MEASURES TAKEN AGAINST WATER POLLUTION IN STARCH AND POTATO PROCESSING INDUSTRIES

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ABSTRACT

The following measures are considered for the reduction and discharge of wastes from potato processing plants and starch mills;

(a) Reduction of waste volume by in-plant measures such as recirculation, water re-use, changeover to other processes etc.

(b) Reduction of pollutional load.

1. Manufacturing of by-products.
2. Purification processes.

(c) Agricultural use.

(d) Direct discharge into a receiving water with a great self-purifying capacity.

1. SURVEY OF PRODUCTION AND UTILIZATION OF POTATOES

The International Symposium of 1965 at Fredericton, Canada on Utilization and disposal of potato wastes also dealt with this subject[1]. In Eastern Europe the emphasis is on quantity and total utilization of the potatoes (e.g. for livestock feed) while quality is steadily getting more attention[2,3]. In the Western countries a condition of crop surplus has become usual. Heavy emphasis is given to improved quality at all levels to stop the decline in total and per capita consumption of potatoes.

In the USA, Canada, Western Europe and Australia new human food uses have been developed since 1945. Regional preferences for potato products vary greatly. The frozen par-fried French fry potato is a major food product in North America, the long French fry of good texture being a premium item. In Europe, except for UK, Belgium and The Netherlands, this product is little known and instead a serious effort is being made to introduce the extruded 'pseudo French fry' made from dried potato mix. Dried dumpling mix is the major processed potato product in West Germany, while it is virtually unknown in North America.

The Netherlands especially have sufficient raw material for the production of potato starch[4]. In this very important industry in The Netherlands more than 1 500 000 tons of potatoes are milled for starch manufacture alone. The starch production in The Netherlands is about 300 000 tons per annum, which means around 80 per cent of the total production in the European

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Economic Confederation. The special selected industrial potatoes are grown on 400000 acres of arable soil in the north eastern part of the country. Most of the thousands of farmers are shareholders of the co-operative potato starch mills. Smaller potato starch mills exist in Germany, Eastern Europe and the potato districts of the USA (Maine) and Canada (New Brunswick). The manufacture of potato starch has a seasonal character; it takes place in The Netherlands from September up to December.

2. WASTE WATER PROBLEMS

Quantitatively speaking we can distinguish three categories of waste-water problems in relation with the utilization of potatoes.

1. Peeling apparatus for hospitals, barracks, prisons etc.
2. Potato processing industry.
3. Potato starch mills.

The first category usually discharges its effluent into the municipal sewers. The main purpose of internal measures in this case is to protect the sewer from clogging and putrefaction. The other extreme is the serious water pollution caused by the large potato starch mills.

All potato starch mills in The Netherlands are located in the north-eastern part of the country, together with the strawboard industry and part of the sugar industry and still discharge their wastes mainly untreated into the inland canals, which are consequently heavily polluted. Approximately 15 million population equivalents are discharged in this relatively small area; as much as the total population of The Netherlands. A standard factory—having a capacity of 1000 hectolitre potatoes per hour—produces 475 m^3 waste water per hour, with a total BOD_5 of 36000 kg per 24 hours. Apart from this, the standard factory discharges 430 m^3 flushing water per hour, with a BOD_5 of 1200 kg per 24 hours. In the first decennia of the potato starch industry, some 130 years ago, water was used up to 125 m^3 per ton of starch. The rapid mechanization around 1950 brought about a reduction to 50 or even 35 m^3 per ton of starch for the processing proper (washing water excluded).

The processing of potatoes into foodstuffs delivers waste water from the peeling stage as the main source of pollution. Lye-peeling especially produces a heavily polluted waste water. In most cases reduction of the total wastage of raw material during processing is possible, e.g. by using improved peeling methods. As the wastes of the potato processing industry have no toxic components, they can be treated by biological processes common in normal sanitary engineering. A primary treatment could be necessary in cases where much suspended solids are discharged.

For the larger processing factories and mills utilization of potato wastes for the recovery of by-products like potato protein and for the production of yeasts, bacterial cells, fungal mycelia and other rich feed concentrates could be economical and should get more attention as the world's protein shortage becomes more acute. Work in this field has been done in Eastern Europe, Sweden and the Netherlands[5, 6]. The direct combustion of wastes as a method of disposal seems to be impractical at present.

Where water resources are becoming scarce, emphasis is given to a reduction of the overall amounts of process water. A high recirculation rate will be a common practice in future. It seems that we could manage in most cases with 10–25 per cent of the present usage of water for processing without loss of product quality.

3. COMPOSITION OF POTATO TUBER AND POTATO JUICE

The main component of the potato tuber is starch, which amounts to 80 per cent of the dry solids and 20 per cent of the total mass of the potato. The proper skin and the underlying layers (periderm) are starch-free. The starch grains are embedded in the cells of the parenchym. Relatively little starch is formed in the cells surrounding the vascular strains and in the pith. The starch grains have a flattened, oval shape and measure $\pm 50\mu$. After disintegration of the cellular walls, the contents of the cells become fluid, thus the starch grains can be washed out.

In the starch plant the components of the potato are divided into:

1. Pulp (cell walls, skin material etc.).
2. Potato juice (containing practically all soluble components).
3. Starch grains.

Potato starch is a rather pure polysaccharide, containing both linear are branched chains based on the monomer glucose (respectively amylopectine and amylose). The industrial product is delivered with a standardized moisture content of 20 per cent.

The starch content of the tubers varies from 0–25 per cent but usually amounts to about 20 per cent. The amount of proper cell walls in the potato is about 1.3 per cent among which 0.6–0.8 is cellulose. The waste pulp produced at the starch plant, however, contains approximately 40 per cent starch and approximately eight per cent crude protein with relation to the dry solids. Usually the starch content of the pulp is controlled (and especially the part that could be washed out with extra water) in order to prevent intolerated losses of more than five per cent. Thus the starch recovery amounts to approximately 95 per cent.

The undiluted potato juice contains about five per cent dry solids, approximately half of which are organic nitrogen compounds, mainly proteins and amino acids. The amount of potassium is 0.5–0.9, mainly as K_2HPO_4. The potato juice discolours in contact with air, due to oxidation of the amino acid tyrosine catalysed by the enzyme tyrosinase. The colour first changes to red and finally becomes black as a result of the formation of polymeric pigments (melanine). These reactions are inhibited or delayed when sulphur dioxide is added. The pigments are strongly adsorbed by the starch, but can be washed out. Proteins, however, adsorb the pigments almost irreversibly. It is necessary to prevent an extended contact of starch and potato juice after the disintegration of the cells and to wash the starch intensively.

4. POTATO PROCESSING INDUSTRY

(i) Waste water production in the potato processing industry

In the potato processing industry the skins of the pre-washed tubers are usually loosened by a lye treatment or by steaming, followed by the removal of the skins in rotating washers. Trimming is done on grading belts, which convey the potatoes to the slicers or other processing apparatus. The average peeling and trimming losses can amount to more than 20 per cent by weight. The wastes from the afterwasher are consequently heavily polluted, with a BOD_5 up to 3000 ppm.

Several studies have shown that approximately 90 per cent of the BOD from a potato processing industry comes from the peeling operation regardless of the particular method used. An essential dry peeling method would greatly reduce the waste water problems. Experiments have been made with new peeling techniques, such as by gentle abrasion, by contour knives, by flame and by improved lye peelers, in order to find a commercially feasible solution. Losses of product into suspension or solution at other stages of processing are also investigated, with a view to modifying machines or techniques used for processing potatoes.

(ii) Potato processing waste water treatment

Primary treatment or removal of solid particles and sludge is already common practice, especially in Western USA where most potato plants can meet a standard of 97–99 per cent removal of the insoluble solids, resulting in a COD reduction of 55–60 per cent. Prompt fluming and screening out of solid waste is necessary. Coarse particles, e.g. culls and trimmings greater than a quarter inch dimension, can be easily removed by screening. Screens or strainers could also be used for removal of much smaller particles but straining of these fines has certain limitations where a rather dry material is required. Very fine particles and sludge can better be removed by sedimentation. The vibrating type of screen appears to offer the great advantage of producing a relatively solid cake that could be used as a feed for livestock. Screening proper, however, has no great beneficial effect on the total waste discharge. Total solids removal of 35 per cent by screening potato wastewater through a 20 mesh screen is the best that could be expected. If the objective is to provide a system which will significantly reduce the organic load, a good sedimentation system will be necessary. In this case additional equipment for sludge dewatering and processing will also be required. An efficient primary treatment system prevents or greatly reduces the costs of a secondary treatment.

Secondary treatment can be achieved in trickling filters, activated sludge plants, oxidation ditches and stabilization ponds. Plastic biofilter packings could be used as very effective oxidation units for quickly removing about 50 per cent of the BOD_5 from strong wastes. High rate activated sludge treatment has been successfully used in Maine and results in about 95 per cent removal of the BOD_5. With present knowledge, the production of fuel (methane) from potato wastes is not economically attractive. Lagoons are usually 'in a bad smell' unless they are not overloaded and controlled properly. Without mechanical aeration they can deal with organic loads of 10–20 kg BOD_5/acre/day in northern climates based on an annual cycle. Good mechanical aeration could speed up the whole process. A tertiary treatment in a suitable lagoon could be a valuable addition to most secondary plants.

Oxidation ditches appear to be a very good system for treating potato wastes from smaller plants as they are simple to construct, operate and maintain and can deal with heavy and fluctuating loads. The purification rate can reach 95–98 per cent.

5. POTATO STARCH MILLS

(i) The manufacture of potato starch (*Figure 1*)

(a) *Washing of potatoes.*—Water is used to rinse away sticking sand and peat together with foul potatoes and other contaminants. Any—even polluted—water is good enough for this purpose, provided that it is free from sand, in order to prevent exorbitant wear and tear of apparatus. If necessary waste water from other parts of the plant may be used for this purpose. It will be understood that in case of high costs of water a suitable solution can be found to remove the sand and re-use the water[8]. In this part of the plant scarcity of water will immediately induce an economization. Therefore we may expect the consumption of water and thus the discharge of waste water at this part of the factory to be reduced in the near future to a small percentage of the current quantity. Two or three hundred litres of clean water per ton of potatoes are sufficient to rinse away the adhering polluted water.

(b) *Grinding.*—The washed potatoes are disintegrated with rasps, consisting of a rotating cylinder to the surface of which are fitted many blades like those used in hack saws. These saws rupture the potato cells and liberate the starch grains. The slurry of grated potatoes might be diluted with water, at any rate a solution of sulphur dioxide is added in order to inhibit the darkening of the fruit water.

The starch milk is removed as completely as possible on a screen after which the remaining pulp is ground and extracted another time. This time rasps of a slightly different construction are used in which the ground pulp is forced through a perforated plate. Regarding the large power consumption of these machines, the liberation of the last per cent of starch is omitted.

(c) *Screening.*—Before 1939 flat vibrating screens were used to wash the slurry of ground potatoes but in 1950 these were replaced almost everywhere by rotating machines of different types. As an example we mention the centrisieve, in which the extracted pulp is forced by centrifugal action through the wide end of the cone. *Figure 2* shows a scheme on which the pulp moves in counter-current with clean water in order to accomplish a minimum of water consumption. In practice, however, this experience is not yet fully applied. In most cases 30–35 m^3 water (of which at least 15 m^3 clean water) is used per ton of starch.

From the angle of water economy it is attractive to use as little water as possible in every stage of the operation and to use more stages if necessary. The utmost minimum is the quantity required for fluidisation of the dewatered pulp from the centrisieves. For the last stage of grinding this means approximately 5 m^3/ton of starch. In the first stages more water is required, but the missing quantity can be supplied with water from one of the starch washing machines.

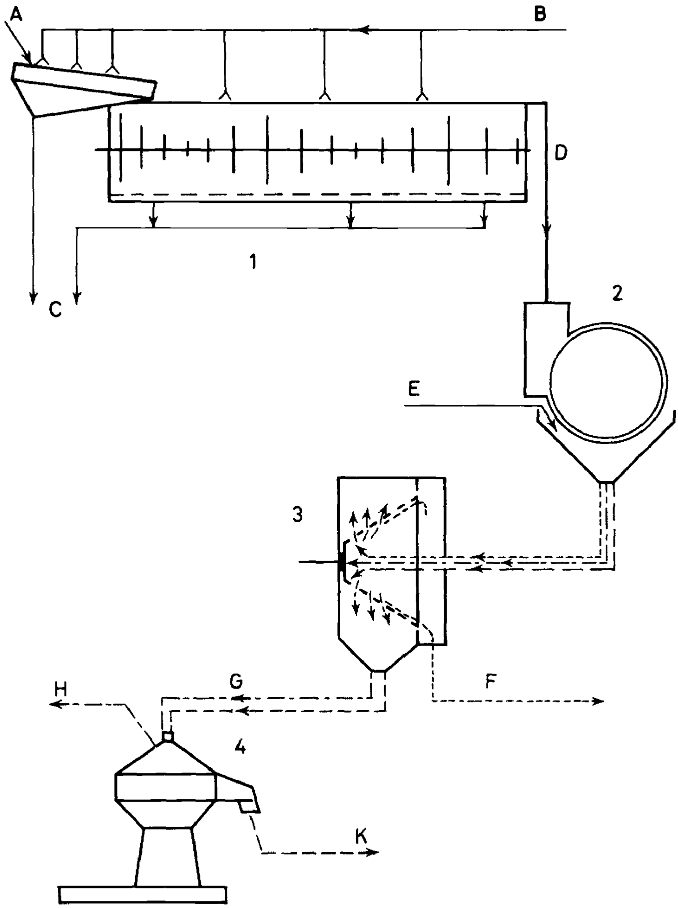

Figure 1. Starch plant.
1. Potato washing
2. Rasp
3. Centri-sieve
4. Separator

A. Potatoes
B. Water
C. Washing water
D. Washed potatoes
E. SO_2-water
F. Pulp to secondary rasp
G. Starch milk
H. Protein water to protein plant
K. Starch concentrate

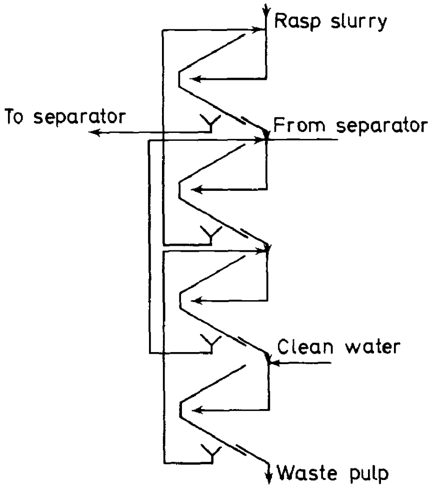

Figure 2. Counter-current starch extraction with centri-sieves.

(d) *Separation.*—This operation may have two purposes:

1. The immediate separation of starch and fruit water, in order to prevent as far as possible the discolouring of the starch.
2. The collection of as much as possible of the highly concentrated dissolved components for the recovery of by-products.

For the second purpose filtration through vacuum filters or sieving centrifuges could be applied. In practice, however, this brings about serious problems. The most common practice therefore is the concentration of the starch milk until a suspension of approximately 30 per cent (at most 45

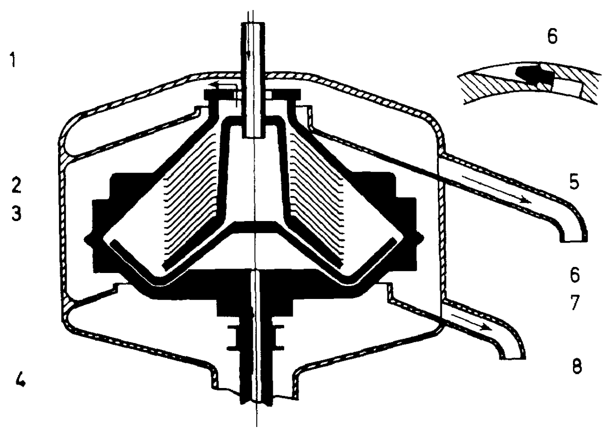

Figure 3. Disk separator

1. Supply
2. Stator
3. Disks
4. Hollow spindle for washing water
5. Wastewater discharge
6. Nozzle
7. Starch milk discharge
8. Hood

per cent) dry solids. For this purpose hydrocyclones or disk centrifuges could be used. An important improvement is the disk centrifuge in which the concentrate is washed near the nozzle in counter-current with clean water, which makes it possible to reduce the remaining pollutants by 85 per cent (see *Figure 3*).

(e) *Washing of starch.*—After concentration the starch milk usually passes two more washing separators with a suitable dilution in between (see *Figure 4*). The minimum of water required for a counter-current washing

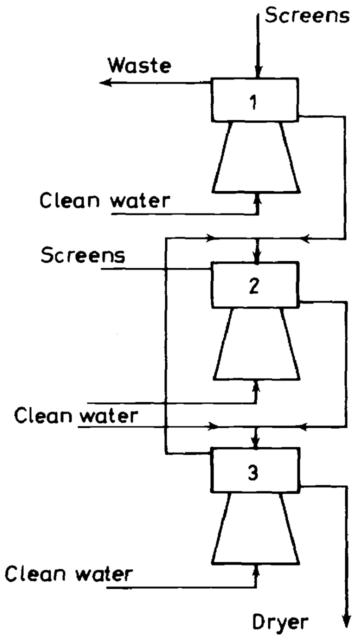

Figure 4. Counter-current starch washing with disk separators.

amounts to 5 m^3/ton of starch. But furthermore 2–8 m^3/h of water is required per machine for flushing within the rotor. Regarding the counter-current washing this ought to be clean water only in the last stage. For various reasons, however, it is undesirable to use polluted water in these machines.

(f) *Dewatering and drying.*—As no polluted water is produced here we will not deal further with these stages of starch manufacture.

(ii) Possible recovery of by-products[9]

As the utmost minimum of water consumption we have to reckon with 15 m^3/ton of starch: 5 m^3 for the screens and 10 m^3 for the washing stages. In case of a homogeneous mixture this would mean a dilution of the potato juice of approximately 1:3. In case of recovery of by-products this could be a disadvantage. Therefore a separated collection of concentrated fruit water and diluted process water could be profitable. About 50–70 per cent of relatively concentrated fruit water (or protein water) could thus be collected.

The following quantities of valuable components are discharged every year together with the waste water of the potato starch mills in The Netherlands.

15000 ton protein
15000 ton non-polymeric nitrogen compounds, among others amino acids
5000 ton sugars
15000 ton minerals, mainly K_2HPO_4

It will be clear that this could be a source of valuable by-products, which especially in times of war has focused considerable attention. Especially the coagulable protein could be isolated on a technical scale. An economically usable process, however, was not achieved until about 1950.

In this year the co-operative starch industry in The Netherlands started renewed research in this field. A patented process has been worked out which already has been applied at three Dutch, one Romanian and two Japanese starch plants[10].

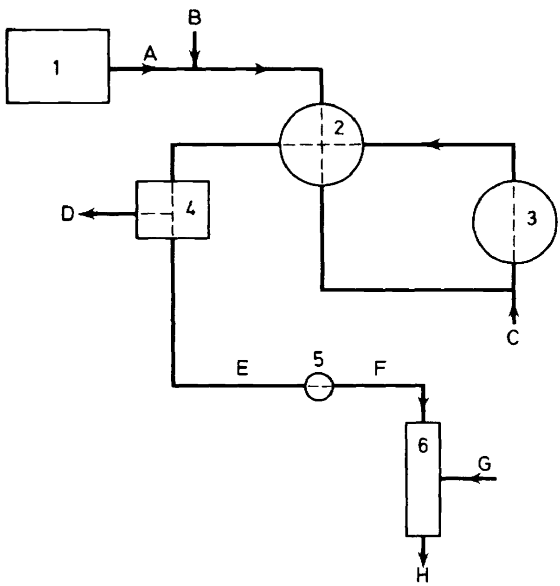

Figure 5. Protein plant (schematic).

1. Starch plant
2. Heat-exchanger
3. Coagulator
4. Dewatering
5. Grinder
6. Dryer

A. Protein water
B. SO_2-water
C. Steam
D. 'Rest-water' to biological treatment
E. Protein cake
F. Wet protein powder
G. Dried product

(iii) Protein recovery

About one per cent of the potato tuber consists of real proteins, of which 20 per cent are of albuminous and 80 per cent are of globulinous character. Globuline coagulates at a low pH value already at room temperature, while albumine can only be flocculated by heating until at least 80°C. This underlines once more the necessity of collecting the fruit water as concentrated as possible, from an angle of heat economy.

Figure 5 shows a scheme of the protein process. The pH of the fruit water is reduced to $4\frac{1}{2}$ with sulphur dioxide and it is next warmed up by heat-exchange with the already heated protein water. The proper coagulation takes place by steam injection. The flocculated protein is thickened and dewatered. More attention will be paid to the following parts of the process.

(a) *Heat-exchanger.*—A common heat-exchanger is inclined to be rapidly stopped up by proteins which coagulate on the heat-exchanging surfaces. Rather good results can be achieved by cooling in a vacuum evaporator. The steam produced is used to warm up the entering fruit water in a barometric condensor.

(b) *Coagulation.*—The heating until 95 per cent can be achieved most simply by means of a steam ejector. In order to ensure a good dewatering by means of filterpresses, it is necessary to do this with steam of at least seven atmospheres.

(c) *Concentration and dewatering.*—By means of sedimentation in a suitable system a protein concentrate containing about four per cent of dry solids can be obtained. Further dewatering can be achieved by filtration or with separators. The filter cake can be disintegrated and dried in a pneumatic dryer. The liquid concentrate of a separator can be worked up in a spray dryer.

(d) *Product characteristics and purification effect.*—The dried product has a content of valuable protein of 70–75 per cent and may be used in feed-mixtures, e.g. for young pigs. The reduction of the BOD_5 of the original fruit water amounts to approximately 50 per cent.

In case of a fruit water recovery of 50–70 per cent in the first stage of the starch plant the reduction of the total pollutional load amounts to approximately 25–30 per cent.

(iv) Further treatment of the deproteinised 'rest-water' and other diluted wastes

The deproteinised 'rest-water' of the protein recovery plant contains among others amino acids, sugars and inorganic nutrients and thus forms an ideal medium for many micro-organisms and can be compared with corn steep liquor. Recovery of certain compounds separately as by-products has been considered and it has even been proved possible to produce asparagine on a small scale, but the market for such expensive products is extremely limited. The rest-water could also be used as a matrix for various microbial syntheses, e.g. of vitamin B_{12} and fodder yeast. Working in monocultures, however, is not attractive with regard to the enormous amounts of waste water which are to be dealt with.

Investigations have therefore been made as to whether it would be possible to purify the rest-water by means of a biological treatment with activated sludge. It was intended to utilize the activated sludge also in one form or another as a livestock feed component. It is well known that such an activated sludge may contain large quantities of vitamin B_{12}.

An oxidation ditch which had been adapted to this aim, has been used as a pilot plant. The waste (BOD_5 about 10000 ppm) was fed to the circuit of 200 m^3 volume at a rate of 3 m^3 per hour. The detention time thus was three days. In the ditch, three rows of cage rotor each of a length of about 4 m were installed. Without any sludge recirculation a suspended sludge content developed up to a level of 5000–10000 ppm. After centrifuging, the BOD_5 of the effluent was normally less than 500 ppm. The separation of the sludge from the effluent by means of sedimentation sometimes gave rise to difficulties and needs further investigation.

The bacterial sludge has a very high vitamin B_{12} content *viz.* 10 ppm of the dry solids. In this experiment the protein spray dryer which was available during weekends only, had to be used for the drying of the stored sludge, in which putrefaction occurred which resulted in a very bad-smelling product.

It proved to be possible to initiate a lactic acid fermentation by adding two per cent glucose to the concentrated activated sludge. This fermentation has a preservative effect, similar to that in sauerkraut, buttermilk and yoghurt. Such a lactic acid fermentation occurs spontaneously in wet stored potato pulp, which is also used as a livestock fodder.

The described procedure even makes it possible to postpone the working up of the lactic acid sludge till after the end of the campaign which has considerable advantages. The dried product still has a vitimin B_{12} content of 5 ppm of the dry solids.

With the process of deproteination together with aerobic biological treatment of the 'rest-water', 60 per cent of the total BOD_5 of the potato waste can be removed. On the basis of calculations it may be expected that this result could be achieved without either heavy losses or high profits.

For the treatment of the residual 40 per cent of the pollution which is largely contained in the more diluted part of the waste water, an oxidation ditch type of treatment could be used. For this purpose Pasveer suggests an aeration of the waste in a series of aeration basins, each basin with a volume providing for a detention period of 12 hours[11]. The capital cost of such an installation is restricted to a necessary minimum.

6. DISCHARGE OF POTATO WASTES INTO ESTUARIES

All over the world estuaries play an important part as receiving waters for large quantities of organic and inorganic wastes. These can be transported by the rivers, yet they are also discharged directly as mixtures of domestic sewage and industrial wastes from the generally densely populated regions in the deltas.

The scientific treatment of estuarine problems is particularly difficult since the estuary is a boundary region of variable conditions between fresh and saline water. In spite of the obvious difficulties, much work has been done to assess loads and to indicate suitable places of discharge and measures to obtain satisfactory pollution control.

Eggink has done this with relation to the enormous quantities of wastes from potato mills and strawboard factories in the north eastern part of The Netherlands[12]. As a result of this study a project for constructing a pipeline to the Eems estuary has been worked out. It is expected that the oxygen balance can be controlled sufficiently. No forecast was made with respect to the ecological conditions of the natural biotope of the estuary and the Waddensea. Further studies have made clear, however, that the pollutional load will have to be greatly reduced before discharge to the estuary.

7. AGRICULTURAL USE

Waste from potato starch mills shows high fertilizing value and lacks substances which are harmful to the soil and to plants so that agricultural utilization is rational and effective.

In Poland most of the starch plant effluent is utilized for the irrigation of pastures and fields[2]. Szebiotko supplies the following information on this subject, applying to a waste water production of 20–22 m^3 ton of potatoes.

1. The optimal annual dose for the irrigation of grassland is 300–500 mm.
2. On fields irrigated with effluent the most effective results were obtained with plants for fodder: namely beets, sunflower, corn, cabbages, potatoes, cereals, sugar beets and carrots.

Effluent dosage up to 400 mm may be satisfactory under the condition that in the case of cereals they should not be above 200 mm. When fields are irrigated by spraying, the dosage should not exceed 200 mm, otherwise correct assimilation cannot be assured and the nutrients move into the groundwater, which is undesirable. For rapid and economic effluent utilization on light soils, the fields treated with effluent should be irrigated with pure water during the summer. Pine forests should not be irrigated with effluent from starch plants as even low doses destroy the trees within a few years.

In The Netherlands Riem Vis investigated the fertilizing effect of nitrogen, phosphate and potash from process effluent of potato starch factories in four long-term field trials and one pot experiment[13]. Dressing of at most 125 mm effluent (1250 m^3/ha) can be considered safe for the most frequently grown edible crops. When this quantity is supplied the usual application of fertilizers can be omitted. Crops with a long growing period, e.g. potatoes, sugar beets and in particular leys, give the best results. The process effluent decreases the pH and increases the supply of easily soluble phosphates, potash and magnesium in the soil.

REFERENCES

[1] *Proceedings International Symposium Utilization and Disposal of Potato Wastes.* Fredericton. New Brunswick, (1966) (with many references).

[2] K. Szebiotko. *Total Utilization of Potatoes, including the Disposal of Industrial Wastes.* Ref [1].

[3] Malcher *et al. Die Stärke* **18**,141–154, 390–392 (1966).

[4] J. C. Hesen. *The Potato Processing Industry in the Lowland Areas of Europe and the Utilization and Disposal of Potato Waste.* Ref. [1].

[5] J. Jenicki, K. Szebiotko and St. Stawicki. *Potatoes and their Industrial Wastes as Media for Yeast Production.* Ref. [1].

[6] A. G. Jönsen, *Die Stärke* **16**, 66–71 (1964).
[7] W. Kröner and W. Völksen, *Die Kartoffel* Leipzig (1950).
[8] A. H. A. de Willigen. *Saving of Water in the Potato Starch Industry (Dutch)* Proceedings of Machevo-congress, Ijmuiden, The Netherland
[9] H. Peters. *De Ingenieur* **72**, Ch. 47 (1960).
[10] M. Vlasblom and H. Peters. Netherl. pat. 87150 (1957).
[11] A. Pasveer. *The Use of the Oxidation Ditch for the Purification of Domestic and Industrial Wastes.* Ref. [1].
[12] H. J. Eggink. *Predicted Effects of future Discharges of Industrial Wastes into the Eems Estuary.* Proc. 3rd Int. Conf. on Water Polln. Research, Washington, D.C. (1966).
[13] F. Riem Vis. *H_2O* **2**, 105–107 (1969).