Torula Yeast from Potato Starch Wastes

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Torulopsis utilis has been grown on the protein waste water from potatoes to yield a product with 55% protein. As much as 50% of the solids may be recovered as a yeast product without addition of any nutrients. When 40% of the solids are recovered with an accompanying 60% reduction in the B.O.D., an economic analysis based on 200 operating days per year and a 30-ton starch plant shows a total cost of 5 cents per pound. At this cost, the product would be competitive with fish meal. Further improvements, such as blending the yeast with the waste pulp from a starch plant, may make this process competitive with soybean and meat meal.

Most of the organic wastes from potato starch plants are concentrated in the protein wash water and potato pulp. Contamination of water supplies by starch plant wastes may be an important factor, as in the case of the Presque Isle Air Force Base during World War II (*21*). The pulp, which contains 95 to 96% water, may be limed, pressed, and dried for stock food. Concentrations of approximately 1.7% solids in the protein water at present make recovery of the dissolved solids which contain about 38% protein unattractive economically. Adequate quantities of inorganic nutrients and nitrogen suggest the extraction of this dissolved matter through yeast cultivation.

Laboratories of the Bureau of Agricultural and Industrial Chemistry have studied yeast production from citrus (*20*), pear (*15*), dairy (*14*), potato (*21*) sweet potato (*5*), and peanut (*11*) wastes. Propagation on wood sugar has been studied at the Forests Products Laboratory (*8*). Commercial propagation of *Torulopsis utilis,* which is commonly called torula yeast, on sulfite waste liquor is carried on at Rhinelander, Wis. (*23*). All these operations appear to be marginal for the production of a stock food. Dairy wastes are too dilute for economical recovery of the product. Most of the other wastes require the addition of nutrient nitrogen, phosphorus, and potassium for yeast to utilize sugars in the waste. Harris and coworkers (*8*) found that torula yeast required about 3.2 pounds of nitrogen, 1.5 pounds of phosphorus pentoxide, and 1 pound of potassium chloride per 100 pounds of reducing sugar. Higher nitrogen concentrations gave a higher protein yeast (*11*).

Torulopsis utilis has been found most suitable for the production of a food yeast from most waste liquors. It resists contamination by other organisms when the pH is held to 5 or below and yields a palatable product which is high in protein and vitamin content. It has been used both as a high-protein food and a vitamin B complex supplement.

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Propagation of Torula Yeast

Torula yeast is grown under aerobic conditions at temperatures of 28° to 36° C. Diffusional processes control the growth rate, which will depend upon the transport of food and oxygen to the cell and removal of the carbon dioxide and other products. In fortified sugar solutions, nearly half of the sugar is utilized in supplying energy to the cell. Various devices have been used for aeration and agitation of the medium. Air may be added by sparging tubes or supplied through vanes in an impeller agitator. Foaming which results from aeration is generally broken by the addition of chemical agents. Foaming has been partially or completely controlled mechanically by the use of downbeat impellers located near the liquid surface (*15*) or circulation of the liquid through a draft tube to control the formation of a foam layer on top of the liquid (*19*). The latter type, known as the Waldohf fermentor, has been used successfully in the continuous production of yeast from wood sugar and spent sulfite liquor without addition of antifoam agents. However, use of antifoam may be justified because of the apparently better growth in its presence and the decreased volume of the aerated solution (*2*). Better growth has been explained by the ability of surface active agents to decrease the bubble size greatly and thereby decrease the thickness of the films through which diffusion occurs (*9*).

The fermentation industry is turning to the use of continuous processes which give better control and lower operating costs (*24*), and require smaller and less equipment. Batch fermentation processes generally have a very slow rate of growth at the start, known as the induction period. As the organisms acclimate themselves, the reactions speed up. Continuous processes may be designed to operate in this range. If constant conditions are maintained within the fermentor by uniform addition and withdrawal of liquid, the material will have a certain average residence or holding time in the reactor. This time is calculated as the ratio of the active fermentor volume to the feed rate. If a high degree of sugar utilization is desired, the use of several reactors in series will be more efficient than a single reactor, because there is less chance that some of the feed will be "bypassed" directly to the product stream (*6*). When a high average conversion is desired, the presence of even minor amounts of unreacted feed in the product will necessitate nearly complete conversion of the remaining material and long holding times result. The holding time required for propagation of a yeast on waste liquors will be a function of other variables such as aeration, temperature, medium, agitation, and antifoam. However, at near optimum conditions, values ranging from approximately 2 to 4 hours have been reported for pear (*15*) and citrus (*20*) wastes, wood molasses, and sulfite liquor (*7*). A holding time of 4 hours is reported for the commercial plant at Rhinelander (*23*) which produces yeast from sulfite liquor.

Propagation on Potato Protein Water

In order to determine the feasibility of growing torula yeast on the protein water from a potato starch plant, a 30-liter fermentor described by Rivett *et al.* (*16*) was used. A $^1/_8$-inch copper cooling coil for heat transfer studies was added, as shown in Figure 1. Other modifications were the installation of four baffles having a width equal to 10% of the tank diameter and the use of a $^1/_{15}$-hp. variable-speed stirring motor with a rheostat control. Steel parts of the fermentor were coated with Tygon paint for corrosion resistance.

A protein water substrate for yeast growth was prepared by grinding potatoes with three times their weight of wash water containing 0.02% sulfur dioxide. After the solid material was filtered off, a protein water containing about 1.2% solids was obtained. These solids analyzed approximately 37% protein, 12% sugar, and 0.8% starch. The solution had a 5-day B.O.D. averaging 7720 p.p.m. Yeast propagations with and without added phosphorus, potassium, and calcium showed no advantage when these nutrients were added, and indicated that they are present in ample amounts. Various commercial antifoam agents were tested by bubbling a measured amount of filtered air through a mixture of protein water and the defoamer in a method similar to that described by Morse and Moss (*13*). The foam height at the end of a given time was recorded and a yeast count was made. Swift's inedible defoamer No. 1000 was found to be very effective in controlling foam and gave yeast growths many times greater than the substrate with no defoamer. Therefore, this defoamer was selected for yeast growth studies. It was added manually as needed to control foam formation.

A culture of *Torulopsis utilis* NRRL Y-900 was obtained from the Northern Regional Research laboratory for use in this investigation. Fresh cultures were maintained on agar slants. Before use, the yeast was acclimated by growth on the protein substrate.

An aeration rate of 1.2 volumes per solution volume per minute at a stirring rate of 400 r.p.m. was selected for this study. These conditions appeared optimum for the production of penicillin and streptomycin in this type of fermentor (*7*).

The temperature was maintained between 30° and 32° C. by immersion of the fermentor in a water bath. Approximately 3500 calories per gram of yeast produced were removed by cooling coils in the solution to maintain a constant temperature.

Yields and Operating Conditions

Preliminary propagations of yeast at pH's ranging from 4 to 8 showed a pH of 5 gave nearly optimum conditions without bacterial contamination. Higher values resulted in greater recovery of solid material from the protein solution, but showed serious contamination. At a pH of 5, *T. utilis* remained the dominant strain. Therefore, subsequent investigations were carried on at this pH.

The percentage of initial solids recovered through yeast growth and the corresponding reduction in the 5-day B.O.D. of the solution following separation of the yeast are shown in Figure 2. The propagation was carried on batchwise for 8 hours and then changed to a continuous process by feeding and withdrawing 2.5 liters per hour from the 10 liters of medium. The peculiar shape of the solids-recovery curve, *B*, may be explained by the precipitation of some protein by aeration alone, which is shown in curve *D*. If the per cent of solids precipitated by aeration alone is deducted from the total recovery by yeast propagation, a typical fermentation curve for a batch process is obtained, as given by curve *C*.

The solids-recovery curve for a batch process may be used to calculate the average holding time for continuous process, as explained by Adams and Hungate (*1*). Curve *B* indicates that 45% solids recovery is near the economic optimum because it shows both a high rate of recovery and a recovery only about 5% below the maximum. If the solids recovery of 45% is divided by the rate of solids recovery, which is 12.7% per hour at this point, a holding time of 3.55 hours is obtained. Actually, the medium was added and withdrawn at a rate which gave a holding time of 4 hours. Inspection of curves *A* and *B* indicates that this feed rate was too slow to hold the recovery or B.O.D. reduction constant and both continued to increase. A decrease in these values immediately after starting continuous operation was probably the result of the yeast's reaching a mature and less active stage as the nutrients were being exhausted. Utilization of some of the protein precipitated from the solution by aeration and yeast growth probably accounts for the correspondingly greater decrease in the solids recovery than in the B.O.D. reduction.

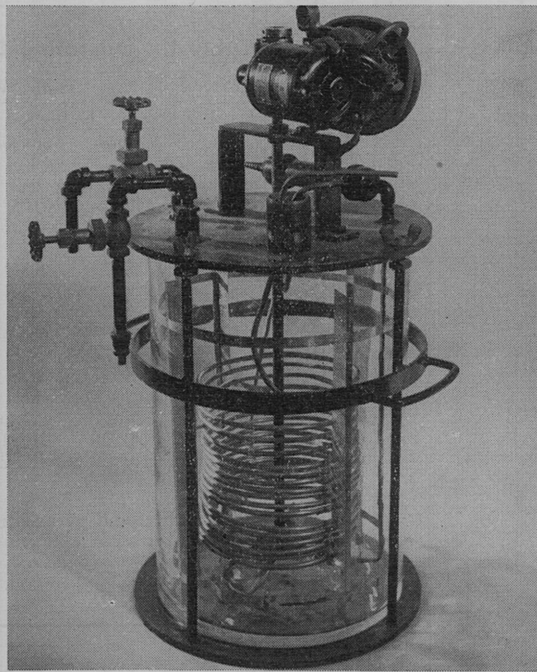


Figure 1. 30-liter laboratory fermentor

The yeast produced had a protein content of approximately 55%. Limited chick feeding tests indicate that it is about equivalent to a blend of fish, meat, and soybean meal as source of supplementary protein in a standard poultry ration.

After preliminary runs had been made in the fermentor described, some larger scale propagations were carried on, using 40 gallons of solution in an 80-gallon, jacketed, stainless-steel kettle. Air was admitted through a copper sparging ring in the bottom. The solution was stirred by an air-powered stirrer set at a 15° angle from the vertical and equipped with two 5-inch marine propellers. This design did not permit the use of aeration and agitation rates as large as desired or as those used in the small fermentor.

Preliminary Design of a Commercial Plant

The operating conditions used in the laboratory and those reported for the Rhinelander sulfite-liquor plant are shown in Table I. Also shown are the conditions chosen for the preliminary design of a yeast plant operating on the protein wash water from a 30-ton starch plant. The better mixing achieved with a Waldohf-type agitator should allow a considerable reduction in the aeration and agitation rates below those used in the small laboratory fermentor. For penicillin production, Brown and Peterson (*2*) found an aeration ratio of 0.09 volume of air to

Table I. Operating Data for Yeast Production

	Protein Water, Laboratory, 10 Liters, Batch	Protein Water, Laboratory, 10 Liters, Continuous	Protein Water, Laboratory, 40-Gal. Batch, I	Protein Water, Laboratory, 40-Gal. Batch, II	Sulfite Spent Liquor	Proposed Protein Water Plant
Feed						
Total solids, %	1.2	1.2	1.1	1.3	8.0[a]	1.7
Protein in solids, %	40.3	40.3	33.2	40.0	Negligible	38.5
Rate, gal./hour	...	0.66	...	...	5200	6700
Agitation energy						
Hp./100 gal.	5.1[b]	5.1[b]	0.02[c]	0.59[c]	1.25[d]	1.25
Aeration rate						
Volume ratio/min.	1.2	1.2	0.16	0.36	0.63	0.6
Yield data						
Solids recovery, %	45	45+	40	40	65[e]	40
Holding time, hours	3.6	4.0	12.6	9.1	4.0	4.0
Chemical requirements						
Nutrients added	None	None	None	None	N, P, K	None
H_2SO_4, lb./lb. yeast	0.20	0.11	0.28	0.28	None	0.11
Defoamer, lb./lb. yeast	0.20	0.023	0.14	0.12	None	0.023

[a] Fermentable sugar content of 1.5%.
[b] Fermentor was unbaffled and part of energy wasted in vortex formation.
[c] Estimated from Rushton's correlations (*17*).
[d] Estimated from equipment capacity.
[e] Estimated recovery of dissolved sugars.

solution per minute with the Waldohf type about equal to a ratio of 0.73 with the type of fermentor used in this study. If equal superficial air velocities are used as a basis for scaling up as recommended by Wegrich and Shurter (*22*), the aeration rate for a large plant could be reduced greatly from that shown in the table. Further experimentation is needed to establish more exact design conditions for agitation energy and heat transfer rates using methods described by Rushton (*18*), but the conditions chosen appear to be on the conservative side. A firmer correlation between the yeast yield and time is needed for an economic balance to determine whether one or two reactors in series would be more feasible. Greater recoveries would favor a series of reactors.

The conditions chosen for the design of a commercial plant as shown in Table I are based upon a 40% solids recovery, at which the corresponding B.O.D. reduction is approximately 60%. Higher yields and B.O.D. reduction are possible but at the expense of a longer holding time and larger equipment. Continuous operations require considerably less defoamer and acid than batchwise operations.

A flow sheet for the proposed plant is shown in Figure 3. Many features of the plant are similar to the Rhinelander plant (*23*) growing yeast on spent sulfite liquor, but in the potato waste plant many items of equipment can be omitted. There is no need for pretreatment of the liquor to remove sulfur dioxide and no nutrients need be added. As pollution is no great problem at present, only enough storage capacity for the medium is necessary to maintain constant feed conditions.

The propagator for this plant is the same as used at Rhinelander. A 50% expansion in the medium was observed upon aeration in the laboratory, but a 75% increase was allowed in this design which would require a 46,000-gallon tank for 4 hours holding time. The Rhinelander tank also has a working capacity of 46,000 gallons and is 26 feet in diameter and 14 feet high with a central draft tube 4 feet in diameter and 10 feet high. The propagator is fed from a 10,000-gallon storage tank of painted steel. Laboratory data indicated that about 3500 calories per gram of yeast product would have to be removed by cooling water and a heat transfer coefficient for the outside film of 175 B.t.u./(hour)(sq. foot)(° F.), and approximately 1500 feet of 3-inch aluminum pipe would be required to hold the temperature at 30° C. Further work may show 38° C. to be more feasible, as this temperature has been used for torula propagation and was selected for the Rhinelander plant. If aluminum-lined tanks are unobtainable, the material of construction is stainless-clad steel. However, the use of aluminum as a construction material is in-

Table II. Equipment and Fixed Costs of 4.5-Ton Yeast Plant[a]

Process equipment, installed cost	
10,000-gallon storage tank (painted)	$ 4,300
46,000-gallon agitated propagator (stainless-clad)	26,000
Blower for aeration of propagator	2,500
Aluminum cooling coil with pump (1500 feet of 3-inch pipe)	6,000
5000-gallon holding tank with agitator	9,200
Centrifugal yeast separator	21,000
Drum dryer	23,000
Product grinder	1,000
Solids storage bin for yeast product	2,000
Bagging machine	2,000
Total	$ 97,000
Instrumentation and laboratory at 10%, piping at 20%, building at 20%, auxiliary facilities at 5%, and contingencies at 15% for 70% additional	67,900
Total equipment costs	$164,900
Fixed costs	
Depreciation at 10%	$ 16,500
Working capital at 5%	8,200
Insurance, taxes, and maintenance at 8%	13,200
Total fixed costs per year	$ 37,900

Fixed cost (9100 pounds per day, 200 days per year) = 2.08 cents per pound.

[a] Actual production, 9100 pounds per day.

Table III. Operating Cost for 4.5-Ton Yeast Plant[a]

		$/Day
Operating costs		
Steam		
Evaporation of 85% water from centrifuged product, 55,000 lb. of steam at 40¢ per 1000		22
Electricity, hp.		
Propagator agitator	500	
Blower for aeration	10	
Cooling water pump	10	
Centrifuge	25	
Grinder	5	
	550	
Miscellaneous at 20%	110	
	660 hp. at 1¢ per kwh.	130
Labor		
Continuous duty of operator at $2/hour		48
Technical man on day shift at $3/hour		24
Daily cost of labor and utilities		224
Raw material costs, cents/lb.		
Defoamer, 0.023 lb./lb. of product at 18.75¢		0.43
Sulfuric acid, 0.11 lb./lb. of product at 12¢.		0.13

[a] Actual production, 9100 pounds per day.

creasing rapidly because of its desirable properties and reduced cost (*26*).

The product from the propagator flows into a 5000-gallon, stainless-clad tank with an agitator. This acts as a foam separator and serves as a culture tank in preparing inoculum for starting up.

Centrifugal separators separate the yeast solids from waste liquid. Approximately 15% solids content would be expected in solids coming from the separator, which are fed into drum dryers. After drying, the product is ground and blown into a hopper for bagging.

Economic Analysis

Cost estimates used in this work are based on data given by Chilton (*4*), Zimmerman and Lavine (*25*), and Dickson (*12*). The data are corrected to current prices by using the *Engineering News-Record* and Marshall and Stevens cost indexes (*3*). An installed cost of $164,900 is estimated for a plant to produce 9100 pounds of yeast per day on the protein waste water from a 30-ton starch plant, as shown in Table II. Based upon 200 days of operation per year, the capital costs per pound of product are calculated to be 2.08 cents per pound.

Estimates of the operating costs are shown in Table III. Instrumentation of this plant should make it possible for one operator to run it under the supervision of a technically trained man.

Table IV. Unit Cost of Yeast Production for 4.5-Ton Yeast Plant[a]

	Cents/Lb.
Raw materials	0.56
Labor and utilities	2.36
Fixed costs (200 days per year)	2.08
Production cost per pound	5.00

[a] Actual production, 9100 pounds per day.

The summarized unit costs given in Table IV show that the total production cost will be about 5 cents per pound. This price would not make such a venture economically attractive for a product competitive with soybean and meat meal which sell at about this figure, but it would be an important competitor to fish meal, which at present sells for about 9 cents per pound. The construction of a smaller plant would make the unit cost somewhat higher, as equipment costs are generally proportional to the 0.6 power of the capacity.

The waste pulp from a starch plant might be blended with the high-protein product to make propagation of the yeast more feasible. A 30-ton starch plant would produce about 13,300 pounds of waste pulp, for which a market is needed. By blending this with the 9100 pounds of yeast that might be produced and supplemental cereals, it seems that a well-balanced chick feed could be made. The composition of a blend based on average compositions as shown in Table V approximates the composition of chick feed and could represent the bulk of such a feed.

Table V. Composition of Ingredients and Blend of Yeast, Pulp, and Corn

Material	Pulp	Yeast	Corn[a]	Blend
% in blend	35.6	24.4	40	100
Composition (dry basis)				
Starch	42.0	..	62.0	40
Protein	6.0	55.0	13.0	21
Fiber	10.8	0.8	2.4	5.4
Fat	0.2	4.8	6.7	3.9
Ash	4.9	9.1	1.6	4.6

[a] Average of high and low fat values reported by Kerr (*10*).

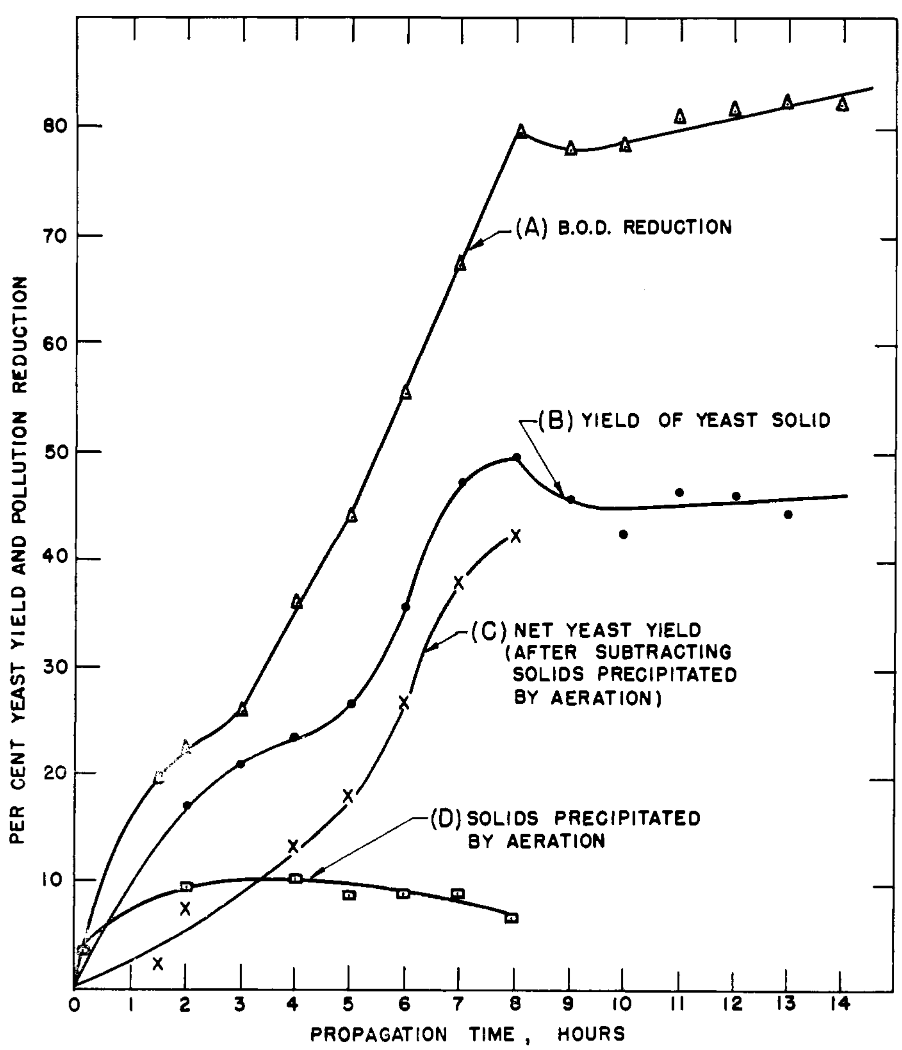
Another promising usage of the pulp by yeast growth exists in the addition of the pulp to the protein water fed to the propagator. The amphoteric nature of the nitrogenous material in the pulp makes dewatering of the pulp by pressing rather difficult. Yeast growth might aid in removal of such nitrogenous material and give a combined product of yeast and pulp that could be centrifuged and dried. This would eliminate costly pressing operations and make pulp utilization by drying more feasible than at present.

Conclusions

Laboratory scale experiments have demonstrated the possibility of propagating torula yeast on the waste protein water from a starch plant. Reductions of 60% or better in the 5-day B.O.D. would attend the production of a yeast food amounting to about 40% of the total solids fed in the solution. A 30-ton

Figure 2. Yeast growth on potato protein water

B.O.D. reduction of filtered solution and yields of solid product as per cent of solids in initial solution



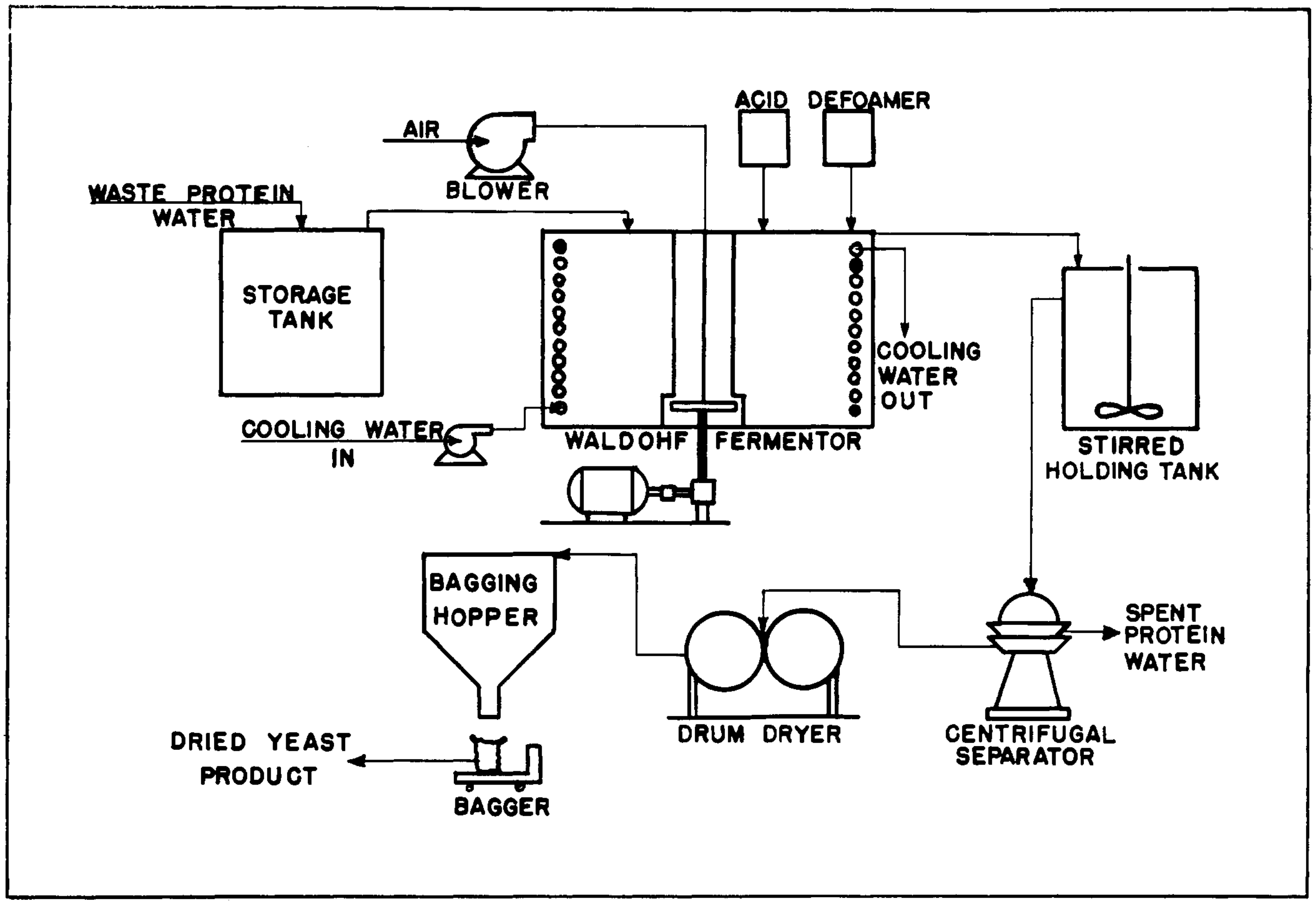


Figure 3. Flow sheet of proposed yeast plant

starch plant could produce approximately 4.5 tons of yeast daily at a cost of 5 cents per pound and an investment of $165,000. This cost may be reduced through a determination of the optimum economic conditions and the availability of aluminum equipment. Blending of the yeast with the waste pulp stream may make the process more attractive.

Acknowledgment

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Literature Cited

(1) Adams, S. L., and Hungate, R. E., *Ind. Eng. Chem.*, **42,** 1815 (1950).
(2) Brown, W. E., and Peterson, W. H., *Ibid.*, **42,** 1823 (1950).
(3) *Chem. Eng.*, **60,** No. 3, 220 (1953).
(4) Chilton, C. H., *Ibid.*, **56,** No. 6, 97 (1949).
(5) Dawson, P. R., Greathouse, L. H., and Gordon, W. O., "Crops in Peace and War," Yearbook of Agriculture, 1950–51, pp. 199–200, Washington, D. C., U. S. Government Printing Office.
(6) Eldridge, J. W., and Piret, E. L., *Chem. Eng. Progr.*, **45,** 290 (1950).
(7) Fortune, W. B., McCormick, S. L., Rhodehamel, H. W., Jr., and Stefanick, J. J., *Ind. Eng. Chem.*, **42,** 191 (1950).
(8) Harris, E. E., Hannan, M. L., and Marquardt, R. R., *Ibid.*, **40,** 2068 (1948).
(9) Hixson, A. W., and Gaden, E. L., *Ibid.*, **42,** 1792 (1950).
(10) Kerr, R. W., "Chemistry and Industry of Starch," p. 31, New York, Academic Press, 1950.
(11) Klatt, T. J., Parker, E. D., Pomes, A. F., and Porges, N., *Oil and Soap*, **22,** 319 (1945).
(12) Littleton, C. T., "Industrial Piping," p. 305, New York, McGraw-Hill Book Co., 1951.
(13) Morse, R. A., and Moss, H. V., *Ind. Eng. Chem.*, **44,** 346 (1952).
(14) Porges, N., Pepinsky, J. B., and Jasewicz, L., *J. Dairy Sci.*, **34,** 615 (1951).
(15) Ramage, W. D., and Thompson, J. H., "Producing Yeast from Processing Wastes," Yeast Symposium sponsored by Quartermaster Food and Container Institute, Milwaukee, Wis., Nov. 8, 1948.
(16) Rivett, R. W., Johnson, M. J., and Peterson, W. H., *Ind. Eng. Chem.*, **42,** 188 (1950).
(17) Rushton, J. H., *Ibid.*, **44,** 2931 (1952).
(18) Rushton, J. H., Costich, E. W., and Everett, H. J., *Chem. Eng. Progr.*, **46,** 468 (1950).
(19) Saeman, J. F., *Anal. Chem.*, **19,** 913 (1947).
(20) Veldhuis, M. K., Proc. First Natl. Public Health Engr. Conf., p. 24, Univ. of Florida, May 1952.
(21) Weaver, E. A., Heisler, E. G., Porges, N., McClennan, M. S., Treadway, R. H., Howerton, W. W., and Cordon, T. C., "Aerobic Microbiological Treatment of Potato Starch Factory Wastes," U. S. Dept. Agr., Bur. Agr. Ind. Chem., Eastern Regional Research Lab., **AIC-350** (1953).
(22) Wegrich, O. G., and Shurter, R. A., Jr., *Ind. Eng. Chem.*, **45,** 1153 (1953).
(23) Wiley, A. J., Holderby, J. M., and Hughes, L. P., *Ibid.*, **43,** 1702 (1951).
(24) Willkie, H. F., *Chem. Met. Eng.*, **52,** No. 5, 132 (1945).
(25) Zimmerman, O. T., and Lavine, I., "Chemical Engineering Costs," p. 142, Dover, N. H., Industrial Research Service, 1950.
(26) Zimmerman, O. T., and Lavine, I., *Chem. Engr. Costs Quart.*, **3,** No. 2, 41 (1953).

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