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COST OF PHOSPHATE REMOVAL IN MUNICIPAL WASTEWATER TREATMENT PLANTS

H. Schuessler

Translation of "Kosten der Phosphatelimination in kommunalen Klaeranlagen", gwf/wasser/abwasser, vol. 122, no. 6, 1981, pp. 251-257

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16. Abstract Construction and operating costs of advanced wastewater treatment for phosphate removal at municipal wastewater treatment plants have been investigated on orders from the Federal Environmental Bureau in Berlin. Particular attention has been paid to applicable kinds of precipitants for pre-, simultaneous and post-precipitation as well as to different phosphate influent and effluent concentrations.

The article offers detailed comments on determination of technical data, investments, capital costs, operating costs and annual costs as well as potential cost reductions resulting from precipitation. Selected results of the cost investigation are shown in graphical form as specific investments, operating and annual costs depending on wastewater flow.

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COST OF PHOSPHATE REMOVAL
IN MUNICIPAL WASTEWATER TREATMENT PLANTS

H. Schuessler

1. Introduction /251*

Data regarding costs of treatment by precipitation have been available on a larger scale since approximately 1968. They involve essentially either data based on flat rates or experience made by extant facilities. The first pioneering studies regarding various phosphate influent and effluent concentrations were published by Bischofsberger et al. (1) with the use of aluminum and iron salts as well as by Hruschka/Hegemann (2) with the use of a combined lime/iron precipitation.

To facilitate assessment of the cost data published so far, the following must be pointed out:

--Bischofsberger et al. (1) used in determination of operational costs for the key cost factor "cost of precipitants" the median price of available precipitation agents. However, it must be kept in mind that, e.g., when a transportation distance of 200 km is involved, the prices franco wastewater treatment plant, depending on the precipitation agent, can range anywhere from 40 to 340 German Marks per ton.

--While Bischofsberger et al. (1) and Hruschka/Hegemann (2) as well as Schlegel/Kinder (5) did conduct extensive investigations on a technical scale with various precipitation agents in pre-, simultaneous and post-precipitation, their cost data fail to reflect the costs of precipitation sludge treatment which, according to (8), depending on the type of precipitation process and the type of precipitation agent can amount to between 15% and 65% of the total operation costs.

--In the case of individual operational cost items there is often no indication which cost-generating factors are included, e.g., with or without sludge processing, with or without personnel costs, etc.

*Numbers in the margin indicate pagination in the foreign text.

--Disregarded in most cases was also the fact that various types of precipitation agents call for different facilities for storage, solution and dosage which in turn call for differentiated investments.

To obtain comparative data regarding investments, operational and annual costs of wastewater processing by precipitation using various types of precipitation processes and varying precipitation agents, a corresponding investigation was carried out on orders from the Federal Environmental Bureau in Berlin in 1978/1979. The subsequent text points out the key findings contained in the research report (8).

2. Principles of Cost Computation

For varying reasons the cost data relate to the year 1978.

They were derived from offers, price lists, cost investigations and itemized data from the represented companies. As the supply of usable precipitation agents includes, e.g., a number of chemical or waste products with only regional availability, to simplify the classification of precipitation agents it was decided to select only those that call for identical investments for storage, solution and dosage. The following groups of precipitation agents were taken under consideration in computation of construction and operational costs:

Me^{14} liquid - e.g., iron perchloride, iron perchloride sulfate, aluminum perchloride, aluminum sulfate
Granulate - e.g., AVR, ferri-FLOC
Fe^{24}
Ca^{24}

/252
In addition, a determination of the costs for a combined lime/iron precipitation was made for pre- and post-precipitation.

As regional differences must be expected in phosphate concentrations reaching the processing plants, subsequent studies were carried out with the use of P-influent concentrations P_0 = 10, 20 and 30 mg/l, while the P-effluent concentration P_e should amount to <2 in pre- and simultaneous precipitation and to <1 mg/l in post-precipitation. This limitation in regards to P-effluence quality in pre- and simultaneous precipitation was necessitated on the basis of the experiments described in (7), because even under optimum precipitation conditions at P-influent concentrations of $\geq$20 mg/l it is impossible to achieve median P-effluent concentrations of $<$1 mg/l which can be attained at lower influent concentrations, as is often described in references.

2.1 Technical Data Regarding the Precipitation Facilities

The requisite technical data for cost computation at any wastewater processing plant and be found and combined from the outline presented in Table 1.

The *Key Layout Data* are constituted by the size of a given wastewater processing plant. From these, by following the corresponding guidelines, can be derived the *Technical Installation Data* for construction, machinery and electrotechnical equipment groups. The attainable environmental data for effluent discharges from municipal wastewater processing plants with proper layout, balanced operation and appropriate operation of mechanico-biological and chemical purification stages are shown in Table 2. Additional sludge occurrence can be computed approximatively as an accretion of solids according to Poepel (4) with the use of the following equations:

Iron salts	m_{Fe}	$= EW_p \cdot (1.42\ e + 3.45\ \beta)\ \lvert g/E \cdot d \rvert$
Aluminum salts	m_{Al}	$= EW_p \cdot (1.42\ e + 2.52\ \beta)\ \lvert g/E \cdot d \rvert$
Lime	m	= 1.35-times the lime dosage $\lvert g/g \rvert$
wherein	m	= accretion of solids
	EW_p	= phosphate occurrence in g P/E $\cdot$ d
	e	= phosphate elimination
	β	= relative volume of precipitation agent.

The computation of the corresponding sludge volume occurrence can be done under the assumption that with the use of lime the sludge has a 5% contents of solids, 1% in all other cases. /253

Determination of the use of personnel for operational economy data is made on the basis of Table 3 which reflects surveys made of extant installations in Germany, Sweden and Switzerland.

TABLE 1. Outline of Technical Data and Costs /252

Technical Data	Dim.
Key Layout Data	
Rated water volume	m^1/h
Wastewater volume	m^1/d
E + EGW	–
Influent P precip.	mg/l
Precipitant vol. β	mol/mol
Techn. Install. Data	
Construction Equipment	
Acreage required	m^2
Precipitant stored	m^3
Floccul. tank volume	m^3
Sedim. tanks volume	m^3
Thickener volume	m^3
Machinery Equipment	
Precipitant on hand	m^3
Dosage pump output	l/h
Sludge pump output	m^3/h
Repumping output	m^3/h
Electrotech. Equip.	
Electr. consump.	kW
Environmental Data	
P-contents runoff	mg/l
BSB – " "	mg/l
CSB – " "	mg/l
TOC – " "	mg/l
SS – " "	mg/l
pH-value runoff	–
Sludge formation	m^3/d
	t TS/d
Operational Data	
Manpower use	h/d
Precipitant cons.	t/a
Water consumption	m^3/a
Power consumption	kWh/a

Investments	Dim.
Land Acquisition	
Structural Group	
Site layout	DM
Water storage	DM
Earth moving	DM
Precipitant o/h	DM
Floccul. cont.	DM
Sedim. tanks	DM
Thickener	DM
Other	DM
Total Struct.	DM
Machinery Eq.	
Precipitant o/h	DM
Floccul. tank	DM
Thickener	DM
Dosage pump	DM
Sludge pump	DM
Repumping eq.	DM
Other	DM
Total Machin.	DM
Electr. Equip.	
El. install.	DM
El. Distrib.	DM
Lighting	DM
Total Elec.	DM
Installation Investments other than acreage	DM
Other investments	
Fees & charges	DM
Constr. finan.	DM
Total Other I.	DM
Total Investm.	DM
Specific Total Investments	DM/E
	DM/m

Annual Costs (1978)	Dim.
Capital Costs	
Interest earnings	DM/a
Construction annuity	DM/a
Machinery annuity	DM/a
Electrotech. "	DM/a
Other inv. annuity	DM/a
Subtotal Cap.Costs	DM/a
Operational Costs	
Repair & maintenance	DM/a
R&M Const.,Mach.,El.	DM/a
Personnel costs	DM/a
Gen. Admin. costs	DM/a
Precipitant costs	DM/a
Water costs	DM/a
Power costs	DM/a
Sludge dehydr. costs	DM/a
Gen. oper. materials	DM/a
Subtotal Oper. Costs	DM/a
Specific Oper. Costs	DM/E·a
	DM/m^3
Savings	
Wastewater savings	DM/a
Total Costs	DM/a
Specif. Total Costs	DM/E·a
	DM/m^3

TABLE 2. Environmental Data for Precipitation

	Dim.	Runoff Concentrations at		
		Pre-P.	Simult. P.	Post-P.
P_{total}	mg/l	2	2	1
BSB_5	mg/l	15	12	10
CSB	mg/l	80	70	55
TOC	mg/l	25	20	18
Volat. sub.	mg/l	20	15	10

TABLE 3. Manpower Use in Precipitation Processes

Kläranlagengröße E + EGW (1)	(2) Personaleinsatz (h/d) bei Fällmittel					
	(3) flüssige Eisensalze Granulat Kalk (nur bei VF, NF)			(4) kristalline Eisensalze (nur bei VF, SF) Kalk + Eisensalze (nur bei VF, NF)		
	VF	SF	NF	VF	SF	NF
up to 5000	0,5	0,5	1,0	1,0	1,0	1,5
5000– 10000	1,0	1,0	1,5	1,5	1,5	2,0
10000– 20000	1,5	1,5	2,0	2,0	2,0	2,5
20000– 50000	2,0	2,0	2,5	2,5	2,5	3,0
50000–100000	2,5	2,5	3,0	3,0	3,0	3,5
100000–200000	3,0	3,0	3,5	3,5	3,5	4,0

Key: (1) Size of treatment facility; (2) Manpower use with precipitants; liquid iron salts; granulate; lime (only in VF and NF); (4) Crystalline iron salts (only in VF and SF); lime and iron salts (only in VF, NF).
VF = pre-precipitation; SF = simultaneous precipitation;
NF = post-precipitation.

The data for consumption of the precipitation agent are computed from the relative precipitation agent volume β, the phosphate concentration fed to the precipitation stage, the wastewater volume and the contents of effective substances of the given precipitants.

In determining the water consumption consideration must be given to both the water used for solving as well as that used for purification.

The annual electricity consumption is computed from the required electric power demand.

2.2 Investments

All the requisite investments for each wastewater treatment plant can be computed from the outline shown in Table 1. The subsequent text will discuss some of the key investments in closer detail.

Investments for the required supply of precipitation agents differ according to the type of agents. In general, the operational contents of storage containers for all precipitation agents should be selected in an amount that

1. would make it possible to deliver the precipitants in 23-ton

2. would be sufficient to provide an adequate supply of the precipitation agents for operating the precipitation stage for approximately 7 days.

The specific investments for storage of liquid and crystalline metal salts are shown in Figure 1, whereby the specified costs relating to machinery are generated only if crystalline metallic salts are used. Instead of the storage containers made of plastic-coated reinforced concrete, the costs of which are reflected in the figure, it is possible to use plastic tanks for storage of liquid iron salts, the procurement price of which is lower. However, the difference in total investments is negligible, as cellar space must be provided for setting up such tanks and the relevant costs must be included. When the plastic tanks and dosage systems are set up in open air the requisite investments are substantially smaller, however, among other factors, their shorter service life must also be taken into consideration.

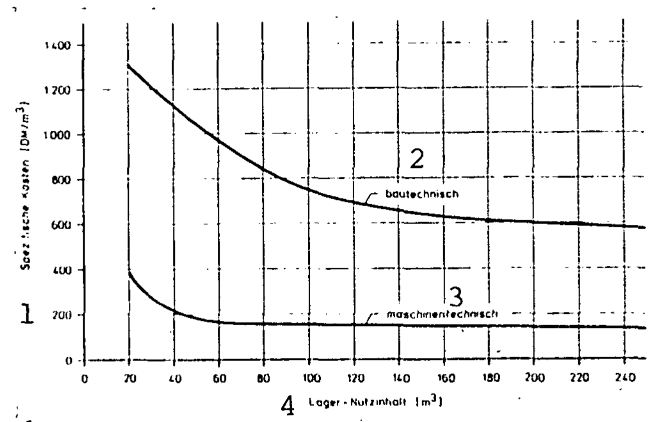


Figure 1. Investments for Storage of Liquid and Crystalline Metallic Salts in 1978 Prices.
Key: 1 - Specific costs; 2 - construction-related; 3 - machinery-related; 4 - effective storage volume.

Silos with the requisite machinery are widely available for storage of granulate and hydrated lime, the effective storage volume of the silos being on the order of 50 or 80 m^3. These silo sizes were used in the performed computations, when a larger silo volume is needed, more silos must be set up. The price for a 50 m^3 silo in 1978 was DM 47,000, that of an 80 m^3 silo approximately DM 53,000. Herein it /254
must be kept in mind that silos for granulate were offered complete,

to include a dosage system and electrical equipment, while the costs for electric equipment are not contained in the prices quoted above for lime silos.

Investments for the requisite settling tanks, flocculation tanks and thickeners can be derived from Figure 2. Use of a flotation facility for improved flocculation with the use of precipitation agents containing aluminum can result is smaller investments than those needed for a sedimentation tank, however, there is a considerable increase in operational costs.

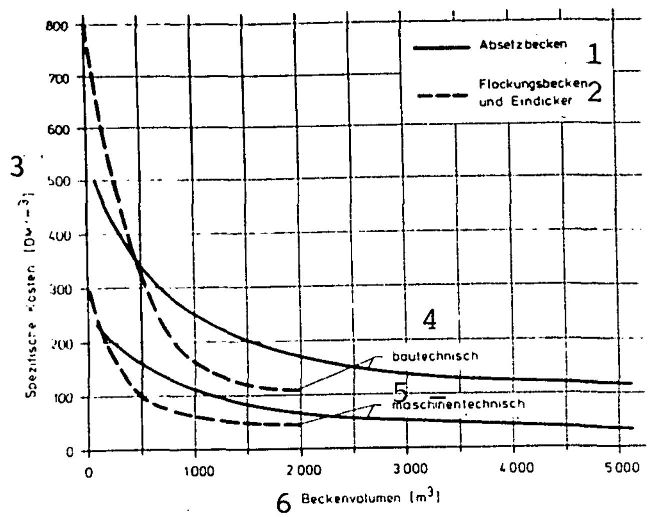


FIGURE 2. Investments for Settling Tanks, Flocculation Tanks and for Thickeners in 1978 Prices.
Key: 1 - Settling tank; 2 - Flocculation tank and thickener; 3 - Specific costs; 4 - construction-related; 5 - machinery-related; 6 - tank volume.

2.3 Capital Costs

Capital costs can in general be determined by means of static and dunamic proceses. As in the present case a cost comparison is made between several operationally feasible precipitation variants, capital costs can be computed by means of the static method "Comparative Cost Computation" in which the capital costs = capital services KD are computed according to the following equation:

$$KD = a_A \cdot £$$

wherein a_A = procurement cost
f = capital service factor
= annuity factor

$$= \frac{(1 + i)^n \cdot i}{(1 + i)^n - 1}$$

wherein n = service life
i = interest rate.

The service life n of the individual installation components can be assumed to be as follows:

Constructio-related facilities	n = 20 years
Machinery-related facilities and pumps	n = 8 years
Other facilities	n = 15 years
Electrotechnical facilities	n = 15 years.

2.4 Operational Costs

The *Costs of repair, upkeep and maintenance* of the facilities can on the basis of extensive data be estimated for the extant facilities to be as follows:

for construction-related facilities = 2% of construction investments,

for machinery-related facilities = 10% of machinery investments

for electrotechnical facilities = 5% of electrotechnical investments.

Personnel costs consist of gross wages and salaries as well as extra expenses for wages and salaries to be paid by the employer. In view of the usual wage structure and various allowances at wastewater processing plants the average hourly wage that comes under consideration is DM 20.04 per hour.

In general, *administrative costs* can be set with adequate precision at 20% of personnel costs.

Average prices of various precipitation agents are given in Table 4 for determination of the *cost of precipitation agents*. Determination of volumes took into consideration the varying contents of effective metal ions.

As shown in Table 4, granulates are delivered for the quoted price franco the wastewater processing plant, while in the case of the other precipitation agents the cost of transportation must be added to the costs of precipitation agents.

The extent of transportation costs depends on three factors:

1. The type of vehicle used for transport
   --truck for iron sulfate
   --silo-hopper for granulate and lime
   --tanker for liquids
2. *Transportation distance*
3. Volume of load.

TABLE 4. Average Prices of Precipitation Agents Based on Costs in 1978

Class of Precipit. Agents	Precip. Agent	Active Subst. mol/kg	Cost DM/t	Price Dpf/mol	Remarks
Granulate	AVR	3.1	210	6.77	franco treatment facility
	ferri--FLOC	2.7	210	7.77	" " "
Me^{3+}--liquid	Fe_2Cl_6 sulfate	2.2	120	5.45	+ transportation costs
	Fe_2Cl_6	2.5	140	5.60	+ " "
	Aluminum sulfate	1.4	300	21.43	+ " "
	Aluminum chloride	1.5	150	10.00	+ " "
Fe^{2+}	Iron sulfate	1.6	5	0.14	+ " "
Ca^{2+}	Hydrated lime	13.5	110	0.81	+ " "

The exact freight rates are to be looked up in the State Truck Tariff (3). Figure 3 provides an outline of the incurred costs.

The requisite relative amounts of precipitation agents β--in relation to the phosphate volume fed to the precipitation stage--were established through experimentation at industrial scale for a number of years (7), whereby an approximately 10% phosphate elimination is provided for in the mechanical, and a 25% phosphate elimination in the mechanico-biological purification stage and is duly taken under consideration. The values shown in Table 5 largely coincide with the data published in technical literature so far. In analyzing these figures it should be noted that post-precipitation was carried out with the cost-effective sludge contact process, i.e., that the optimum contact sludge volume established through experimentation was circulated in the post-precipitation stage. Detailed information in/255 regards to this process can be found in (6) and (7).

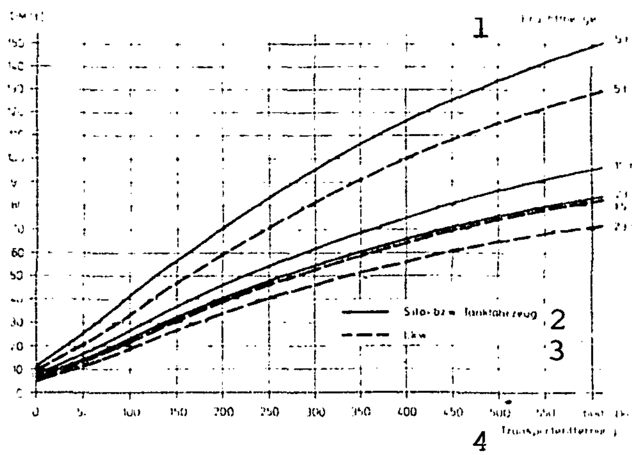


FIGURE 3. Cost of Transportation for Precipitation Agents in 1978 Prices
Key: 1 - Freight volume; 2 - Hopper or tanker; 3 - Truck; 4 - distance over which transported.

TABLE 5. Phosphate Concentrations and the Requisite Relative Amounts of Precipitation Agents Depending on the Precipitation Method

		1 P_0 (mg/l)	2 P_z (mg/l)	3 P_e (mg/l)	4 η (%)	β (Mol/Mol)
Vorfällung	5	20	20	<2	90	2,9
Simultanfällung	6	20	18	<2	89	2,0
Nachfällung	7	20	15	<2	87	1,2
		20	15	<1	93	2,7

Key: 1 - Phosphate concentration fed into the processing plant;
2 - Phosphate concentration fed to the precipitation stage;
3 - Phosphate concentration leaving the processing plant;
4 - Effectiveness of the precipitation stage;
5 - Pre-precipitation; 6 - simultaneous prec.; 7 - post-precip.

The *price of water* was set for 1978 at an average of 1.20 DM/m³.

The *price of electricity* was set for 1978 at an average of 0.15 DM per kWh.

The *cost of sludge treatment* depends on the type of sludge treatment. Chemical sludge can in principle be treated in the same way as the primary and excess sludge from the mechanico-biological stage. As the varying sludge treatment processes result in widely varying costs, subsequent computations use machine-aided dehydration of the thickened sludge in a travelling-screen press, as these costs represent about medium costs for the various sludge treatment processes. The costs for operation of a travelling-screen press can be derived from Figure 4.

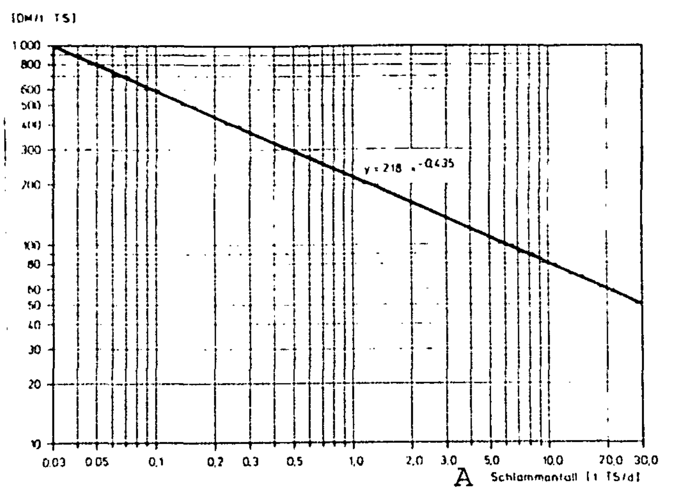


FIGURE 4. Costs for Operation of a Travelling-Screen Press in 1978 Prices.
Key: A = Sludge occurrence rate.

The *costs of general materials required in operations* , e.g., for lubricants, chemicals, small parts, etc., are hard to establish with any degree of precision and even investigations in existing facilities did not produce any usable results. On the basis of our own experience the costs of operational materials can be set adequately at exactly 10% of the costs for repairs, upkeep and maintenance.

2.5 Cost Savings

In new construction of a mechanico-biological stage with pre-precipitation it is possible to save investments as compared to one without pre-precipitation, as the latter can mean an up to 40% lighter load on the biological stage. Whether this leads to a reduction in annual costs in spite of higher operational costs and additional investments must be examined from case to case.

In simultaneous precipitation organic contaminants are trapped into the chemico-biological sludge flakes in such a manner as to prevent them from using any more oxygen. This should reduce the need for introduction of oxygen into the activation tank and, consequently, electricity costs for aeration. On the other hand, with the use of bivalent iron that must be oxidized to effective trivalent iron, the need for more oxygen and the with it connected higher electricity costs for aeration must be expected. Nevertheless, an analysis of standard operational procedures at wastewater processing plants as well as our own experiments did not produce any results that would be conductive to a computer-aided determination of these higher or lower costs. The above described expectations could be confirmed in individual cases, but contrary findings have also been encountered. The reason for this discrepancy is due to the different composition of wastewaters and, in many cases, inadequate control of O_2 injection.

Thus, for subsequent computations, no provision can be made for keeping track of differing costs of electricity under the heading "aeration".

However, after the wastewater discharge law becomes effective, it will be possible to achieve savings through precipitation treatment, as the 3rd purification stage will eliminate not only phosphates, but also other substances contained in wastewaters. An analysis of /256
literary sources as well as the experiments described in (7) show, e.g., that CSB, the most important pollution factor for computation of wastewater discharge, can be reduced through pre-precipitation by at least 10%, through simultaneous precipitation by at least 20% and by post-precipitation by approximately 40%.

2.6 Annual Costs

Figures 5 through 7 provide an example of specific investments, operational costs and annual costs for simultaneous and post-precipitation. The costs of pre-precipitation show only an insignificant difference from those of simultaneous precipitation, so their presentation at this point was dispensed with to facilitate a clearer orientation.

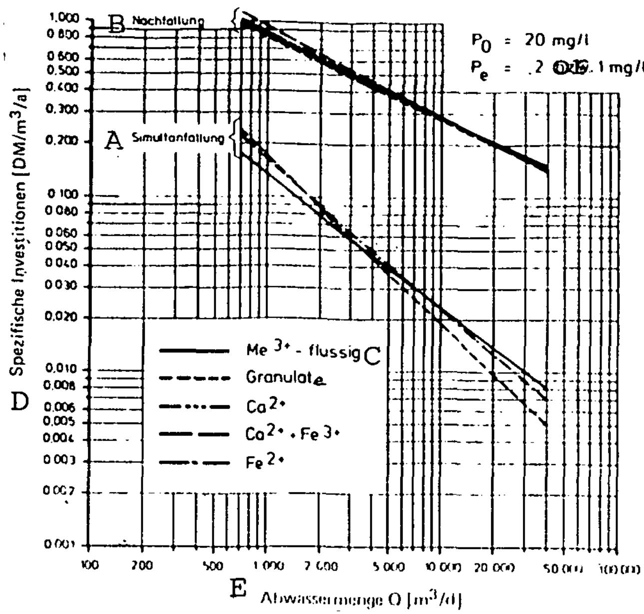


FIGURE 5.↑ Specific Investments for Simultaneous and Post-Precipitation in 1978 Prices.

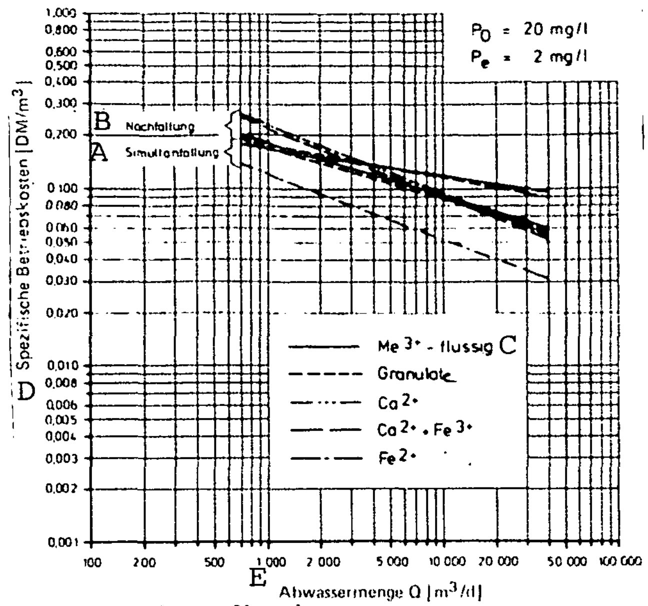
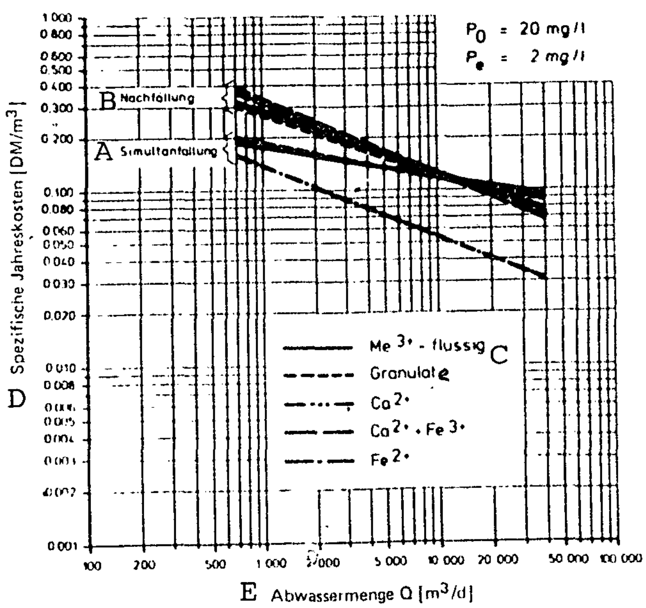


FIGURE 6.↑ Specific Operational Costs for Simultaneous and Post-Precipitation in 1978 Prices.



←FIGURE 7. Specific Annual Costs for Simultaneous and Post-Precipitation in 1978 Prices.

Key to Figures 5-7:

A - Simultaneous Precipitation
B - Post-Precipitation
C - Liguid
D - Same as costs listed in caption
E - Wastewater Volume.

To achieve a true cost comparison between the individual precipitation processes, the cost curves have been plotted for identical concentrations of the influent and effluent phosphate, in this case P_o = = 20 mg/l and P_e = 2 mg/l. It turns out that in spite of the considerably higher investments the annual cost of post-precipitation can be lower than that of simultaneous precipitation, but also that the absolutely most cost-effective precipitation method is simultaneous precipitation with bivalent iron salts.

Other concentrations of influent and effluent phosphate produce considerable changes in both the amount of specific costs as well as in the relation between individual types of precipitation agents. As an example, Figure 8 shows the differences in operational costs of post-precipitation with $P_e = 2$ and 1 mg/l for identical concentrations of influent phosphate; the additional cost for improved effluent quality range in this case, depending on the precipitation agent and the size of the processing plant, between 0.01 AND 0.06 DM/m^3.

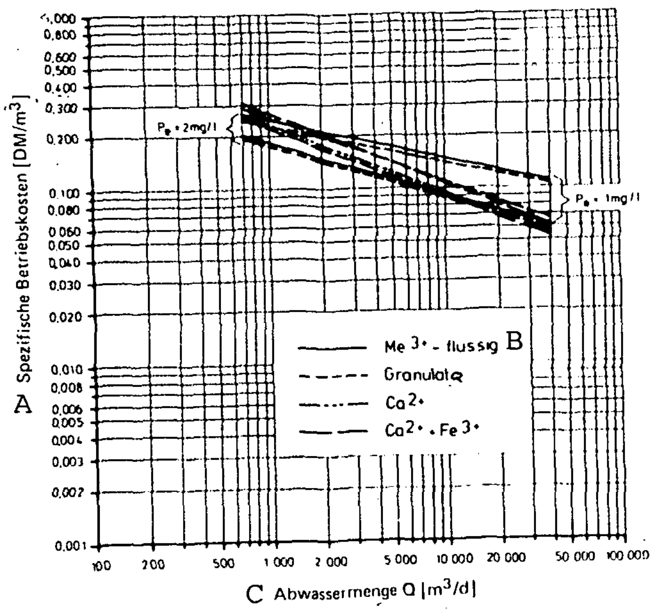


FIGURE 8. Operational Costs of Post-Precipitation for Varying Quality of Effluent Discharge. P_o = 20 mg/l. In 1978 Prices.

Key: A - Specific Operational costs; B - Liquid; C - Wastewater Volume.

Extensive graphical representations of specific costs in relation /257
to wastewater volume and the relevant residential equivalents as well as tabular outlines such as provided by Table 1 are contained in (8) or in the form of extracts in (6) for 306 variants of wastewater processing facilities.

4. Cost Write-off

All costs can be written off with the aid of price indices compiled and published by the Federal Statistical Bureau in Wiesbaden. Price development prognoses must be used for cost computations for later periods. Cost write-off guidelines and equations are contained in (6) and (8).

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