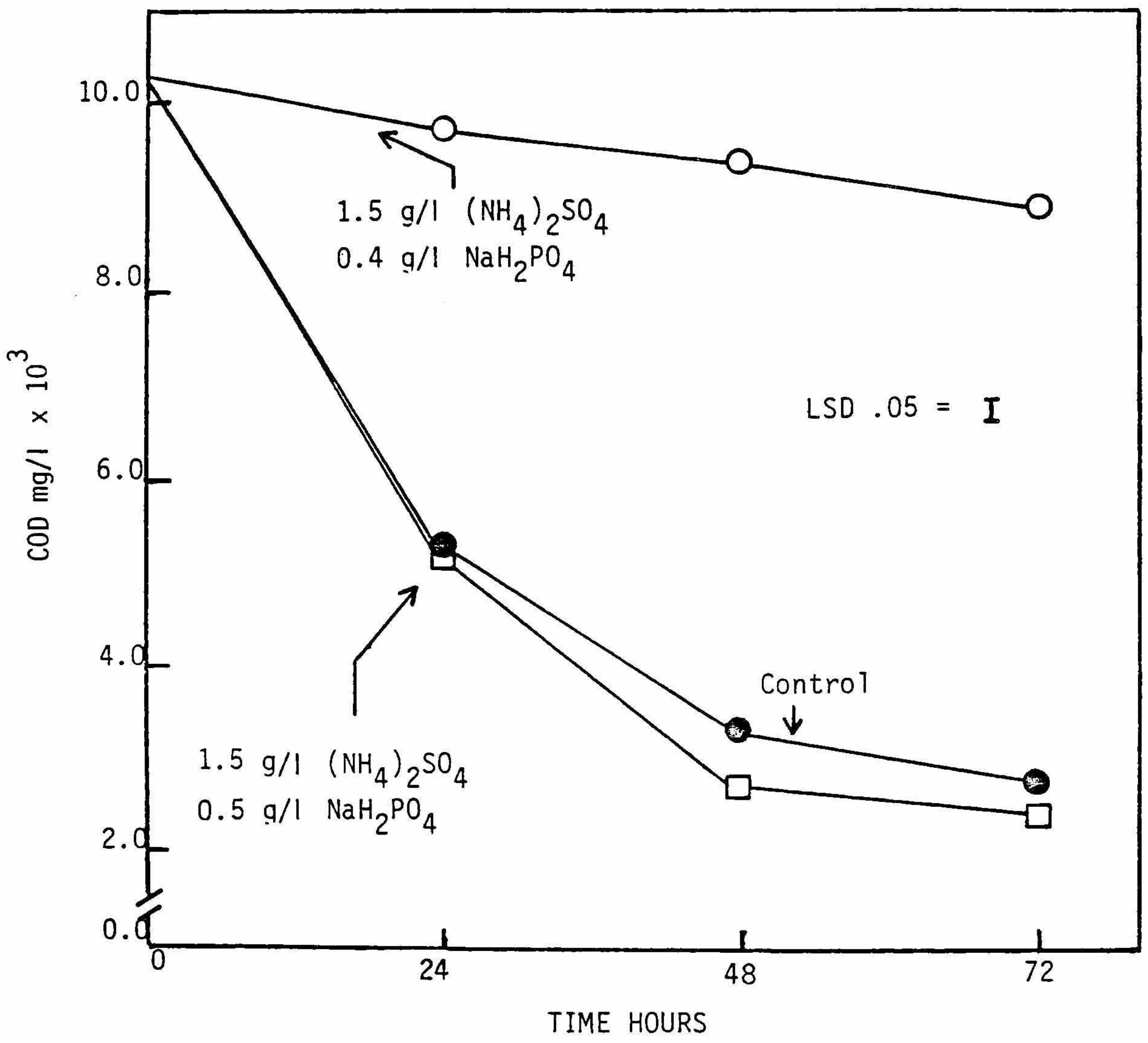

Fig. 6. Effect of addition of nutrients and fermentation time on the growth and reduction of COD in total effluent from hominy by N. sitophila NRRL 2884 at an initial pH of 10.

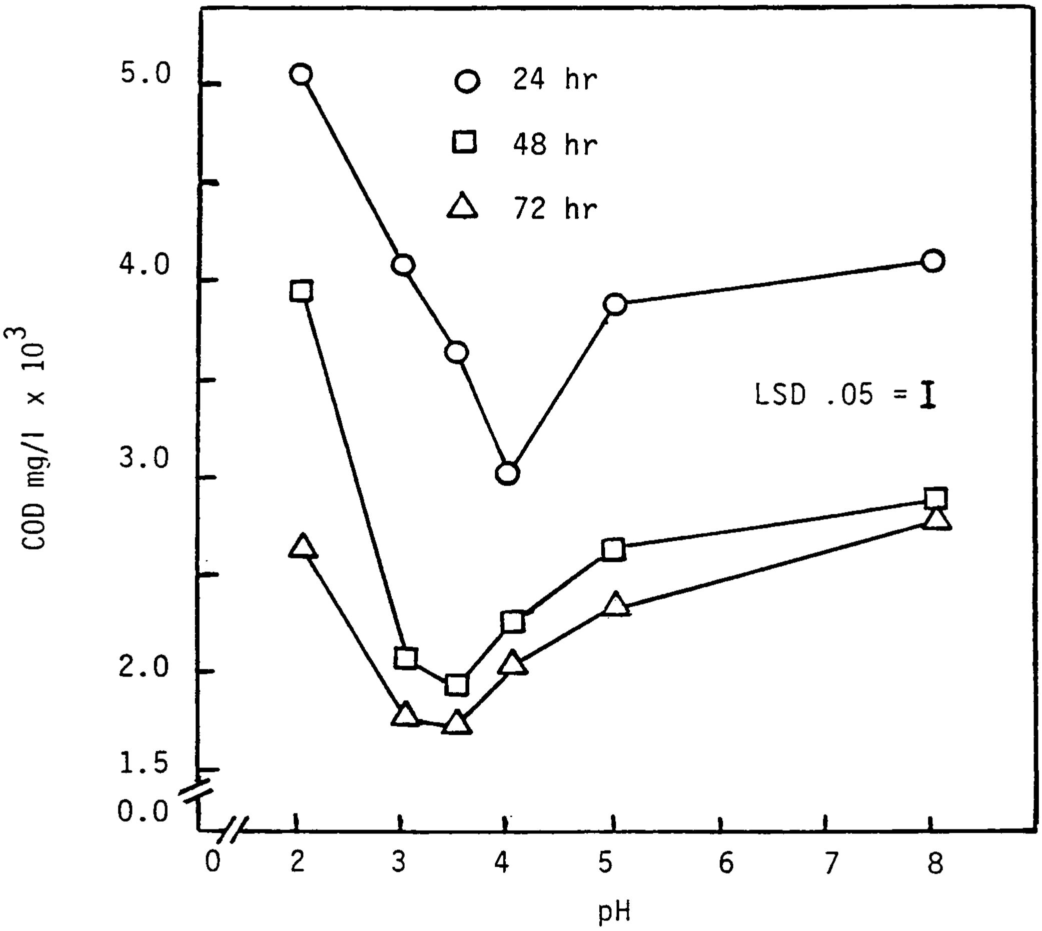

Fig. 7. Interactive effects of initial pH and fermentation times on reduction of COD by the growth of *T. viride* NRRL 6418 in total effluents of hominy.

LITERATURE CITED

1. APHA., AWWA, WPCF. 1975. Standard methods for the examination of water and wastewater. 14th ed., American Public Health Association, Washington, D.C.

2. Atkins, P.F., Jr., and Sproul, O.J. 1966. Feasibility of biological treatment of potato processing wastes. J. Water Poll. Cont. Fed. 38:1287.

3. Bass, J.H., and Evans, R.R. 1951. Sedimentation and flocculation equipment for treatment of industrial wastes. Sewage and Ind. Wastes 23:1523.

4. Beuchat, W.R., Bough, W.A., and Young, C.T. 1978. Use of alkaline-peeling effluents from vegetable and fruit processing operations by Neurospora sitophila. J. Food Protein 41(1):24.

5. Bishop, D.F., O'Farrell, T.P., and Stamberg, J.B. 1972. Physical-chemical treatment of municipal wastewater. J. Water Poll. Cont. Fed. 44:361.

6. Bough, W.A. 1974. Physical-chemical treatment of waste effluents from canning of leafy green vegetables. J. Milk Food Technol. 37:205.

7. Bough, W.A. 1975a. Coagulation with Chitosan-an aid to recovery of by-products from egg breaking wastes. Poultry Sci. 54:1904.

8. Bough, W.A. 1975b. Reduction of suspended solids in vegetable canning waste effluents by coagulation with Chitosan. J. Food Sci. 40:297.

9. Bough, W.A., and Landes D.R. 1976. Nutritional evaluation of proteinaceous solids recovered from cheese whey by coagulation with Chitosan. J. Dairy Sci. 59:1874.

10. Bough, W.A., and Shewfelt, A.W. 1973. Treatment of concentrated pimiento wastes with polymeric flocculating agents. J. Milk Food Technol. 36:619.

11. Bough, W.A., Shewfelt, A.L., and Salter, W.L. 1975. Use of Chitosan for the reduction and recovery of solids in poultry processing waste effluents. J. Poultry Sci. 54:992.

12. Bough, W.A., Landes, D.R., Miller, J., Young, C.T., and McWhorter, T.R. 1976. Utilization of Chitosan for recovery of coagulated by-products from food processing wastes and treatment systems. Proc. 6th Nat'l Symp. Food processing Wastes. U.S. Environ. protection agency, EPA-600/2-76-244.

13. Church, B.D., and Nash, H.A. 1970. Use of fungi imperfecti in waste control. Water poll. Cont. Res. Ser. 12060 EHT 07/70.

14. Church, B.D., Erickson, E.E., and Widmer, C.M. 1973. Fungal digestion of food processing wastes. Food Technol. 27:36.

15. Church, B.D., Widmer, C.M. and Espinosa, R. 1977. Fungal conversion of Carbohydrate wastes to animal feed protein-vitamin supplements. Proc. 8th Nat'l. Symp. Food Processing Wastes.

16. Clise, J.D. 1974. Poultry processing wastewater treatment and reuse. Water poll. Cont. Res. Ser. EPA-660/2-74-060.

17. Dostal, K.A. 1969. Secondary treatment of potato processing wastes. Water Poll. Cont. Res. Ser. 12060-07-69.

18. Ebertova, H. 1965. Anylolytic enzymes of *Endomycopsis capsularis*. I. Formation of the amylolytic system in cultures of *Endomycopsis capsularis*. Folia Microbiol. 14:14.

19. Environmental Protection Agency. 1970. Aerobic secondary treatment of potato processing wastes. Water Poll. Cont. Res. Ser. 12060 EHV 12/70.

20. Environmental Protection Agency. 1976. Anaerobic and Aerobic treatment of combined potato processing and municipal wastes. Environ. Prot. Technol. Ser. EPA-600/2-76-236.

21. Environmental Protection Agency. 1971. Combined treatment of domestic and industrial wastes by activated sludge. Water Poll. Cont. Res. Ser. 12130 EZR 05/71.

22. Environmental Protection Agency. 1975. Process design manual for suspended solids removal. U.S. EPA Technology Transfer, Washington, D.C.

23. Eldridge, E.F. 1947. Symposium on industrial wastes, canning industry. Ind. and Engr. Chem. 39(5):619.

24. Esvelt, L.A., and Hart, H.H. 1970. Treatment of fruit processing waste by aeration. J. Water Poll. Cont. Fed. 42:1305.

25. Esvelt, L.A., and Thomson, H.W. 1978. Reuse of treated fruit processing wastewater in a cannery. EPA 600/2-78-203.

26. Geisman, J.R., and Henne, R.E. 1973. Recycling food brine eliminates pollution. Food Engr. 45(11):119.

27. Glaros, T. 1978. Recycling and rejuvenating pickle brines from cucumber fermentations. Master's thesis, Ohio State Univ., Columbus, OH.

28. Grammes, L.M., and Kueneman, P.W. 1969. Preliminary treatment of potato processing wastes with by-product feed recovery. J. Water Poll. Cont. Fed. 41(7):1358.

29. Hang, Y.D. 1980. Assimilation of lemonade-processing wastewater by yeasts. Appl. Environ. Microbial. 39(2):470.

30. Hang, Y.D. 1977. Waste control in sauerkraut manufacturing. Process Biochem. 12(3):27.

31. Hang, Y.D., and Woodams, E.E. 1979. Characterizations of baked bean processing wastewater and its assimilation by _Aspergillus_ _foetidus_. J. Food Sci. 44:1548.

32. Hang, Y.D., and Woodams, E.E. 1981. Rapid removal of lactic acid from wastewater by a flocculant yeast. J. Food Sci. 46:1498.

33. Ismail, M.A. 1978. Physico-chemical treatment of Citrus packinghouse wastewater: Chemical coagulation. Proc. Fla. State Hort. Soc. 91:142.

34. Jarl, K. 1969. Symba yeast process. Food Technol. 23:1009.

35. Karim, M.I.A. 1984. Treatment of potato processing wastewater with coagulating and polymeric flocculating agents. J. Food Sci. _In_ _press_.

36. Karim, M.I.B.A. 1984. Potato wastewater treatment by physical-chemical and microbiological methods. Ph.D. Dissertation, Univ. of Arkansas, Fayetteville, AR.

37. Kasaeian, A.E. 1984. Use of chemical and biological methods in reduction of suspended and total solids of effluent from processing dry beans and hominy. Ph.D. Dissertation, Univ. of Arkansas, Fayetteville, AR.

38. Lamer, V.K. and Healy, T.W. 1963. Absorption flocculation reactions of macromolecules at the solid-liquid interface. Rev. pure appl. Chem. 13:112.

39. Leentvaar, J.,Buning, W.G.W., and Koopers, H.M.M. 1978. Physico-chemical treatment of municipal wastewater. Coagulation flocculation. Water Res. 12:35.

40. Lemmel, S.A., Heimsch, R.C. and Edwards, L.L. 1979. Optimizing the continuous production of *Candida utilis* and *Saccharomycopsis fibuliger* on potato processing wastewater. J.Appl. Environ. Microbiol. 38:227.

41. Lemmel, S.A., Heimsch, R.C., and Korus, R.A. 1980. Kinetics of growth and amylase production of *Saccharomycopsis fibuligera* on potato processing wastewater. J.Appl. and Environ. Microbiol. 39:387.

42. Mercer, W.A., and Rose, W.W. 1968. Chemical oxygen demand as a test of strength of cannery wastewater. NCA-WRL Rept. No. 816-56-B.

43. Moreton, R.S. 1978. Growth of *Candida utilis* on enzymatically hydrolyzed potato waste. J. Appl. Microbiol. 44:373.

44. National Canners Association. 1970. Preliminary summaries of a survey of solid wastes from canning and freezing. For Bureau of Solid Waste Management, U.S. Dept. HEW.

45. National Canners Association. 1971. Liquid wastes from canning and freezing fruits and vegetables. Water Poll. Cont. Res. Ser. 12060 EDK 08/71.

46. Neely, M.B. 1978. Effect of processing methodology on quality of wastewater and the quality of canned dry beans. Master's thesis, Univ. of Arkansas, Fayetteville, AR.

47. O.Melia, C.R. 1972. Coagulation and flocculation. In physico-chemical processes for water quality control. J.B. Weber, Jr. (ed.), Wiley-Interscience, N.Y.

48. Sistrunk, W.A. 1977. Primary treatment studies on wastewater and peeling methods for hominy. Unpublished data, Food Sci. Dept., Univ. of Arkansas, Fayetteville, AR.

49. Sistrunk, W.A. 1979. Water, waste and quality management during preparation and processing of vegetables. WRRC publ. 65, Univ. of Arkansas, Fayetteville, AR.

50. Skogman, H. 1976. Production of symba-yeast from sweet potato wastes. *In* Food and Wastes, Birch, G.G., Parker, K.J. and Worgan, J.T., (eds.), Applied Science publishers, London.

51. Smallwood, C., Jr., Whitaker, R.S. and Colston, N.V. 1974. Waste control and abatement in the processing of sweet potatoes. Water poll. Cont. Res. Ser. EPA-660/2-73-021.

52. Teot, A.S. and Daniels, S.L. 1969. Flocculation of negatively charged colloids by inorganic cations and anionic polyelectrolytes. Environ. Sci. and Technol. 3:825.

53. Whitehead, W.K. 1976. Evaluating and treating poultry processing wastewater. *In* 7th Nat'l. Symp. on Food Processing Wastes. EPA-600/2-76-304.

54. Wu, A.C.M., Bough, W.A., Holmes, M.R., and Perkins, B.E. 1978. Influence of manufacturing variables on the characteristics and effectiveness of cheese whey solids. Biotechnol. Bioeng. 20:1957.