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MEASURES TO MINIMIZE AQUEOUS WASTE POLLUTION FROM
FERTILIZER PLANTS SITUATED IN AN INTEGRATED CHEMICAL COMPLEX^{1/}

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We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche.

1. Outline of the situation

Near Geleen in the southern part of the Netherlands a large chemical complex is located comprising production facilities of DSM and its affiliate UKF (Unie van Kunststofabrieken), a major fertiliser producing company in the Netherlands. Some 25 plants at this site can be divided into five groups, four of which manufacture chemical products:

- a. the Nitrogen Fixation Works (NFW) of UKF; main products; fertilizers and urea;
- b. the Organic Products Group (OPG); main products: caprolactam, acrylonitrile and melamine;
- c. the Hydrocarbons Group (HG); main products: ethylene and propylene;
- d. the Polymers Group (PG); main products: high- and low-density polyethylene, synthetic rubber, polyvinyl chloride, and, shortly, ABS resin.

The fifth Group, the General Technical Services Group, provides for a range of general utilities by power stations, water-treatment plants, sewer systems, purification installations, etc.

The water effluent of these plants is typical for a integrated chemical complex in which fertiliser production takes an important place.

It is discharged to the river Maas by 4 routes, which are indicated in figure 1 by I-IV. Additional information is given in the table I, showing that all waste water is now subjected to mechanical purification and that the biologically degradable components of one of the streams are disposed of in a Pasveer ditch. The other components, including all nitrogen compounds, are discharged to the river Maas. The quantities are shown in table II. Table III indicates DSM's*) share of the total pollution of this river (amounting to 21.5 % of the total N quantity).

As a consequence a number of problems arise.

- 1) The flow of the river Maas depends on the rainfall and is therefore subject to strong fluctuations, amounting to more than $10^3 \text{ m}^3/\text{s}$ in winter time and, often, to less than $2 \text{ m}^3/\text{s}$ at the end of the summer. (The figures represent daily averages.) The total volume of the waste water discharged by DSM is nearly $1 \text{ m}^3/\text{s}$, which means that hardly any diluting effect occurs during the dry season and that the risk of fish mortality is high.
- 2) In the river the ammonium compounds are oxidized into nitrate, during which process a large amount of oxygen is used.
- 3) The nitrate discharged and formed through oxidation of ammonium compounds has a detrimental effect on the quality of the drinking water, which is to be prepared from the river water to an increasing extent according to government plans.
- 4) The nitrogen compounds promote eutrophication (growth of algae) in the river.

It will be clear, particularly now that the Act on Pollution Control of Surface Waters has become effective, that also DSM is required to drastically limit the discharge of waste materials. In accordance with an advice given by the Working Group for Sanitation of the River Maas (a Working group installed by the Government) it is the intention to reduce not only the discharge of organics but also that of nitrogen compounds, considering DSM's large share. Prior to dealing with the methods DSM intends to apply to realize this, a few remarks are made about the existing facilities for the purification of waste water.

*) For the sake of convenience in the following the word DSM will be used, when the whole complex of DSM and UKF is meant.

2. Existing facilities

In all discharge routes mechanical purification apparatus is installed (table I) by means of which suspended substances are removed. Route II comprises the so-called Pasveer ditch, for removal of biodegradable organics. This installation was put into operation in 1964, initially for the main purpose of purifying the waste water discharged by the two coking plants then operated by DSM. The last coke-oven battery was shut down in 1968. To-day, the whole water effluent of the Hydrocarbons and Polymers Groups, as well as part of the waste water discharged by the Organic Products Group, is disposed of by this route.

The decision to construct the Pasveer ditch was made after extensive research had been carried out by a team headed by the late Ir. D. Adema, who has greatly contributed to its realization. The work also comprised two years of testing on a semi-technical scale:

- a) in an active-sludge installation, with retention times of from 3 to 5 hours at high sludge loads;
- b) in an oxidation ditch, with retention times of from 2 to 3 days at low sludge loads.

The investigations clearly showed that the oxidation ditch operating according to Dr. Pasveer's guiding principles (low sludge loads and a long retention time and, hence, a large buffer capacity), involves a major advantage compared to an active sludge installation, namely a great insensitiveness to shock loads. Especially in a chemical plant, these may be brought about through a number of causes. Leakages, overflowing of tanks, minor and larger calamities may result in huge amounts of waste materials suddenly reaching the sewer and, subsequently, the purification installation, so that complete or partial elimination of the biomass would ensue.

The insensitiveness to shock loads becomes apparent, from figure 2 showing the influence of a period of very low pH on both types of waste water treatment, during the period of testing in semi-technical plants. It is quite clear that the oxidation ditch was capable of absorbing peaks with practically no consequences, whereas the purification process in the active-sludge installation is interfered with (see References 1). Figure 3 provides an impression of the installation in its present design. Originally, aeration was only by means of rotors; in 1969 and 1972 floating impeller-type

aerators were added and in 1973 waterjet aerators, which will be treated in more detail later on. The total oxidation capacity now equals about 0.5 million p.e. (1 p.e. equals 54 g/d BOD).

In table IV the purification results for three typical periods are listed, and table V gives a broad summary of the costs.

In general, the installation has performed excellently and a large quantity of biologically decomposable material has been removed from the effluent discharged to the river Maas. Disturbances have occurred only very rarely, which shows that, in accordance with expectations, the ditch is very well capable of coping with shock loads. The COD load, though constantly increasing in the course of the years, could be dealt with without any great problems. For further information see References 2 and 3.

As regards the sludge production the following remarks have to be made. Sludge production is small as long as an installation is operated in accordance with Dr. Pasveer's principles, and the sludge will be largely mineralized, so that rotting no longer occurs when the sludge is dumped. It was therefore expected that the sludge surplus, together with the material separated off in the settling basins, could be lumped in quarries. In practice, however, the 'Pasveer' conditions were deviated from rather soon. The ditch was subjected to heavier loads, so that the sludge was mineralized to a lesser extent and the amount was larger than expected and dumping became impossible. For this reason the sludge surplus has so far been discharged together with the effluent. Although plans were made for the construction of a sludge treatment installation, such plans were not put into effect when it became clear that the Pasveer ditch would be too small for future needs and would not satisfy the demands to be expected. As already mentioned DSM will have to remove not only organic substances but also nitrate- and ammonium-nitrogen, and under the conditions prevailing in the Pasveer ditch, this does not take place, or to a small extent only.

Since a large portion of DSM's waste water is discharged in non-purified condition a control system was designed in 1970 after fish mortality in the river Maas had occurred a few times. The quality of the water discharged into the river is checked permanently by means of frequent analyses and a continuous fish test. Moreover, all disturbances occurring in the plants are reported immediately at a central point. In case of difficulties, measures can be taken rapidly. For instance, the water effluent may be wholly or partly

caught in a buffer pond for a certain period. It has appeared possible in this way to avoid peaks in the discharge to the river, so that even at low water volumes no abnormal fish mortality rate has occurred so far (see Reference 4).

3. Future situation and measures planned

In consultation with the authorities it has been agreed for DSM to aim at reconditioning, prior to 1977, the effluent discharge to the river Maas, in which not only the discharge of organics but also of nitrogen compounds will be reduced drastically.

Various methods are available for removal of these components from waste water:

- COD: adsorption to active carbon; biological decomposition.
- NH_4^+ : ion-exchange; stripping with air; oxidation with chlorine; biological oxidation (nitrification).
- NO_3^- : ion-exchange; biological reduction (denitrification).
- Organically bound N (which, though not yet mentioned, is also present in DSM's waste water): adsorption to active carbon; biological decomposition, during which NH_4^+ is formed (organically bound N and NH_4^+ -N are, together, called Kjeldahl-N).

Considering the current level of technology, DSM is of the opinion that a mixed waste water stream like hers can best be purified biologically, in spite of the objections attaching to this, viz. sensitiveness to poison and the fact that only the biodegradable part of the organics is removed. Considering, amongst others, the favourable experience acquired with the Pasveer ditch in its present design, DSM decided, to construct a new purification installation for removal of organics, Kjeldahl-nitrogen and nitrate-nitrogen with the aid of bacteria.

It is obvious that it would be unwise if all waste water now discharged would, without further consideration, be passed through this new installation.

The costs of constructing and exploiting an installation of this size are high, and it should first be investigated what had better, and in a cheaper way, be done in the plants themselves. Moreover, it should be seen to that the erection of new plants does not present new problems.

The measures to be taken may, therefore, be classed in three categories:

- a) reconditioning of the existing plants;
- b) construction of new purification installations;
- c) reducing the water effluent in new plants as much as possible, and promoting the possibility of its purification.

The extent of the reconditioning measures to be taken in the plants in relation to the purification installation is, in the first instance, a matter of economics. However, an important aspect is also the limit imposed by the authorities in the discharge permit. Materials which are not or hardly removed by the purification installation will have to be retained in order to conform to the limit, irrespective of the costs involved.

The three categories mentioned will be dealt with in more detail successively.

4. Reconditioning of existing plants

This may be done in two ways:

- a) by carrying out modifications of the plant;
- b) by recovering materials from the waste water of certain plants.

At DSM, an investigation is being made in all plants to find out what can be done in this respect. In the past, it is true, such investigations were also made, but on these occasions particular attention was paid to the loss of product. Now, however, also the expected purification costs are taken into consideration. It has appeared that, occasionally, spectacular results can be achieved if this matter is given sufficient attention, preferably by a single functionary who is well acquainted with the plant and whose sole task for a certain period of time it is to scrutinize the entire unit.

The possibilities are manifold: recirculation of (minor) streams, installation of more controlling-equipment, e.g. safety devices and alarms on tank overflows, the sweeping up of solids instead of washing them away, and last but not least: promoting discipline amongst the operating personnel.

A few examples are added:

- a) In a certain case, losses could be reduced drastically through installation of a conductivity meter, so that the operator is warned immediately if material drops into the sewer (e.g. if a sampling cock has not been turned off).

Formerly this was sometimes noticed only after days had passed.

- b) In the production of caprolactam a rather large quantity of ammonium sulphate dissolved in water forms as a by-product (approximately 4.5 tons of ammonium sulphate to every ton of caprolactam). The water is passed through multiple-effect evaporators during which the ammonium sulphate, which is sold as fertilizer, crystallizes out. In these installations (see the diagram of figure 4) substantial losses of ammonium sulphate occurred as a result of

droplets being carried off and joining the condensate. Moreover, control of the level in the evaporators was difficult, so that foaming over occurred occasionally.

The losses, which, as late as in 1971, still amounted to about 3 t/d N, have now been reduced to approximately 0.4 t/d N

- by improved level control in the evaporators,
- by instruction of the personnel, in which the consequences of discharge were pointed out,
- and, particularly, by providing thresholds in the vapour lines which serve to catch mist without an appreciable pressure drop.

c) In one of the plants a waste water stream is produced containing urea in concentrations which are so low that the urea is no longer recoverable. This stream, which has so far been discharged to the sewer, will be treated in a separate installation, in which the urea will first be hydrolyzed into ammonia and carbon dioxide by a thermal treatment, whereupon the ammonia can be recovered by stripping with steam and be recirculated to the process. More details are given in the last paragraph.

In this way, losses will be reduced from about 5100 kg/d N to about 100 kg/d N. The costs of this installation, which is now under construction, will amount to approximately Dfl. 3.5 million.

The total investment for reconditioning the plants near Geleen is estimated to be between Dfl. 15 and Dfl. 20 million.

d) In order for the final waste water treatment installation to be kept as compact as possible, not only the amount of waste materials but also the waste water volume should be limited as much as possible. Wherever feasible, therefore, separate sewer systems will be installed for the discharge of clean water (e.g. the cooling tower discharge and non-polluted rain water) and of polluted water. This has already been put into effect on the sites of the Hydrocarbons and Polymers Groups. A new sewer system was constructed for the impurified water sent to the Pasveer ditch. The existing sewer system is only used now to convey clean water to a new sewer for separate discharge to the river Maas. Reconstruction work was completed in 1971 and the costs amounted to about Dfl. 5 million.

5. Construction of a new purification installation

Part of the NH_4^+ -N lost is in so dilute a state that recovery of ammonia is not realizable economically, or the waste water has become impurified by foreign components, so that only highly impurified, and hence valueless, ammonia can be recovered. Streams of this kind must be considered for treatment in a central purification installation. The same holds for NO_3^- -N and COD streams. For a few years the possibilities and technical modes of realizing this by a biological method have been studied by DSM's Central Laboratory. The result has been a method obtained by the combination of processes already known for a long time, in which the NH_4^+ is removed by nitrification, the NO_3^- formed and the nitrate already present by denitrification, and the COD by biological oxidation into CO_2 and H_2O . During this process the reactions indicated in table VI occur.

It appears that in some reactions the presence of oxygen is essential, and its absence necessary in others. So it is evident that purification in only one basin would be impossible and that it has to be carried out stepwise. In this way NH_4^+ and NO_3^- for a major part originating from the fertiliser production can be removed by making use of the fact that the waste water of an integrated chemical complex contains COD.

In principle, the installation will be designed in accordance with the diagram of figure 5.

Investigations have been carried out on a laboratory scale ($1 : 10^7$), a semi-technical scale ($1 : 10^5$) and, for one and a half year now, in a pilot plant ($1 : 200$).

It is not possible to report exhaustively about the investigations in this context. Roughly, it may be said that removal of NH_4^+ and NO_3^- to more than 95 % and COD to about 80 % has appeared possible. It is expected that the effluent of the new installation, which is operated according to this process, can be discharged to the river Maas without any objection. The investment involved in this project is now estimated at Dfl. 80 million.

In the aerated steps of the installation use will be made of a new aeration system developed by Stanicarbon. This system, the waterjet aerator is shown in fig. 6. Its operation is as follows (see Figure 7):

The pump installed at the edge of the aeration basin draws water from this basin and forces it through a tube placed horizontally across the water. This tube has holes on one side. The water spouts onto the water surface through these holes. This creates a flow in the basin and effects a proper transfer of oxygen from the air to the water.

Many variables play a role in this oxygen transfer, e.g. the angle between the water jet and the surface of the water in the basin, the speed of the jet, and the distance between the tube openings and the water surface. The oxygen transfer obtained in this way amounts to 2 kg of O₂ per kWh under field conditions, which is comparable to the efficiency of vertical rotors. With a test rig higher efficiencies, even up to 3 kg of O₂ per kWh have been found. An important advantage of this type of aerator is formed by the lower investment costs of the aeration equipment. A further advantage is the high degree of freedom in the choice of the shape of the aeration basin. It is well known that vertical rotor systems require special measures, in dependence on the shape of the basin, if oxygen transfer and mixing are to be kept efficient. This is because the entire body of water tends to rotate with the rotor, especially in cylindrical basins. The water-jet aerator does permit of using a cylindrical basin. This shape is attractive because it involves less wall area per volume unit of the tank than do square or oblong tanks or ponds. The latter types are mostly used where vertical rotor systems are applied. It can be said that, depending on the size of the installation, a cylindrical basin can be up to 30 % cheaper than a basin of the type most common in the Netherlands: the oxidation ditch. In this way major savings in the investment for the aeration basin can be realised as well.

6. New plants

New plants should be so constructed that

- a) as little as possible material ends up in the waste water;
- b) waste materials, which will inevitably form, are disposed of in the best, and preferably cheapest, way possible.

These aspects should not be paid attention to only when the erection of the plant is commenced, but right from the start, one might say at the cradle of the process, which, in case of a chemical process, means the laboratory bench. This applies again and again during all subsequent stages.

In the development of a process via the laboratory, the semi-technical and, possibly, the pilot plant scale for use in a commercial plant the following points are of importance:

- a) A high efficiency and a great selectivity of the process. To the extent that these factors are better, the quantity of waste materials will be smaller.
- b) As many waste streams as possible should be recycled.
- c) The auxiliary agents chosen should allow easy processing; for instance, if biological purification is required, one should choose biologically degradable solvents, extracting agents, etc.
- d) Proper processability of the waste streams should be kept in mind. For instance by working in a water-free medium, or by seeing to it that concentrated waste streams form, in many cases combustion of the waste materials is actually possible.

For the design stage of the plant the following points should be mentioned:

- a) A good plant with proper equipment and accessories should be built. Excessive economy in this respect often results in substantial losses. For instance, if instead of a diaphragm valve one chooses a cheaper type with a stuffing box and an extra loss of 1 ton of ammonia-N/year is suffered on this account (which is not much), this will give rise in the near future in the Netherlands to a levy of Dfl. 1,400.- per year (at Dfl. 20.-/p.e. of 180 g/d OD) or to about the same amount for purification.
- b) A plant should comprise three separate sewer systems, viz. for waste water which need not be purified (like the cooling tower discharge), for waste water to be treated in a purification installation, and for waste water which may be recycled to the process (stuffing box leakages, losses through flushing, sampling, etc.). This design has been fully incorporated in the acrylonitrile plant of DSM.

- c) Surface condensers instead of mixing-condensers should be used, so that the cooling water will not become impurified and need not be discharged via a purification installation.
- d) There should be a sufficient buffer capacity in order to cope with failures and discharge peaks, for instance during shut-down and start-up of the plant.
- e) Air-cooling should be applied wherever possible, so that the consumption of cooling water (and, hence, thermal pollution of the river or formation of mist) is limited.

As an example of the type of measures in order to reduce pollution the treatment of ammonia and urea containing process condensates from urea manufacturing can be taken.

The process condensate originates in the vacuum condensers and is collected in a tank. The condensate will contain approximately 3 to 4 % by weight of carbon dioxide, 3 to 6 % by weight of ammonia, and 0.3 to 0.5 % by weight of urea.

If no special demands are made on the waste water, the condensate is stripped with the aid of live steam in a desorption column (Figure 8).

The water leaving at the bottom of the column still contains 600 to 800 ppm of ammonia and practically all urea originally present; after heat exchange and cooling have taken place, it is discharged to the sewer. The gas leaving the column at the top is returned to the recirculation section.

Frequently, the ammonia and/or urea contents of the bottom product will be too high for the condensate to be discharged to the sewer direct. If one wants to reduce only the ammonia component, the desorption section may be extended as is shown in Figure 9.

The bottom product of the desorption column is pumped to a heater, which increases its temperature to about 180 °C. By means of an expansion valve the condensate is flashed in a separator installed on top of a 2nd desorption column. The process condensate flashed off is subsequently passed through the 2nd column to be stripped with live steam. The gases leaving the separator are used as stripping media in the 1st column.

This system has been applied now for one and a half years in a 600 stad Stamicarbon urea plant, and practice has shown the ammonia content of the condensate at the outlet of the 2nd column to have decreased to approximately 60 ppm.

If not only the ammonia content but also the urea concentration is to be decreased, the desorption section may be extended as shown in Figure 10.

The only essential difference with the system of Figure 9 is in the installation of a hydrolysis column instead of a heater.

The urea will decompose into carbon dioxide and ammonia, depending on the residence time in this column. This system has been tried in practice, in a revised form, in one of UKF's urea plants. In this plant, the urea containing process condensate and the condensate stream which is free from urea and kept separate.

The system was revised because existing equipment has been used and a fixed connection arrangement had to be started from (see Figure 11).

The urea-containing condensate stream, having a volume of about 23 m^3 per hour, and containing about 0.80 % by weight of urea is raised in temperature to 175°C by heat exchangers and a steam heater, and is subsequently pumped to a hydrolyzer where the urea becomes hydrolyzed to more than 90 %. Next, the condensate leaving the hydrolyzer is passed through a heat exchanger and is flashed in the top part of a desorption column. The gas phase from the desorber is sent to the ammonium nitrate plant, the liquid phase leaving the desorber containing about 500 ppm of urea and 50 ppm of ammonia.

7. Conclusions

This paper gives an impression of the activities of a large chemical company in connection with the reduction and purification of its waste water.

Obviously, only a few examples could be given.

It has not yet been quite defined to what level all discharges will be reduced as a result of the measures discussed. Roughly, it may be said that the discharge of nitrogen compounds will be decreased at least to less than 10 % of the present level, whereas biodegradable organics will be almost completely removed.

8. References

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Annexes: 10

Waste water discharged by DSM's chemical works

stream I	quantity:	about 2,000 m ³ /h
	impurities:	NH ₄ ⁺ NO ₃ ⁻ PO ₄ ^{'''} COD
	treatment:	mechanical purification in thickeners and settling pond
stream II	quantity:	about 800 m ³ /h
	impurities:	COD NH ₄ ⁺ NO ₃ ⁻
	treatment:	a) mechanical purification in settling ponds b) biological purification in Pasveer ditch
stream III	principally some municipal waste water and rain water	
	quantity:	100 to 200 m ³ /h
	treatment:	mechanical purification in settling basins
stream IV	non-impurified water from the Polychemical Works	
	quantity:	about 200 m ³ /h
	treatment:	mechanical purification in a thickener

Total discharge by DSM
(approximate figures)

	volume m ³ /h	COD kg/h	NH ₄ ⁺ -N kg/h	NO ₃ ⁻ -N kg/h
1972 - prior to treatment	3200	2200	1000	200
1972 - after treatment of part of the waste water in the Pasveer ditch	3200	1000	1000	200

Table III

Discharges to the river Maas in 10³ ton/year

	BZV	total N	P
Eysden ^{*)}	49	18	2.0
direct discharges in the Netherlands	36	2	0.7
discharges via ditches from:			
the Netherlands	89	9	1.3
Belgium	10	-	-
Germany	84	8	1.4
DSM	6	10	0.4
total	274	47	5.8

^{*)}Quantities in the river Maas at the measuring point Eysden near the Belgium-Netherlands border.

Purification in Pasveer ditch

major load from	coking plants		cyclohexanone plant		acrylonitrile plant	
volume	m ³ /h	390	625	800		
COD (in solution)	g/m ³	800	1580	360	840	200
(in sludge)	g/m ³	-	-	360	-	270
BOD	kg/h	310	990	-	670	-
phenol	g/m ³	-	-	130	-	6
rhodanide	g/m ³	50	35	0.5	-	-
cyanide	g/m ³	60	40	17	-	-
pH		7.5	8.0	-	about 10	0.1
sludge load	kg COD/kg . h	0.09	0.25	7.9	8.5	7.4
COD of sludge	kg/kg dry sol.	ca. 1.0 (ca. 30 % as)	ca. 1.2 (15 to 20 % as)		0.21	
SVI	ml/g	45-55 (after 1/2 h)	50 to 60 (after 1/2 h)		ca. 1.1 (20 to 30 % as)	
from COD supply:		nitritification	denitrification		nitrit. + denitr.	
not degraded	%					
converted into sludge	%	11	23		25	
oxidized with O ₂	%	17	23		35	
with NO ₃	%	72	47		40	
	%	-	7		-	

Costs of Pasveer ditch of DSM

Investment

(in 1964)

civil	Dfl.	650,000
mechanical	-	1,010,000
electrical	-	220,000
instrumentation	-	50,000
miscellaneous	-	20,000
total	-	1,950,000

Annual costs

per kg COD
oxidized

1965: c. Dfl.	600,000	c. Dfl.	0.15
1966: c. -	640,000	c. -	0.17
1967: c. -	950,000 ^{■)}	c. -	0.20
1968: c. -	750,000	c. -	0.14
1969: c. -	800,000	c. -	0.40
1970: c. -	1,180,000 ^{■)}	c. -	0.60

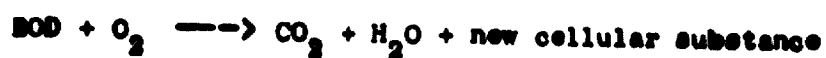
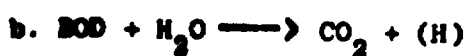
■) extra maintenance work

Break-down of annual costs

energy	c. 20 %
phosphoric acid and other chemicals	c. 5 %
operation and supervision	c. 5 %
maintenance	c. 25 %
depreciation	c. 30 %
miscellaneous	c. 15 %

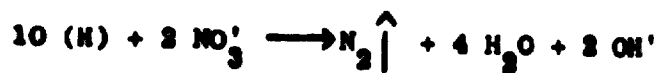
Biochemical reactions

1. Biological oxidation of organic material

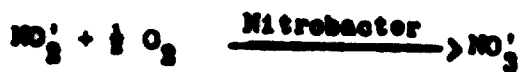


2. Denitrification

In reaction c NO₃' instead of O₂ is used as H-acceptor.



3. Nitrification

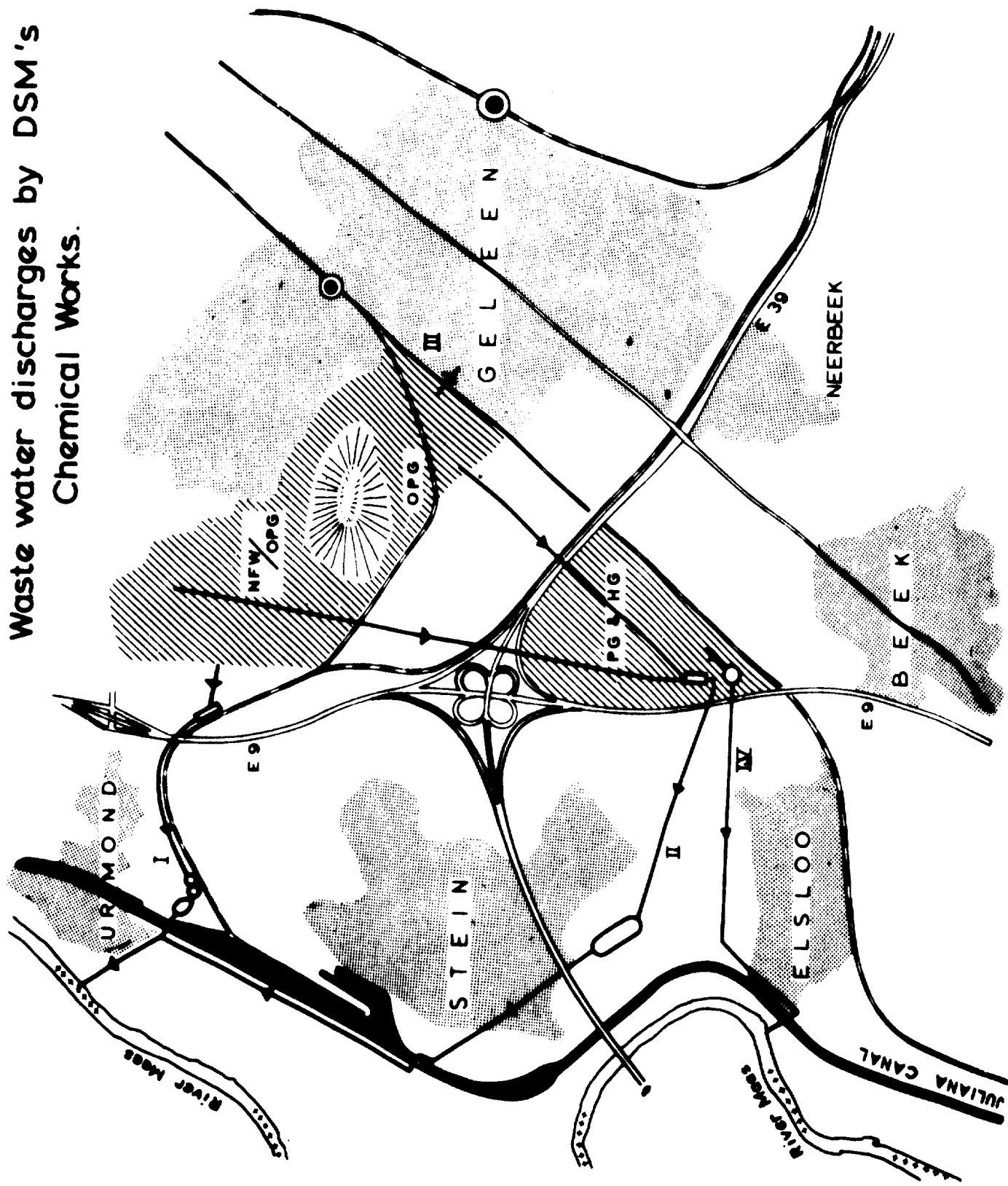


Properties of waste water streams of acrylonitrile plant

		A	:	B
volume ratio	c.	1	:	1
amount of $(\text{NH}_4)_2\text{SO}_4$	c.	1	:	100
amount of org. material	c.	1	:	8
COD g/l		10		50
catalyst		absent		traces
HCN		traces		traces

Fig. 1

Waste water discharges by DSM's Chemical Works.



Influence of a period of low pH of the influent on the purification in a active sludge installation and a Pasveer ditch.

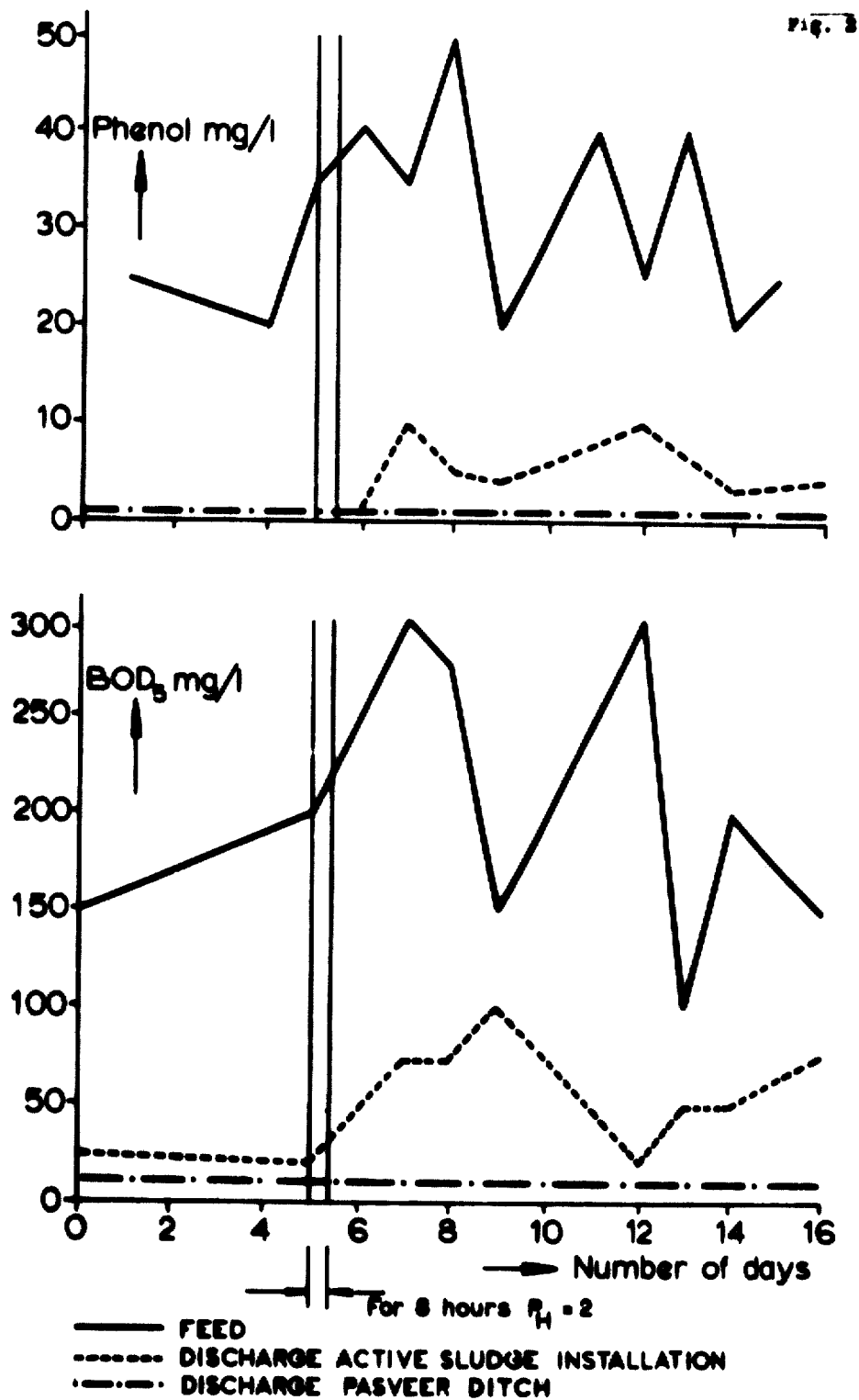


Fig. 3

Pasveer - ditch of DSM

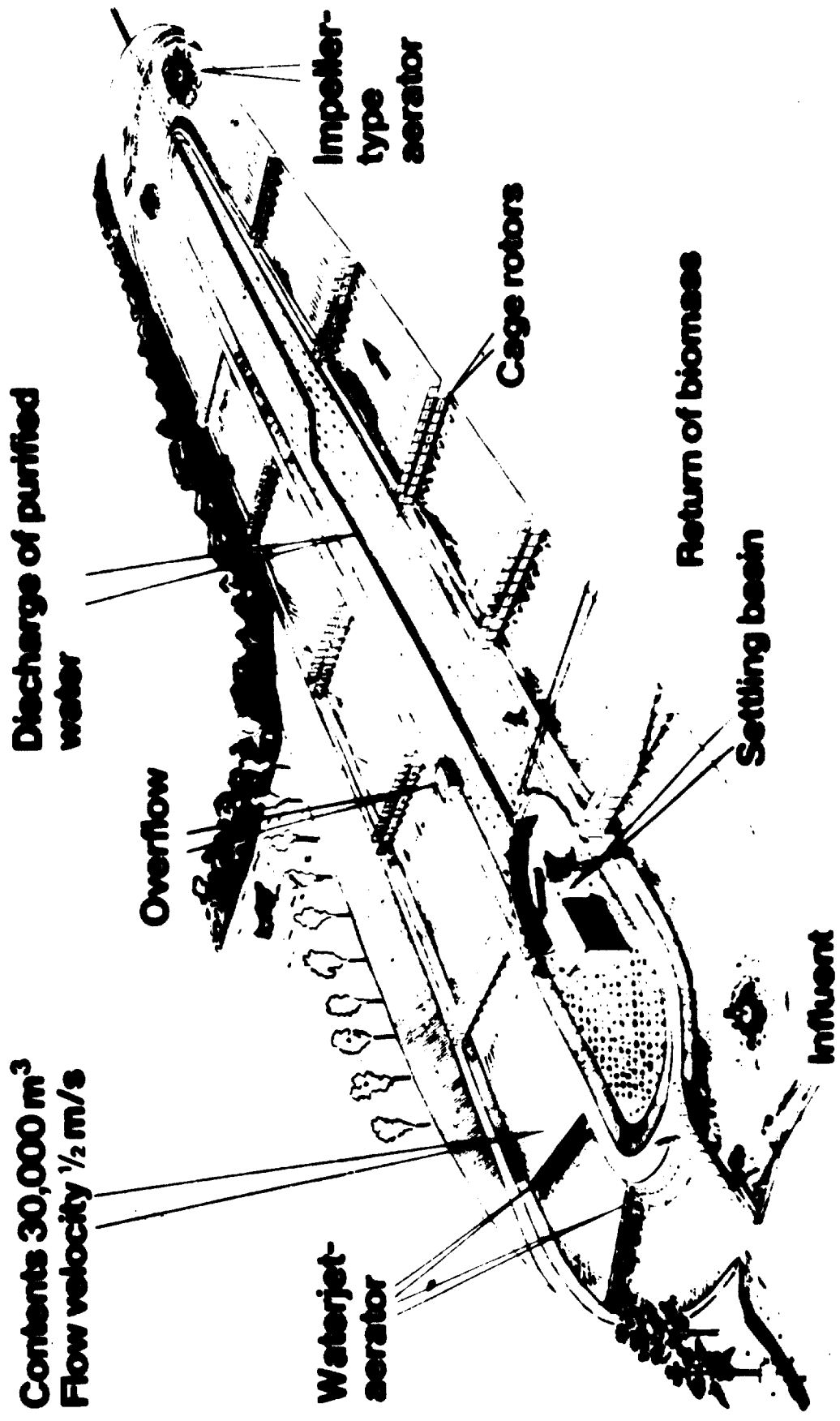
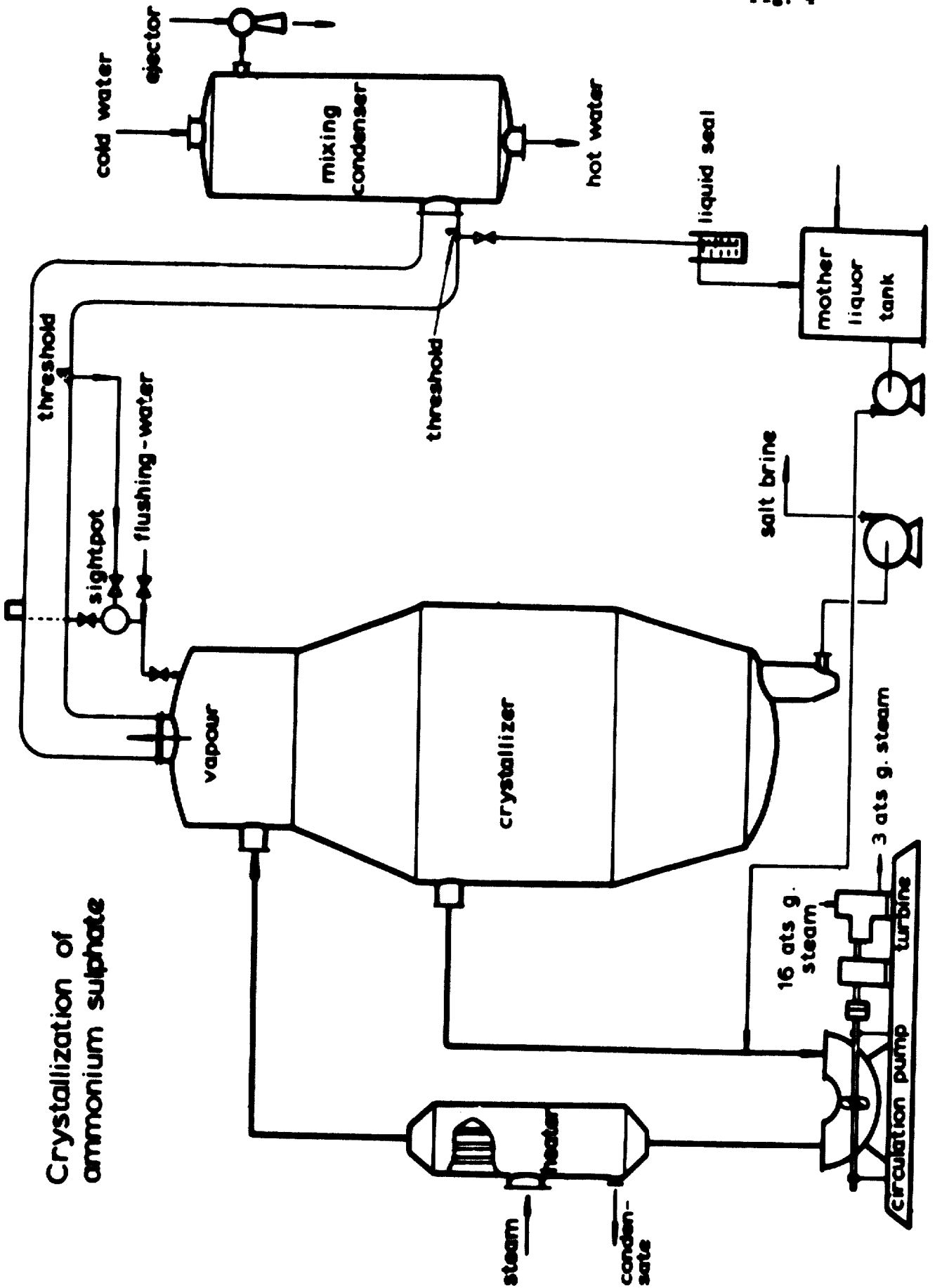


Fig. 4



Crystallization of ammonium sulphate

Biological Purification of Waste Water

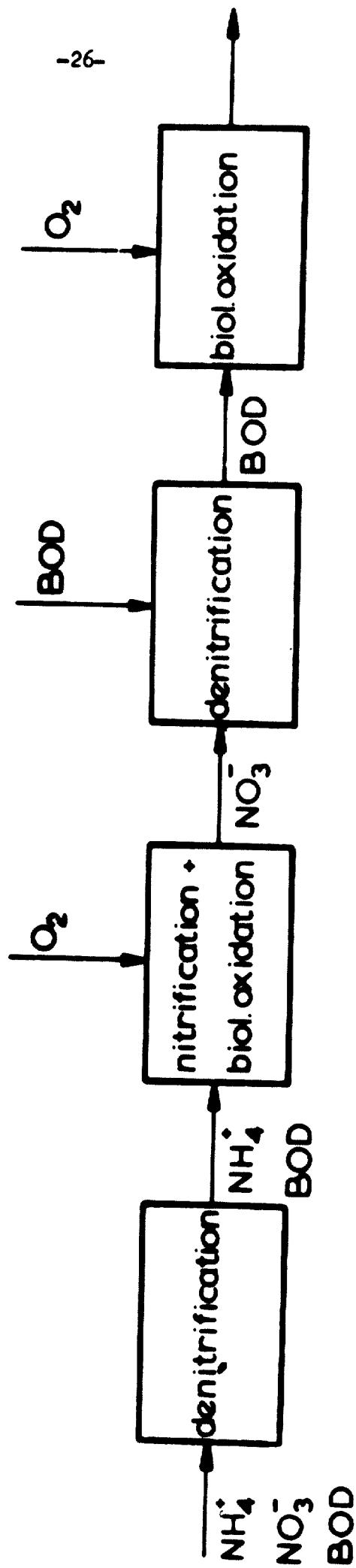
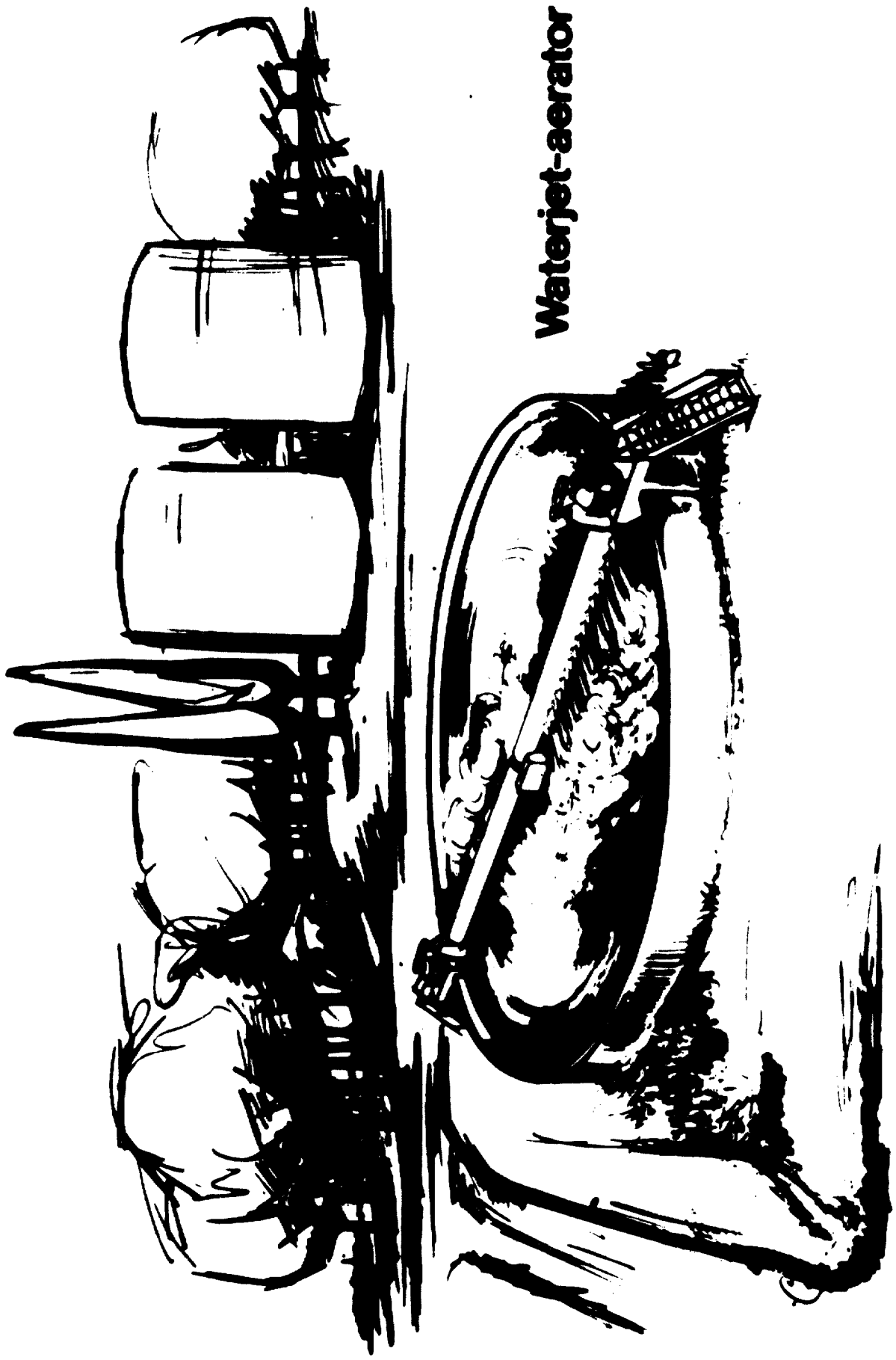


Fig. 5



Waterjet-aerator

Water-jet aerator

FIG. 7

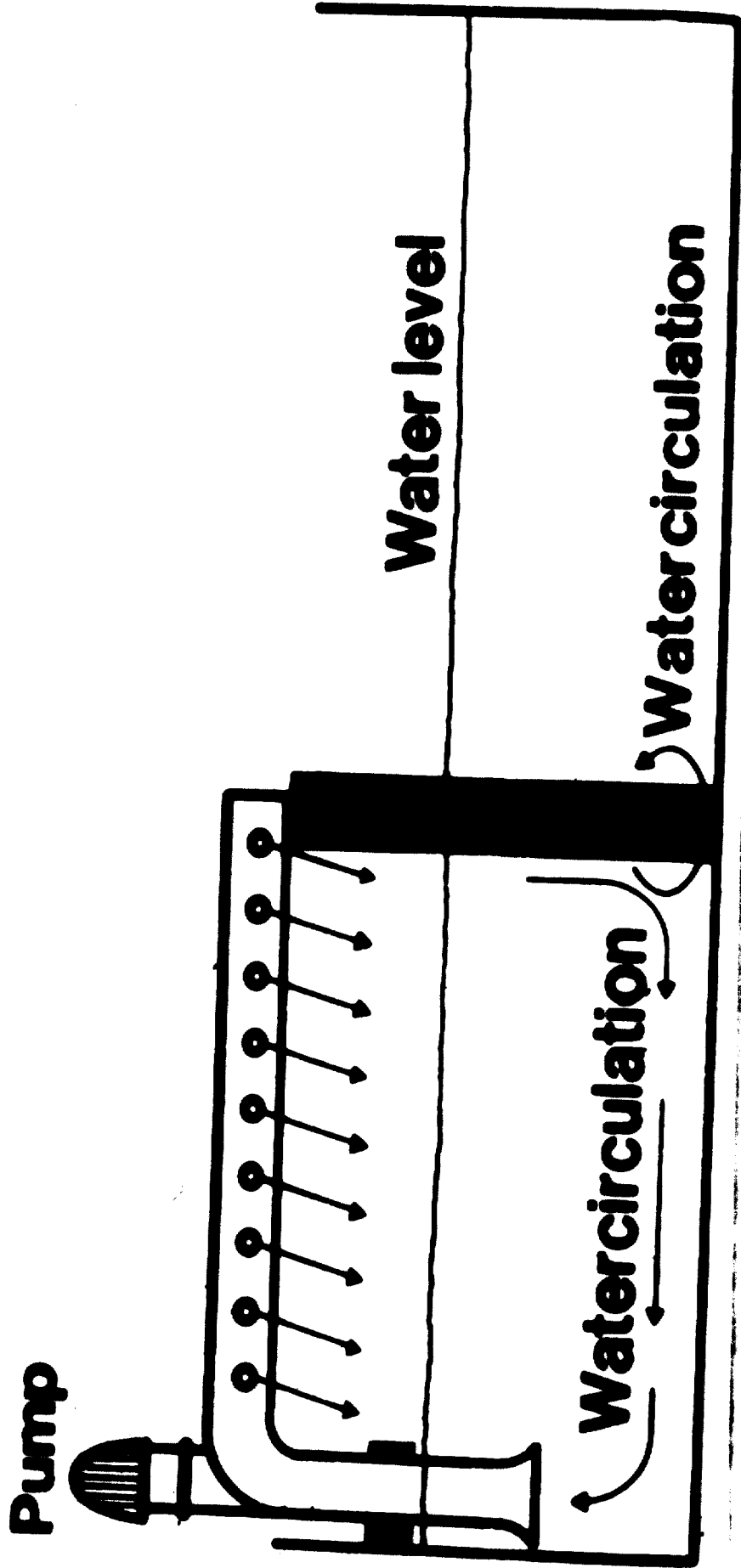
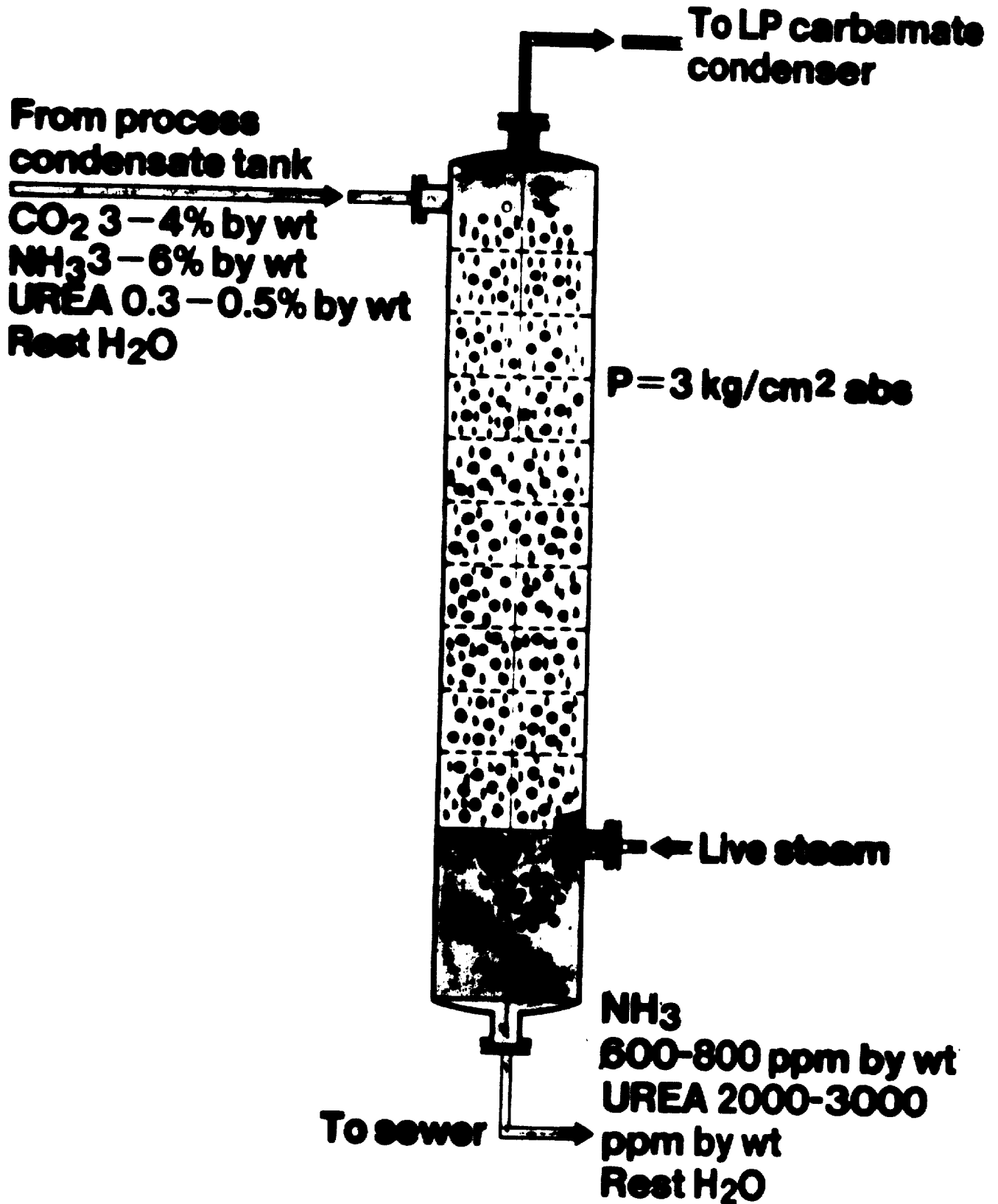


Fig. 6

Normal desorption column



Process condensate treatment

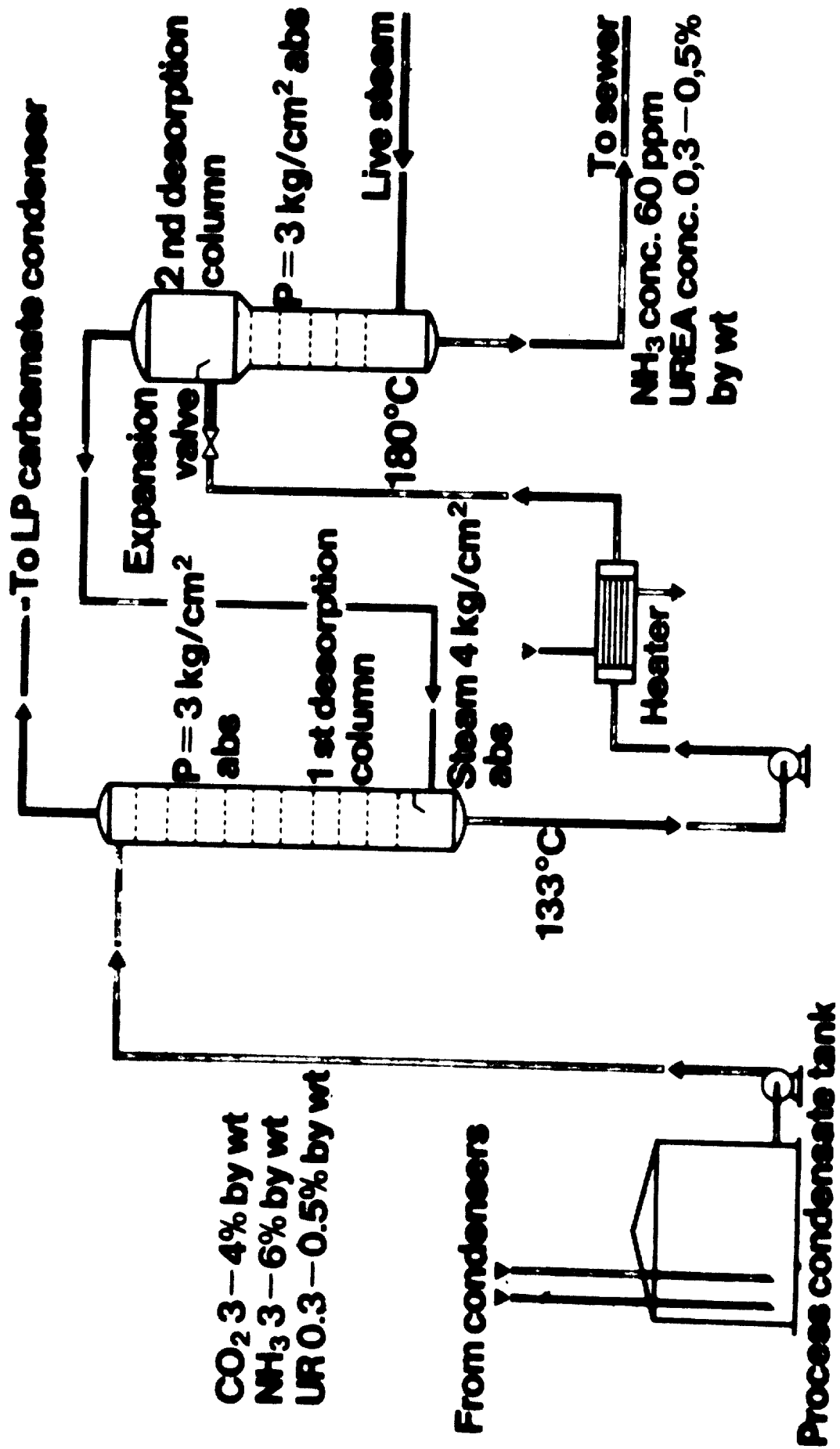


Fig. 10

Process condensate treatment

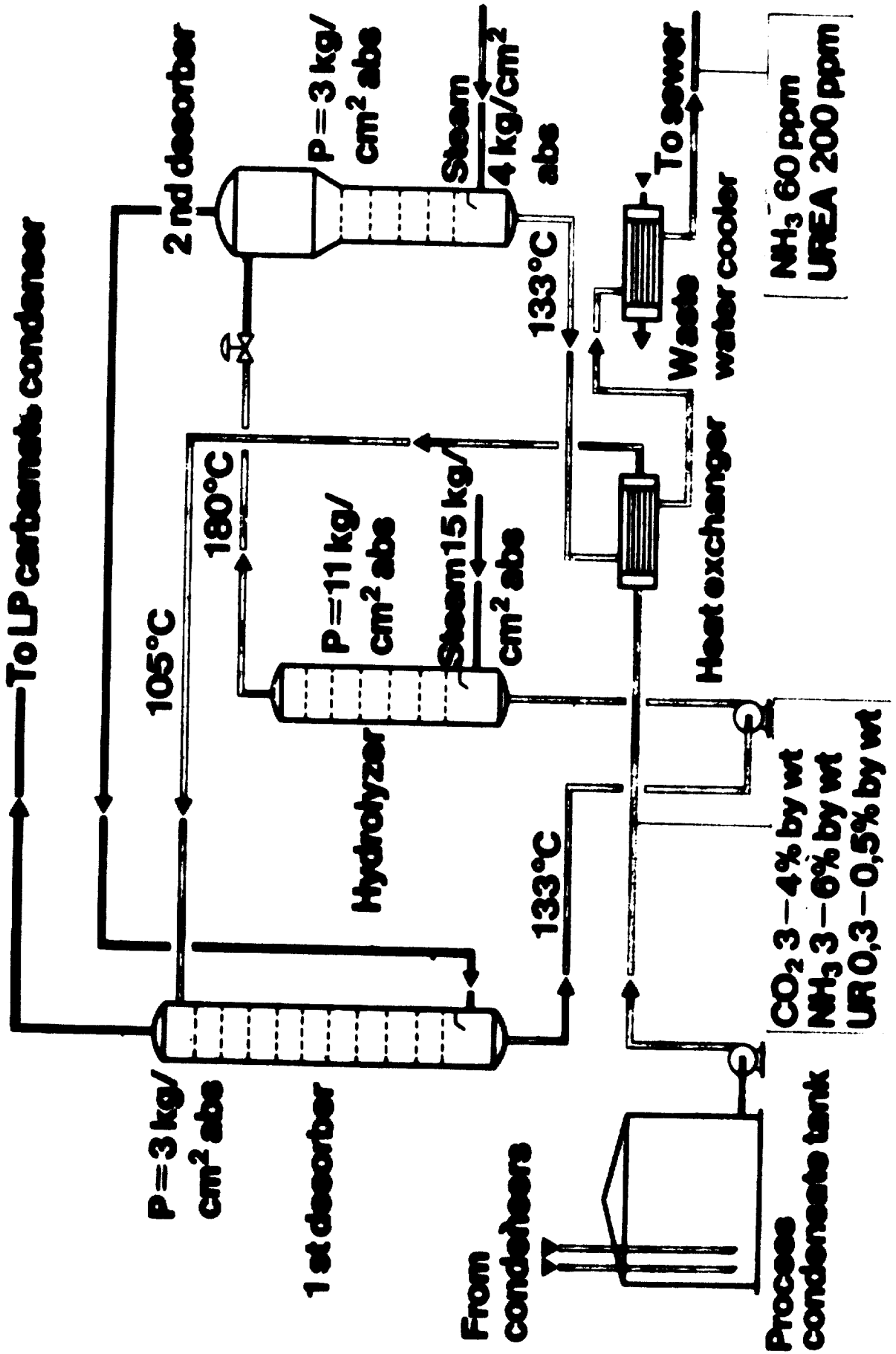
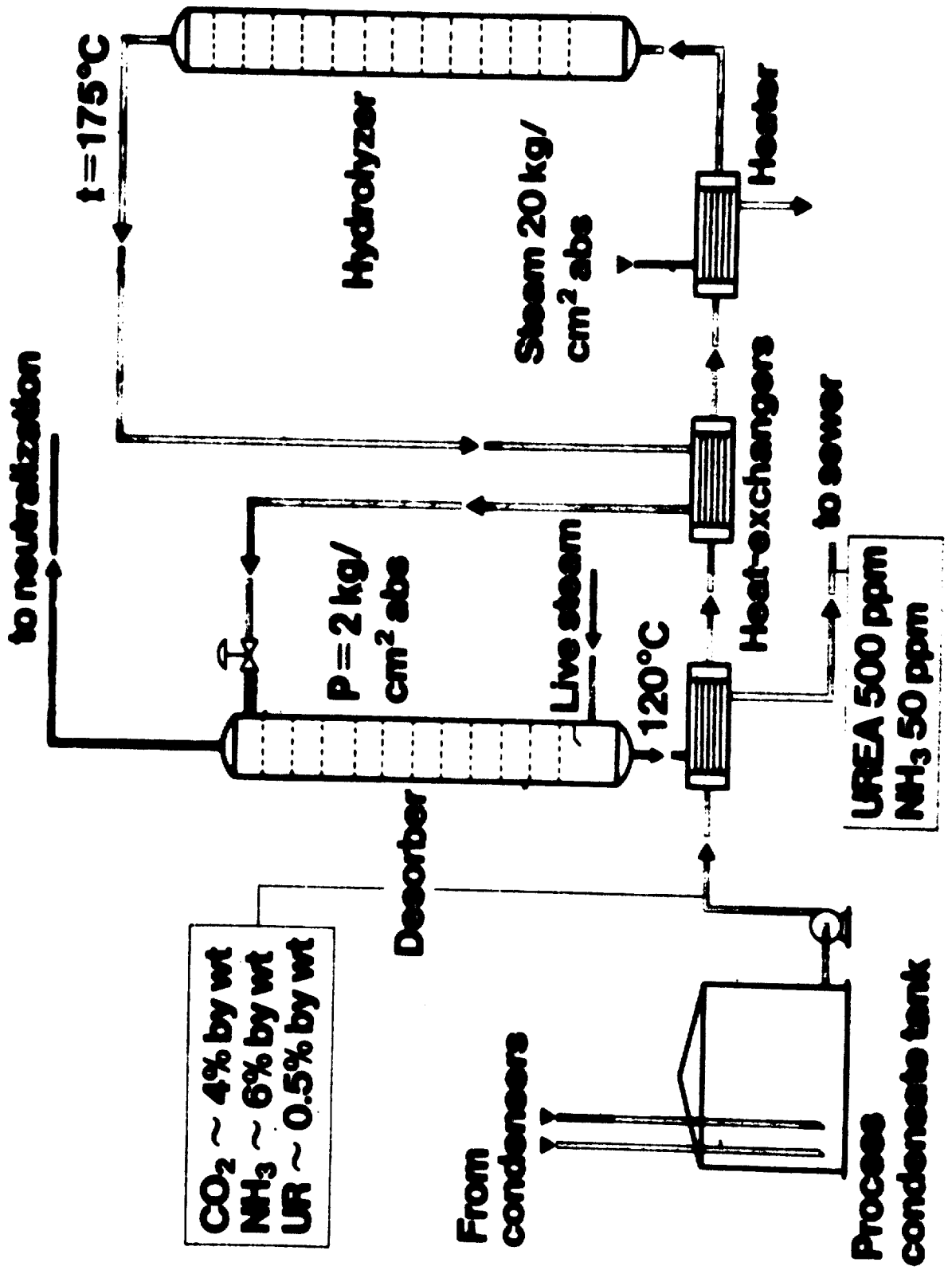
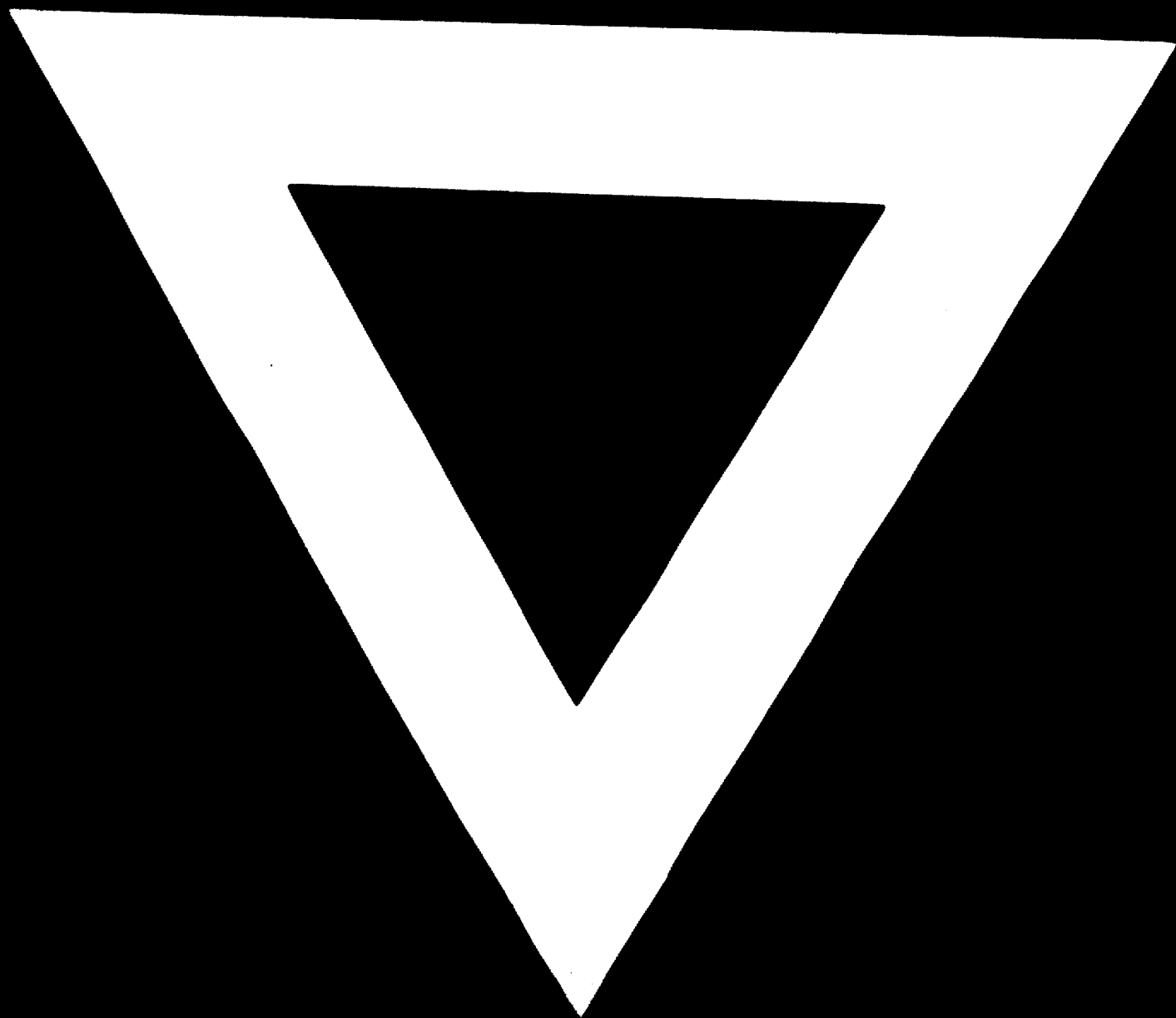


Fig. 11

DSM hydrolyzation section





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