

Phosphate recovery from animal manure the possibilities in the Netherlands

Van Ruiten Adviesbureau/Projectbureau BMA, for CEEP (November 1998)

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1. INTRODUCTION

The Centre Européen d'Etudes des Polyphosphates (abbreviated to CEEP) commissioned a study into the possibilities of recycling phosphate recovered from animal manure. The content of the study is described in a proposal from Van Ruiten Adviesbureau B.V. dated 30 January 1998.

The purpose of the study is to gain an insight into the current level of knowledge and state of affairs concerning the amount of phosphate in animal manure and the available processing techniques, experience and prospects for the recovery of phosphate from manure. The subject is treated in terms of the types of manure produced by four categories of animals: cattle, veal calves, pigs and chickens.

The manner in which these types of manure are distributed, exported and processed in the Netherlands is described.

This inventory of current knowledge is accompanied by a description of the anticipated technical and economic prospects, and an estimate of the amount of phosphate from animal manure that will in principle be available for recycling. Consideration is given to the policy of the Netherlands concerning manure, and to the opportunities and threats that will stimulate and hinder the development of phosphate recycling.

The study focuses primarily on the Dutch situation and has been carried out on the basis of publications that are in the public domain. The computerised database of the project planning office BMA was consulted as an aid to collecting relevant literature information. This database contains a large amount of information on manure and related matters. It is a well-managed and up-to-date documentation system.

The literature that was traced with the help of this system was carefully screened by BMA, after which the selected publications were arranged by subject and then processed.

The collection and processing of the literature data yielded a number of results that were then examined in more detail. This was done by means of telephone and face-to-face discussions with external specialists. The researchers also participated in the Workshop "Energiewinning uit stapelbare pluimveemest" (producing energy from stackable poultry manure), organised by the Informatie Centrum Biomassa. The reactions of the specialists have been incorporated in the report.

Concerning the scope of the study, it should be noted that most manure treatment and processing techniques are not primarily designed to recover phosphate. The number of specific phosphate removal techniques for manure is very limited. In most cases they involve concentrating phosphate in a certain fraction of the manure (for example, by separation) or concentrating phosphate and other minerals by drying and evaporation. For this reason a conscious decision was taken to avoid the extensive descriptions of techniques initially envisioned by the client.

The availability of the phosphate in animal manure has been at the heart of this study. The various operational or promising treatment and processing techniques that were looked at are mentioned in the report, but in conformity with the proposal put forward by Van Ruiten Adviesbureau they are not dealt with in greater detail.

2. THE MANURE PROBLEM (CHRONOLOGICAL DEVELOPMENT)

2.1. The manure problem in the Netherlands

Increasingly intensive methods of stock farming have resulted in a surplus of animal manure in the Netherlands, which primarily means a surplus of minerals (nitrogen and phosphate). Above all, the emergence and growth of “land-independent” (intensive) stock farming establishments in the sandy regions of the southern, eastern and central Netherlands has made a major contribution to this state of affairs. The reason is that the soil type in these regions is not suitable for a high level of production of “land dependent” agricultural crops, and the cultivated area per farm is small.

The import of cheap raw materials for cattle feed and the good infrastructure have encouraged the development of intensive stock farming in these regions. As a counterweight to the import of cattle feed, there are substantial exports of products (meat, eggs, milk, cheese, etc.). However, the excreted minerals remain in the soil. The result is a net increase in the amount of minerals within the country’s borders.

A surplus of minerals causes environmental pollution in the form of contaminated soil, groundwater and surface water. In addition, unpleasant odours are emitted.

Although the signs of the negative effects were already recognised in the 1960s [1], it was not until the 1970s that measures were gradually introduced to limit the loss of minerals into the environment. Although the emission of nitrogen is just as harmful from an environmental point of view as the emission of phosphate, the Dutch government has always geared its legislative and regulatory measures to phosphate (P_2O_5). The significance of this is primarily practical. Nitrogen is more difficult to incorporate in an analysis of inputs and outputs, due to its presence in the form of volatile compounds such as ammonia (NH_3) and nitrogen gas (N_2). In European legislation, however, nitrogen (in the form of nitrate) has been chosen as the “yardstick” element (EU Nitrate Directive 91/676/EEC, [2]).

In the course of the years, the limiting measures taken by the government have been steadily tightened up (phased approach) and the amount of research work into proposed problem solutions has simultaneously increased. In its search for solutions the government has elected for a three-pronged policy of geographically spreading, limiting minerals in cattle feed, and treating and processing manure.

In this study, the focus of attention has been primarily on the third aspect. As an aid to putting the manure processing option in perspective, it is worthwhile to view it against the background of how manure policy developed. Table 1 shows a summary of the most important milestones.

Table 1 How manure policy developed in Holland

1984	Interim law
	<ul style="list-style-type: none"> • Prohibits starting up new establishments for chickens and pigs. Expansion of existing establishments is tied to a maximum.
1987	Soil Protection Act
	<ul style="list-style-type: none"> • Use of manure is limited to the growing season. Introduction of standards governing use. Limits are gradually lowered.
1987	Fertilisers Act
	<ul style="list-style-type: none"> • Introduction of manure production rights coupled to the number of animals. Manure accounting and levy. Landelijke Mestbank (national manure bank) stimulates distribution.
1987-91	First phase of manure legislation
	<ul style="list-style-type: none"> • Use standard is closely related to manure production to prevent the creation of large surpluses.
1992	Nitrate Directive¹) and Veterinary Directive²) (Europe)
	<p>1) Restrictions on the use of animal N (170 kg N/ha).</p> <p>2) Pig manure may only be exported in processed form (pasteurised).</p>
1991-95	Second phase of manure legislation
	<ul style="list-style-type: none"> • The three prongs of the legislation (feed modification; distribution; large-scale processing) are developed further.
1995-2000	Third phase of the manure legislation
	<ul style="list-style-type: none"> • Overall reduction of 30% on land-independent manure production rights. • Reduction of 25% in land-independent manure production rights on transfer or relocation. • Introduction of the mineral reporting system (MINAS) at the farm level. • Levy on losses in excess of the standard loss, on the basis of N and P (start 1998).
1998	Act for restructuring the pig farming sector (in hand)
	<ul style="list-style-type: none"> • Introduction of pig rights and a reduction of 20 to 25% on them
1998	Convenant between LNV* and group of poultry farmers
	<ul style="list-style-type: none"> • Expansion permitted, provided the composted manure is exported after quality control checks.

* LNV = Dutch Ministry of Agriculture, Nature Management and Fisheries

Various actions were taken in response to the manure policy. The redistribution of manure from regions of surplus to regions of shortage was stimulated by the efforts of, for example, the national manure bank. In addition, research into restricting the minerals in cattle feed and into industrial manure processing received a powerful stimulus. Large sums of money were made available by the government and the agricultural industry.

In 1972 the coordinated research program “Megista” study was started by institutions such as LNV, TNO and LUW. From 1985 to 1996, manure research was carried out in the Netherlands within the framework of the Dutch financing committee on research into manure and ammonia, referred to as FOMA (Financieringsoverleg Mest- en Ammoniakonderzoek) [3].

Between 1972 and 1979, research was focussed mainly on the anaerobic fermentation of manure and the generation of methane; mixing, separating and dewatering fattening pig manure (slurry); testing veal calf manure plants under real-life conditions; combating unpleasant odours with air scrubbers; and drying chicken manure.

During the 1980s and 1990s, the focus of research and development in manure processing shifted towards central, large-scale processing. The aim was not so much the selective recovery of minerals but rather the restriction of the disposable volume

(veal calf manure) and/or the production of saleable and exportable (manure) product, preferably in the form of dry granulate that can be used as a plant fertiliser and soil-improvement agent. Recovery of phosphate from animal manure played no significant role in this.

At the end of the 1980s the government urged the stock farming sector to take 25 million kg P₂O₅ (equivalent to about 6 million metric tons of pig manure) out of the market in 1995 through processing. A large number of initiatives were started at that time. A few of the more important ones are shown in Table 2 [4].

Table 2 *Examples of manure processing initiatives*

Description	Product	Initiators
Processing pig slurry	Fertiliser granules	Promest, MeMon, Scarabee
Processing liquid fraction sow manure and veal calf manure	Concentrate	Mestwerk
Drying chicken manure	Fertiliser granules	Vefinex, Ferm-O-Feed
Processing veal calf manure	Processed manure	Mestverwerking Gelderland

With the exception of the processing of veal calf manure (total processing capacity 660,000 metric tons/year) and slurry (evaporation plants with a total processing capacity of 160,000 metric tons/year), these large-scale initiatives ultimately led to nothing, despite the enormous amounts of time and money invested. Promest built a factory for 500,000 metric tons of manure per year (investing more than 100 million guilders), which was shut down only two years later.

There were various causes for these large-scale failures, such as an excessively high processing price in relation to competing options such as geographically spreading; insufficient support from the sector; problems with the choice of location and licences; and uncertainty with regard to the market for the end product.

In addition, in 1995 the EU prohibited the continuation of subsidies for large-scale manure processing and long-distance transportation, and this had an extremely disadvantageous effect on the competitive position of the various problem solutions.

These negative developments gave rise to a climate of considerable scepticism concerning central manure processing, and in the pig farming sector, in particular, there is now a tendency to look for solutions to the manure problem at the farm level.

2.2. The manure problem in other countries

Surpluses also occur in some regions of other countries, for example in Flanders, Brittany, northern Germany and the Po delta. Although this problem is gradually attracting more attention in these regions, partly under the influence of European legislation, far less effort has been devoted to solving it than in the Netherlands.

Table 3 summarises the situation in other countries (in so far as this is known).

Table 3 Manure situation in other countries

Country/region	Situation
Belgium/Flanders	Approach based on the manure action plan (MAP). After 1999, farms with a production of more than 10 metric tons of phosphate per year will be obliged to dispose of the manure outside of the Belgian agricultural sector. Mainly initiatives for processing pig manure.
France/Brittany	On the basis of the Nitrate Directive; management of nitrate levels in groundwater. Attention primarily focused on reducing N-pollution of soil.
Germany	Manure treatment at regional level has been strongly stimulated in recent years by financial support. Project “Umweltverträgliche Gülleaufbereitung und -verwertung” (environmentally compatible slurry treatment and utilisation).
Denmark	In connection with sustainable methods of generating energy, there has been a switch to centralised production of biogas by fermentation in many places. No manure problem.
England	Encouragement of sustainable methods of generating energy from manure by incineration. No manure problem.
Italy/Po delta	High density of pigs; manure disposal problems. Biological treatment (centrally and at the farm level), separation and biogas production.

Places outside of Europe also face the problem of manure surpluses. These include Taiwan, Hong Kong, Malaysia, Japan and the USA.

In view of the fact that very little is known about the situation outside the Netherlands, the study of possible ways of recovering phosphate from animal manure is largely confined to the Netherlands. The following chapter takes a quantitative approach to the manure surplus in the Netherlands, with the aim of obtaining an impression of the amount of phosphate that can potentially be produced from animal manure.

3. AMOUNTS OF PHOSPHATE IN ANIMAL MANURE

The production of animal manure releases a considerable amount of phosphate. The manure comes from a large number of animals, kept on very many farms, which are subdivided into grazing and indoor (intensive) establishments.

This chapter contains background information on the number of animals and establishments, the amounts of manure produced, the amount of phosphate excreted, the use of animal phosphate, the calculated phosphate surplus, and the historical development.

On the basis of the most important manure flows, the emphasis is on the following categories of animals: cattle, veal calves, pigs and chickens.

The number of animals in the named categories is shown in Table 4. The data are taken from the CBS (Dutch Central Bureau of Statistics) agricultural census concerning the Dutch herd over the period 1970-1997 [1].

Table 4. Cattle, veal calf, pig and chicken numbers in Holland, 1970-1997

Source: CBS agricultural census

	1970	1980	1990	1994	1995	1996	1997
• cattle	4,314	5,226	4,926	4,716	4,654	4,551	4,411
<i>including:</i>							
- veal calves	434	582	602	690	669	678	740
• pigs	5,533	10,138	13,915	14,565	14,397	14,419	15,189
• chickens	55,375	81,155	92,764	91,902	89,561	91,441	93,106

It should be noted that the cattle, with the exception of veal calves, are held on the land (grazing animals). Veal calves, along with pigs and chickens, are raised in indoor establishments. This is important with regard to the form in which the manure becomes available. The type of stall plays an important role - for example, farmyard manure (solid) versus slurry (semi-liquid).

Large amounts of cattle feed, and therefore of phosphate, are imported for the livestock industry. A considerable proportion of this phosphate is excreted by the animals. Figure 1 shows the flow chart for phosphate in 1995. It can be seen that 84 million kg P are imported in cattle feed alone (roughly 1/3 of the amount of P that is imported in phosphate ore). The excretion of phosphorus in animal manure is 86 million kg P according to the chart (about 197 million kg P₂O₅). The fact that this amount is higher than the amount of P from imported cattle feed is attributable to the use of domestic cattle feed.

Moreover the figure shows that discharges of household and industrial waste water contain 10 million kg P. This is about 1/10 of the amount of P in animal manure.

The CBS agricultural census also includes data on the number of stock farming establishments in the Netherlands and the area they cover (Table 5)

Table 5. Number and area of stock farming establishments Holland (1970-1997)

	1970	1980	1990	1994	1995	1996	1997
• Number of establishments	111,823	92,448	74,436	70,133	65,027	63,312	61,394
<i>of which</i>							
- grazing establishments	-	-	61,211	58,326	54,613	53,176	51,126
- indoor establishments	-	-	13,225	11,807	10,414	10,136	10,268
• Area per stock farming establishment (ha)	12	14	16	17	18	19	19
<i>of which</i>							
- grazing establishments	-	-	18	19	20	21	22
- indoor establishments	-	-	4	4	5	5	5

The table shows that animal manure is produced at a large number of locations. It is also apparent that the indoor establishments have a lot less ground on average, so that a manure surplus arises more quickly at the farm level. In this context it is interesting to compare the livestock density in the Netherlands with the situation in other European countries (Table 6).

Table 6. Number of animals in indoor establishments in selected EU countries

Country	Area x 1000 km ²	Animal population (x 106)			Population	
		pigs	all cattle	sheep	laying hens	x 106 1)
Belgium	30	6	3	<1	11	10
Denmark	40	9	2	<1	4	5
France	540	12	22	10	69	58
Germany	360	25	15	1	49	81
Greece	30	1	1	11	17	10
Ireland	70	1	6	3	3	4
Italy	300	9	9	12	48	57
Netherlands	40	14	5	1	40 2)	15
Spain	500	16	5	17	-	39
England	240	8	12	26	53	58
WORLD	136,000	1,200	220	780	1,600	c. 6,800

Source: Eurostat, 1988; taken from ref. [2]

1) Situation 1993, data taken from Encarta '97 2) The total number of laying hens and broilers is 93 million in 1997

According to the above-mentioned publication, the total number of pigs in Europe is about 110 million (including 12 million sows). The human population numbers 375 million. In the Netherlands the number of pigs is almost as high as the human population, namely 15 million. Relative to the human population, there are 0.9 and 0.6 pigs to each human resident of the Netherlands and Belgium respectively, while for England the equivalent figure is about 0.1.

From the Table it can be deduced that the livestock density in the Netherlands is more than 3.5 times as high as in England (UK). Due to this high livestock density, the problem of manure surpluses is far worse in the Netherlands than in its neighbouring countries. In some regions of the Netherlands, the livestock density is far higher than the national average. There are areas of high livestock concentration in the provinces of Brabant, Limburg and Gelderland. These areas are darkly shaded black in Figure 2 (inside rear cover and page 12), which shows an overview of the official disposal quotas for phosphate per agricultural area in 1995 (CBS/Mestbank).

The overview also gives an indication of the logistical possibilities. Some 75% of the areas with a large manure excess are to be found within a radius of 50 km.

Table 7: Manure production by the Dutch national herd

Source: CBS Voorburg, Kwartaal Bericht Milieustatistiek, no. 4, 1997; ref. [3].

Million kg	Form	1984	1990	1991	1992	1993	1994	1995	1996
Cattle 1)	slurry	78,579	63,250	63,879	61,693	60,024	58,251	58,183	56,616
	solid	-	837	976	1020	1095	1025	1023	1025
Veal calves	slurry	1,787	2,106	2,176	2,232	2,297	2,413	2,471	2,522
Pigs	slurry	15,926	16,356	16,390	16,349	16,957	16,380	16,146	16,157
Chickens	slurry	1,595	1,434	1,461	1,461	1,394	1,125	905	931
	solid	614	1,045	1,061	1,115	1,076	1,131	1,198	1,222
National herd 2)	slurry	98,554	84,725	85,623	83,490	82,421	79,758	79,247	77,797
	solid	727	2,187	2,373	2,470	2,500	2,463	2,601	2,649

1) Excluding veal calves 2) Whole livestock herd, including sheep, goats, fur-bearing animals and rabbits

Not only the amount of manure but also its composition (content of dry solids, organics and minerals) is of importance with regard to its possible uses. The composition of the manure depends on, among other things, the type of animal, its feed (green forage, concentrate) and its accommodation. The composition of the manure from the types of animals considered in this study is shown in Table 8.

Table 8: Manure composition in kg per 1000 kg manure

Source: ref. [4]; data from March 1996

Category	Description	dry matter	organics	N-total	P ₂ O ₅	K ₂ O kg/m ³	wt/unit vol. P ₂ O ₅ /dm.a)	
Cattle	Liquid manure	25	10	4,0	0,2	8,0	1030	0.008
	Slurry	90	66	4,9	1,8	6,8	1005	0.002
	tie-up cowhouse	235	153	6,9	3,8	7,4	900	0.016
Veal calves	Slurry	20	15	3,0	1,5	2,4	-	0.0075
Fattening pigs	Liquid manure	20	5	6,5	0,9	4,5	1010	0.045
	Slurry	90	60	7,2	4,2	7,2	1040	0.047
	Straw	230	160	7,5	9,0	3,5	-	0.039
Sows 1)	Liquid manure	10	10	2,0	0,9	2,5	-	0.09
	Slurry	55	34	4,2	3,0	4,2	-	0.0545
Chickens	Slurryx	145	93	10,2	7,8	6,4	1020	0.0537
	Dry manure	515	374	24,1	18,8	12,7	605	0.0365
	Litter	640	423	19,1	24,2	13,3	600	0.0378
Broilers	Farmyard manure	605	508	30,5	17,0	22,5	605	0.028
“layer breeders”	Farmyard manure	610	-	19,5	28,5	21,1	625	0.0467

1) Including piglets to about 25 kg 2) From laying hens a) This column was calculated

This overview shows that chicken manure is richest in phosphate. This is not the case in relation to dry matter (for example, chicken slurry: 0.053 kg P₂O₅/kg d.s.; veal calf slurry: 0.075 kg P₂O₅/kg d.s.)

In principle, the amount of excreted minerals can be calculated from the produced amount of manure and its composition. In the case of the mineral phosphate, on the basis of the data compiled by the Dutch Central Bureau of Statistics, the picture is as follows.

Table 9: Phosphate excretion by the Dutch national herd

Source: CBS Press Release du072901.htm; ref. [5]

In millions of kg P₂O₅	1984	1990	1993	1994	1995	1996
Cattle ¹⁾	141	111	118	112	110	96
Veal calves	3	3	3	3	4	3
Pigs	71	69	72	65	60	58
Chickens	37	33	35	33	29	29
National herd	254	220	235	219	209	192

1) Excluding veal calves

The table shows that cattle make the biggest contribution to phosphate excretion (about 50%). As mentioned above, most of the manure produced in the cattle farming sector is from grazing animals. This applies even more so to nitrogen excretion in the cattle farming sector, which is not dealt with further here.

A considerable proportion of the phosphate excreted in the manure is used to fertilise grassland and arable land (placement in farm where produced and distribution). A small proportion is exported or processed. In view of the fact that not all manure can be disposed of in this way, a national manure and phosphate surplus arises. This is illustrated in Table 10.

Table 10: Estimates of national manure production in terms of phosphate, and the disposal options in '96, '98, '02 + '05 under the proposed standards

Source: Dutch Integral Policy Document on Manure and Ammonia; ref. [6]

in million kg P₂O₅		1996	1998	2002	2005
• Phosphate production a)	(1)	206 ¹⁾	200	190	185
- Placement capacity in farm where produced b)	(2)	118	108	103	99
• Farm surplus	(4)	88	92	87	86
- Distribution	(5)	71	69	49	49
- Export/processing	(6)	14	15	20	20
• National surplus	(7)	3	8	18	17

¹⁾ Table 9 indicates that phosphate production is 192 million kg. This is probably due to the fact that different sources were used.

a) See Table 11 b) See Table 12 4 Farm surplus = 1 minus 2 7 National surplus = 4 minus 5 + 6

From the above it is clear that a national surplus will be created as a consequence progressive tightening up of the manure policy. More manure must therefore be taken out of the market or the number of animals should be reduced.

Table 11 shows the amount of manure and phosphate per animal and year for each type of animal, according to the so-called WUM figures (WUM = Dutch abbreviation standing for “work group for standardisation of the method of calculating manure and mineral figures”).

Table 11: Manure and mineral production factors

Source: CBS; ref. 8 and 9

Type of animal kg/animal/year	Manure	1990 P₂O₅	1995 P₂O₅	1996 P₂O₅
Fattening pigs	1,250	5.8	5.3	5.2
Rearing sows	1,300	7.7	6.6	6.2
Sows with piglets	5,200	19.5	15.2	14.3
Laying hens younger than 18 weeks	25.4	0.2	0.17	0.15
Laying hens of 18 weeks and older	63.5	0.5	0.45	0.43

The complete details of manure and mineral production figures per animal for the various years can be found in the above-mentioned references.

From the table it appears that phosphate production figures exhibit a downward trend. This is connected with the far-reaching reduction of phosphate in animal feedstuffs [use of phytase (phosphate uptake enzyme)] and/or adjustment of the feed regime.

The amount of manure that can be spread on cultivated land inside the Netherlands depends on the standards drafted by the government for this type of use. In recent years these standards have been tightened up still further (see Table 12). A national surplus has not yet arisen. This was partly due to the outbreak of swine fever in 1997.

Table 12: Legal standards for spreading manure

Source: CBS; ref. 7

in kg P₂O₅ per ha	1994	1995	1996
Grassland	200	150	135
silage maize	150	110	110
Other arable land	125	110	110

4. SALE AND PROCESSING OF MANURE BY SPECIES

The future cuts in the amount of manure that can be used per hectare will lead to an increase in the national surplus. As a consequence, demand for processing systems that can result in the sale of minerals on other markets may increase. It is anticipated that this will cause selling costs to increase to between NLG 20 and a maximum of NLG 30 per metric ton. The current level of selling/disposal costs is NLG 15 per metric ton of raw manure.

The manure situation is described for the four chosen categories of animals, i.e., cattle (except calves), veal calves, pigs and chickens, with particular emphasis on the mineral phosphate. The aspects dealt with in sequence are: definition of the problem, sales options for manure, manure treatment techniques and their consequences for phosphate, anticipated developments, and an indication of the quantity of phosphate, giving a global assessment of price levels where possible.

4.1. Cattle manure

Definition of the problem

Cattle make the largest contribution to the excretion of minerals (N and P) by Dutch livestock. They account for about 50% of phosphate and more than 60% of nitrogen. In view of the fact that cattle farming is generally dependent on the type of soil, and most farms are not located in manure concentration areas, there is not yet any question of a surplus situation with regard to cattle manure.

Sale

Where the manure is not used as a fertiliser on the farm where it is produced, there are opportunities for selling it to crop farmers. In 1996 the situation was as follows (Table 13, ref [1])

Table 13: Disposal of cattle manure, in metric tons of phosphate (P₂O₅)

Source: Stichting Landelijke Mestbank

Type of manure	Total	User	Treatment	Exported	Stored	Trade	Unknown
Farm yard manure	1.698	1.123	52	8	33	482	0
Slurry	6.019	5.405	29	17	197	369	3
Total	7.717	6.5281)	81	25	230	751	3

1) The total volume of phosphate excreted in cattle manure in 1996 was 96,000 metric tons.

Note

Disposal must be viewed as manure production minus the manure used on the land of the farm where it was produced.

When cattle manure is sold to crop farmers, it competes with other types of manure such as that from pigs and chickens. One of the advantages of these types of manure is that they contain less weed seeds than cattle manure. The reason for this lies in the difference in feed (concentrates versus green forage).

Until now this competition has not resulted in the creation of an undisposable surplus of cattle manure. In terms of phosphate fertiliser, cattle manure contains relatively little phosphate in the dry matter (0.01 to 0.02 kg P₂O₅/kg d.s.).

Manure treatment

90% of the phosphate in cattle manure is undissolved [12]. The treatment of cattle manure is restricted to small-scale manure separation and drying.

Separation

Manure separation causes phosphate to accumulate in the solid fraction. This is due to the fact that the phosphate is present in the manure in solid form. The purpose of separation is to achieve a manure fraction with a higher manurial value and a limited volume, which is more saleable than the raw manure. This technique is useful for establishments with a small surplus. Manure is dried by evaporating the water, so that all non-volatile minerals are concentrated to the same extent in the dry end product. The primary purpose of drying is to create a marketable manure product.

A screw press is a typical piece of equipment for separating cattle manure. Results achieved with this type of machine under the conditions prevailing in the Netherlands have been described by Schepers [2]. The separator is made up of a double screw jack, which rotates in a special drum sieve. Cattle manure with 8.1% d.s. and a phosphate content of 1.5 kg P₂O₅/metric ton was separated, yielding a solid fraction with 25% d.s. and 3.4 kg P₂O₅/metric ton as well as a liquid fraction. The separation efficiency was only 29% for phosphate, which was undoubtedly due to the low solid separation, i.e. only 39% (of d.s.). This is therefore a coarse separation.

Drying

In the Netherlands, cattle manure is dried by Komeco (farmyard manure and slurry) and Culterra (farmyard manure). Since 1970 Komeco has been drying manure at two locations, i.e. Dronten (farmyard manure; two drum dryers with a water evaporation capacity of 4 metric tons/h) and Enschede (slurry; water evaporation capacity of 1.6 metric tons/h). An annual total of about 40,000 metric tons of cattle manure is processed into manure products in the form of powder, pellets and granulate. The products (approx. 8,000 metric tons per annum) contain 1.5% P₂O₅.

Culterra's facility in Workum also treats about 40,000 metric tons of farmyard manure per annum. This consists of cattle manure and an unknown quantity of chicken manure. The manure is not treated as a response to a surplus situation. The products are produced mainly for the domestic gardening market.

Anticipated developments

There are no specific techniques for extracting phosphate from cattle manure.

At this moment in time, no significant developments are expected on the cattle farming sector with regard to the production and sale of manure. It may well be that stricter standards, especially concerning nitrogen on the basis of the Nitrate Directive, could exert extra pressure on manure sales. Treatment of cattle manure on an industrial scale is not anticipated.

The volume of manure disposed of by the cattle farming sector is limited. Expressed as phosphate, it is more than 7,700 metric tons P₂O₅ from a production of approx. 100,000 metric tons per annum. The largest proportion - 6.500 metric tons P₂O₅ (= 84%) - could potentially become available if the manure were not sold to the crop farming sector. This volume could increase if the standards were made stricter. The amount of phosphate in dried manure is no more than 240 (1.5% of 16,000) metric tons of P₂O₅ per year. Because this dried manure is sold profitably (NLG 1500 per metric ton - equivalent to NLG 15 per kg phosphate) on the domestic gardening market, it will certainly not become available for the recovery of phosphate.

4.2 Veal calf manure

Definition of the problem

Veal calves produce a mixture of faeces, urine and washing-down water, which has a very low proportion of dry matter (approx. 1.5%) in comparison with other types of manure. This mixture (which is referred to as veal calf manure, and is comparable to waste water) has a low proportion of dry matter, which is the main reason why it is not easily saleable. About 50% of the phosphate is present in dissolved form.

Due to the fact that veal calf rearing establishments are usually located in areas with a high incidence of livestock farming, veal calf manure makes a major contribution to regional manure surpluses.

Sales

According to the Stichting Landelijke Mestbank [1], the disposal of veal calf manure in 1996 was as follows (Table 14).

Table 14: Disposal of veal calf manure, in metric tons of phosphate (P₂O₅)

Source: Stichting Landelijke Mestbank

Type of manure	Total	User	Treatment	Exported	Stored	Trade	Unknown
Veal calf manure	2.021	892	986	3	52	88	0
Processed manure kgbi 1)	903	568	0	0	243	92	0

1) kgbi = veal calf manure treatment plant

The total volume of veal calf manure (expressed as P₂O₅) in the same year. was 3,000 metric tons

Due to the low proportion of dry matter, the opportunities for selling this manure are restricted to distribution over short distances. It is not profitable to transport 'water' over long distances.

Biological treatment of the liquid manure results in a considerable reduction in bulk as well as in the removal of organic matter and nitrogen. One cubic metre of liquid manure yields 0.16 m³ of treated liquid manure. This treated liquid manure (which is similar to sludge from a sewage treatment plant) can, however, be transported for long distances and sold in crop farming areas.

Manure treatment techniques

Biological treatment and dephosphorisation

Processors in the Netherlands have therefore opted for biological treatment of veal calf manure [3]. This is very similar to the methods traditionally used by municipal sewage treatment plants. Microorganisms and atmospheric oxygen are used to break down organic matter into carbon dioxide and water in the aeration tank. Nitrogen, which is present in the form of ammonia and organic nitrogen, is first microbiologically oxidised to nitrite and/or nitrate (nitrification), before being microbiologically reduced, in the presence of biodegradable organic matter, to nitrogen gas, which escapes (denitrification). The final effluent is discharged into a sewage treatment plant, where further treatment takes place. The surplus sludge (processed manure) from the veal calf manure treatment plant goes through settling and concentration stages before being sold to the crop farming sector as a fertiliser. It is concentrated with the aid of centrifuges until it is highly viscous.

The first plant for treating veal calf manure did not operate continuously and did not remove phosphate (dephosphorisation). The decision to include a phosphate removal stage in liquid manure treatment was taken as a consequence of the high phosphate burden on the wastewater treatment plant due to the discharge of effluent (300 mg/l P), and the tighter discharge regulations for phosphates (in connection with eutrophication). After extensive research [4,5], it was decided to add milk of lime to the aeration tanks (simultaneous dephosphorisation). This resulted in a reduction of the phosphate content of the effluent to about 30 mg/l P. The calcium phosphate that is formed passes into, and is discharged with, the surplus sludge. Treatment plants for veal calf manure have since been converted from discontinuous to continuous operation, with separate nitrification and denitrification tanks and separate final settlement tanks. In 1998, 660,000 m³ of veal calf manure will be treated in four central veal calf manure treatment plants. These plants are located in Ede, Elspeet, Stroe and Putten, and are the property of Stichting Mestverwerking Gelderland. All in all, an annual total of about 940 metric tons of P₂O₅ are discharged with the treated liquid manure from the veal calf manure treatment plants. The treated liquid manure, which contains phosphate in the form of calcium phosphate, has the following composition (Table 15).

Table 15: Composition of processed veal calf manure

Source TAUW ref. [6]

Parameter	Concentration in mg/l
Dry matter	110.000
Chemical oxygen demand	63.000
N-Kjeldahl	6.300
N-NH ₄	2.000
N-NO ₂	none
N-NO ₃	none
Total P ¹⁾	5.800
Chloride	2.700
Potassium	3.600
Sulphate	500
Copper	20
Zinc	165
Cadmium	0,01

1) To convert P to P₂O₅, multiply by 2,29

As a result of the biological treatment, the ratio of P₂O₅ to dry matter has increased from 0,075 to 0,12.

Another three developments deserve mention with regard to the removal of phosphate from veal calf manure. Two cases involve the removal of phosphate from biologically treated liquid manure (effluent).

Crystallisation (Crystalactor™)

In 1987, the engineering consultants, DHV, studied the dephosphorisation of pre-treated veal calf manure in a Crystalactor([7]. The process involves the crystallisation of calcium phosphate on an inert carrier (grains of sand) in a fluidised bed (process description [8]). An advantage of this process over the simultaneous dephosphorisation process is that it results in a purer phosphate product. It may be possible to sell this high-quality product to the phosphate processing industry. The resulting crystal consisted to 80% of calcium phosphate. Under certain test conditions, it was possible to remove 90% of the incoming phosphate, 60% of which was crystallised on the grains. Actually this process involves phosphate recovery rather than phosphate removal.

Various technical problems (CO₂ stripping, addition of extra Ca, particle carryover, etc.) and the good results obtained with simultaneous precipitation were the reasons why this research did not, ultimately, lead to a full-scale plant for veal calf manure.

Precipitation (struvite)

Another phosphate removal process, which can, in principle, result in a cleaner and more useful end product is the KMP (Potassium-Magnesium-Phosphate) process. This process was studied by DHV [9] and GEOCHEM research B.V. [10]. In this process, the undissolved phosphate is precipitated in the form of ammonium magnesium phosphate (NH₄MgPO₄·6H₂O; struvite) or potassium magnesium phosphate (KMgPO₄·6H₂O). A reagent consisting of an aqueous suspension of magnesium oxide is added to the aerobically treated veal calf manure. The reaction proceeds as follows: HPO₄²⁻ + Mg²⁺ + (K⁺,NH₄⁺) + 6H₂O ((K,NH₄)MgPO₄·6H₂O + H⁺

Various parameters of this process have been studied, such as the Mg:P ratio, acidity (pH), retention time, temperature, effect of suspended solids, and the conditioning of the MgO slurry. More than 30% of the precipitate consisted of phosphate (as PO₄, equivalent to 22.7% P₂O₅) and could be readily concentrated. The process is being optimised. For this purpose the veal calf manure treatment plant in Putten has been converted to enable a trial to be carried out on a scale of 100,000m³ liquid manure per year. The experiments recently commenced.

The (manurial) value of the struvite obtained from the veal calf manure is still unclear [11]. However, it is anticipated that crops will readily utilise struvite (T. van Dijk, NMI, Wageningen, 1998 personal communication).

Evaporation/Drying

The third development concerns the evaporation of veal calf manure (usually in combination with the settled sow manure) in an energy-saving manure evaporator from Van Aspert. This concentrates the semi-liquid manure to about 20% d.s. During this concentration the ratio of P₂O₅ to d.s. remains unchanged.

An initial plant with a processing capacity of 25,000 metric tons/year has been erected in Odiliapeel (Coöperatie Mestwerk). Mestbureau Oost has commissioned a second plant with a processing capacity of 135,000 metric tons/year, which has been built in Eibergen. This plant is expected to start operating in early 1998. Demand for the end product (concentrate) - possibly mixed with pig slurry - is good in the crop farming sector. Van Aspert plans to dry the concentrate to a granulate (90% d.s.), which can be sold to the fertiliser industry. Van Aspert has concluded a long-term marketing agreement with the fertiliser industry for this purpose [43].

Anticipated developments

The biological treatment of surplus veal calf manure is generally viewed as a good and cost-effective solution. This is not expected to change in future. It is possible that treatment capacity could eventually be expanded. However, there are currently no concrete plans to do so. Currently the treatment plants can easily handle the volume of surplus liquid manure produced in the Veluwe region.

The volume of phosphate obtained from veal calf manure is probably limited to the treated manure (slurry) from the central veal calf manure treatment plants. As previously indicated, this represents 940 metric tons of phosphate (in the form of P₂O₅) per year, given a treatment capacity of 660,000 m³. This is a relatively small amount.

If struvite precipitation proves to be decisively successful as the final stage of the biological treatment of liquid manure, a certain amount of phosphate will become available as struvite. Calculations show that 660,000m³ of aerobically treated liquid manure and a phosphate reduction from 300 to 30 mg/l P can produce about 1400 metric tons of struvite

($\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$). This contains 408 metric tons of phosphate (P_2O_5). No data are yet available with regard to the purity of the struvite.

Assuming that the cost price for the treatment of veal calf manure is NLG 15 per m³ of supplied manure (P-content approx. 0.7 g/l), calculations show that the approximate price could be of the order of NLG 10 per kg P_2O_5 . When all the costs are contributed to the production of struvite are added together, they amount to NLG 24 per kg P_2O_5 .

4.3. Pig manure

Definition of the problem

A distinction can be made between manure from fatteners and sows. The most significant form of pig manure is slurry (a mixture of faeces, urine and washing-down water). Sow manure contains much more water, mainly due to the use of washing-down water (about 5% d.s. compared with 10% d.s. from fatteners). Disposal of the semi-liquid sow manure is difficult. In view of its low content of dry matter, it has to be distributed in the vicinity of the establishment. The situation is similar to that of veal calf manure. A new situation arises when this manure is separated into a solid and a liquid fraction because most of the phosphate present is in the solid fraction. The solid fraction can be transported long distances, in the same way as manure from fatteners. Thus, a large proportion of the phosphate is removed from the manure surplus area. The liquid fraction must be disposed of locally or possibly subjected to further processing.

Sales

Pig slurry and solid fraction are sold and distributed to the crop farming sector, where they compete with, for example, cattle and chicken manure. If the pig manure has a relatively high content of dry matter (>8%) and a homogeneous composition, it can compete well. Just like chicken manure, it contains few or no weed seeds, because pigs are mostly fed on industrial feed (concentrates). The sale of pig manure is restricted to the Netherlands, because the export of untreated slurry is prohibited (Veterinary Directive EC18/EEC). Since the option of large-scale manure treatment does not exist, distribution currently remains the most important option.

According to the Stichting Landelijke Mestbank, the disposal of pig manure in 1996 was as follows (Table 16).

Table 16: Disposal of pig manure, in metric tons of phosphate, in 1996 (production minus producer's own use

Type of manure	Total	User	Treatment	Exported	Stored	Trade	Unknown
Solid Manure	228	196	1	1	0	28	0
Slurry	22.336	17.564	54	104	2.681	1.924	9
Sow manure	12.066	9.957	2	53	937	1.116	2

The table shows clearly that large amounts of phosphate are disposed of in this sector (a total of 34,630 metric tons P_2O_5). The total amount of phosphate excreted by pigs in 1996 was 58,000 metric tons. Table 15 shows that about 60% of this was disposed of.

Manure treatment

With regard to the mineral phosphate, the phosphate-related treatment and processing techniques for manure are based on concentrating phosphate in a specific fraction of the manure. In this context, methods such as separation, precipitation, absorption, incineration and wet air oxidation were studied.

Separation

Because about 90% of the phosphate in pig manure is undissolved [12], separation of the solids can result in a fraction with a high phosphate content. However, these solids will generally then have to be chemically or biologically digested (possibly after incineration or oxidation) to release the phosphates and make them available for recovery processes (precipitation, absorption...). Table 17 shows the distribution of phosphate over the various (pig manure) fractions.

Table 17: Concentration of phosphate in pig manure

Source: ref.[12]

Phosphate in:	g P/kg
raw pig slurry	1,8
pig slurry centrifugate1)	0,3
pig slurry centrifugate2)	0,16
<hr/>	
pig slurry centrifuge cake1)	10,6

1) using a decanter centrifuge 2) using an ultra centrifuge

The separation of manure for the purpose of improving disposal or further processing (for example, evaporating the liquid fraction and composting the solid fraction) can be carried out in a number of ways. The key aspects are the scale, and the question of whether or not separation occurs in the shed. Table 18 shows a number of separation methods.

Table 18: Separation methods for pig manure

Separation method	Type of manure	Percentage in solid fraction	
		Dry matter	P₂O₅
settling1)	sow manure	68	90
filtration			
#screw press2)	pig manure	35	15
#straw filter	pig manure	79	>90
# sieve-belt press	pig manure	-	-
centrifuging1)	pig manure	71	85
<hr/>			
separation in shed			
# scrapers	pig manure	-	-
# belts	pig manure	83	90

Source [13] 1) with flocculating agent 2) made by Reime

Separation of fatterer manure with a dry matter content of 12.5% (5.1 kg P₂O₅/metric ton) in a screw press results in a solid fraction with 27.5% d.s. and a phosphate content of 8.9 kg P₂O₅/metric ton. Separation efficiency (the percentage in the solid fraction) amounted to only 44% [2] for phosphate. In the study referred to in table 18, the separation efficiency was no more than 15%. The difference in separation efficiency is possibly due to differences in manure quality and machine settings. Here, as for cattle manure, the separation efficiency was low.

It cannot be claimed that manure separation produces a finished end product. This would be the case if the solid fraction were composted. If direct separation under the slatted floor (urine and faeces) is performed with the aid of scrapers or belts, pig manure can be separated into solid (phosphate-containing) manure and urine under the gratings in the shed. This separation could constitute part of a complete farm processing system, including liquid evaporation and composting of the solid fraction of the manure.

Except for the sieve-belt press, the above separation systems are already in practical use on a modest scale.

Manure separation has been the subject of intensive research in the context of centralised manure processing. Various separation systems and types of manure, with and without the use of flocculation agents, have been tested on a (semi-)practical scale. Most experience has been gained in the field of pig manure separation, in particular anaerobically digested manure. A compilation of a large number of results is included in the basic manure separation document published by CIOM [14].

The separation of sow manure by settling has been studied at the experimental pig farm "Zuid- en West-Nederland" [15]. The experiments were carried out both with and without flocculating agents. Table 19 shows some of the results.

Table 19: Solid/liquid distribution of pig manure separated with and without polyelectrolyte (p.e.)

Fraction %	Use of p.e.	Volume	Dry matter	P ₂ O ₅
Solid fraction	no	26	59	57
Liquid fraction	no	74	41	43
Solid fraction	yes	28	68	90
Liquid fraction	yes	72	32	10

This table clearly shows that a cationic flocculating agent must be used to concentrate phosphate in the solid fraction. The dry matter content of the solid fraction is more than 7%.

Similar separation results were also obtained by researchers in Belgium. The separation of fattener manure with 97.3 g/l d.s. (5.65 g/l P₂O₅) using a screw press (mesh width 1/1 mm) results in a distribution of phosphate in the solid and liquid fractions of 16% and 84% - a poor separation result. The use of a decanter centrifuge, both with and without the use of polymers, results in a far better separation of phosphate. The solid pig manure fraction obtained by centrifuging without the addition of polymer has a phosphate content of 21.16 g P₂O₅/kg (d.s. 30.8%). Better phosphate separation is achieved with the use of polymer (less phosphate in the liquid fraction), but in view of the fact that the volume of the solid fraction is greater and the dry matter content is lower (29.2%), the phosphate content of this fraction is lower (15.69 g P₂O₅ /kg) [16]. Other research in Belgium concerns the separation of manure under the slatted floor in a fattener shed (direct separation of urine and faeces), using a filter cloth system. This is a processing system at farm level, involving composting of the solid fraction (filter cake). The solid fraction has a phosphate content of 9.9 g P₂O₅/kg (result in the Netherlands 16.4g P₂O₅/kg). The solid manure is composted on a concrete sheet. Table 20 shows an example of the composition of manure compost [17].

Table 20: Composition of composted manure

Component	Content g/kg
d.s.	481,5
ash	163,0
N-Kj	14,5
N-NH ₄	4,0
P ₂ O ₅	22,8

Composting time 88 days (covered)

Some examples of Italian experience with pig manure separation are reported in [18]. They concern the use of centrifuges and sieves (vibrating sieve, stationary and rotary sieves). One surprising conclusion is that the use of polyelectrolytes does not improve separation to an extent that justifies the additional costs involved. In addition, no significant difference was found between the separation of raw and anaerobically digested manure.

Dephosphorisation

Just as with veal calf manure, work has been carried out on the dephosphorisation of pig manure. Research into the removal of phosphate from aerobically treated filtrate from pig slurry has been carried out by DHV[19]. The cost of removing phosphate has been calculated for three methods: simultaneous precipitation with lime, post precipitation with lime and crystallisation in a CrystalactorTM. Based on processing 1000 m³ pig slurry per day, the costs of this post-treatment step vary between NLG 0.95 and 1.50 per m³.

The environmental technology team of the Agricultural University of Wageningen has carried out research into the biological treatment of pig slurry, including phosphate removal with the aid of milk of lime and CaCl₂[20]. The treatment

system, which has been tested on a laboratory scale, consisted of a SBR (Sequencing Batch Reactor) for nitrification and a USB (Upflow Sludge Blanket) reactor for denitrification. An experiment in which lime was added to the denitrification reactor showed that full dephosphorisation was achieved when the effluent had a pH of 10.9.

In Italy, research has been carried out into biological phosphate removal. The nitrification, denitrification and dephosphorisation of waste water from pig manure (centrifugate from pig manure; $\text{PO}_4\text{-P}$ 19.36 mg/l) were studied in experiments on a laboratory scale, using two SBR reactors. The phosphate removal achieved by means of biological luxury uptake was about 95% [21].

Precipitation

In the context of the Eureka programme EU855 "Euralclar", the removal of phosphate from biologically treated pig manure using a special precipitation agent based on calcium aluminates has been examined. This agent is added after biological treatment, and its purpose is to precipitate not only phosphate but also other anions and heavy metals [22]. In the context of Euralclar, this precipitation agent was also tested for post-treatment of slurry from sheds with a flushing system [23]. The so-called Alclar process is based on bonding negatively charged particles with the aid of calcium aluminates and lime. After a reaction time lasting several hours, the precipitates are separated from the liquid by settling. The process showed a modest reduction in the phosphate and COD content. The prospects for the Alclar process for the purification of slurry from a flushing system were rated as slight [23].

Various publications [24, 25, 26, 27] report on the treatment of liquid fraction from pig manure by precipitating nitrogen and phosphate in the form of struvite (magnesium ammonium phosphate). This so-called MAP process is identical to the KMP process described for veal calf manure. Because manure liquor is rich in N and relatively low in P, phosphoric acid must be added as well as magnesium oxide. This involves high costs. The magnesium ammonium phosphate can be thermally broken down into ammonia and magnesium phosphate, allowing this substance to be reutilised and cutting the cost of buying expensive phosphoric acid. This latter process goes by the name of CAFR (the abbreviation of the German name, which translates as chemical ammonium precipitation and recycling). MAP contains 28% P_2O_5 [24].

This process is known in France as AVDA. There the pig manure is first separated after a flocculation agent has been added. Subsequently phosphoric acid (14.9 kg per m³ of raw manure) and magnesium oxide (about 8 kg per m³ of manure) are added to the liquid fraction, causing the dissolved ammonia to settle out as struvite. Each m³ of manure (4.6% d.s.) generates 95 kg of wet precipitate, containing 28 kg d.s. and 3.9 kg P. This is equivalent to 31.8% P_2O_5 in the dry matter [25]. A mobile plant that operates on the basis of this principle is described in [27]. Treatment costs for pig slurry are 120 FF per m³. Finally, reference [26] reports on Danish experience with the Krüger process. This also involves simultaneous precipitation of N and P.

Incineration

Phosphate can also be concentrated in manure by the thermal removal of water and organic substances. This is done by incineration or wet air oxidation. Both options have been studied with regard to pig manure. The incineration of dewatered pig manure was carried out in a chain grate furnace and a fluidised bed furnace. Both systems yield a different end product, in which the phosphate is contained. Wet oxidation (incineration under water) was investigated for pig slurry with a dry matter content of >8%.

The incineration of pig manure using the Dry Burn Thermal Kinetic system developed by Van den Broek (direct drying followed by incineration) resulted in a slag ash with 380 mg P/kg d.s. and a fly ash with 5,240 mg P/kg d.s. [28]. One of the conclusions drawn in the report was that the quality of the ash residues was disappointing in terms of their phosphorus content.

Incineration of dewatered pig slurry in a fluidised bed furnace was researched by TNO [29, 30; 31]. This research was linked to research into the possibilities of reutilising the ash for its phosphate content as a fertiliser or as feed phosphate. The produced ash is made up of cyclone ash and cloth filter ash. The phosphorus content of these ashes was 124 and 144 g P/kg respectively. The phosphorus inputs and outputs for the incineration process were in balance.

WEET b.v., Eersel, is currently carrying out experiments at an experimental farm in Sterksel on a Russian fluidised bed filled with a catalyst. It has a capacity of 300 l manure per hour.

Research into wet oxidation of pig manure has been carried out by Scarabee [32] at an experimental facility. The plant has an annual processing capacity of 25,000 metric tons, and consists of an oxidation reactor, a drying section and a gas and water treatment section. The forecast production level is approx. 1,900 metric tons per year. The product composition indicates a P₂O₅ content of 7%.

This overview shows that a great deal of research has been carried out into the treatment of pig slurry. Because the techniques are not primarily geared to phosphate, most of the large-scale initiatives have not been included here. Despite all research efforts, in practice very little has been achieved in the field of pig manure treatment. The exception is manure separation, which is used here and there.

Anticipated developments

No major developments are expected in the field of manure processing. After the Promest debacle and the failure of various other large-scale initiatives, the time for the centralised industrial processing of pig manure is over. It is expected that attention will shift to manure processing on the farm. This could involve integrated manure treatment systems, which are optimally geared to environmental and animal welfare aspects. This will also involve a long development path.

In the most far-reaching version, this could lead to the liberation of phosphate-containing manure compost and liquor that is rich in minerals (N and K). A less far-reaching concept involves the separation of manure into a solid and a liquid fraction on the farm.

As long as cheap alternatives are available for manure treatment on the farm, the prospects of such farm developments will remain slight and will certainly be restricted to large-scale establishments.

The distribution of pig manure to crop farmers is expected to continue to be the most significant solution to the problem of pig manure surpluses. The costs are about NLG 15/m³. Processing and treatment are scarcely viable options at this price level.

Two developments are discernable. One is the imposition of a limit on the number of pigs, and therefore on the amount of manure, on the basis of the restructuring law now being drafted. The second is a reduction in the phosphate content of pig manure as a consequence of using low-phosphate feed. It should be possible to stimulate the latter development by reducing the disposal options for manure still further. It is possible that, in the long term, imported concentrates will be (partially) replaced by secondary products from the food industry. The effect of this on the phosphate content of the manure cannot yet be predicted.

If it is accepted that distribution is the most significant option for pig manure, it is reasonable to assume that no large amounts of phosphate will become available from this sector. It is therefore not worthwhile to give an indication of the costs.

4.4 Chicken manure

Definition of the problem

In the poultry sector, changes in the accommodation of the birds has resulted in a shift from thin, liquid manure (slurry) to drier (stackable) manure, above all through aeration of the droppings of laying hens. This trend is the consequence of a desire to reduce ammonium emissions and to produce drier manure (easier to sell, lower transport costs). At several establishments the poultry manure is dried still further - to 85% d.s. - on belts with the aid of ventilation air. This dry chicken manure may be processed into products that can be exported. Most of the surplus chicken manure is disposed of by being distributed, in which case it mainly has to compete with pig slurry.

Sales

The disposal of chicken manure in 1996 is shown below (Table 21).

Table 21: Disposal of chicken manure in 1996, in metric tons of phosphate

Source: Stichting Landelijke Mestbank

Type of manure	Total	User	Treatment	Exported	Stored	Trade	Unknown
Stackable	31.158	13.608	526	7.255	4.611	5.025	133

Slurry	4.541	2.754	510	523	536	214	5
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In the same year, the phosphate excretions of poultry amounted to 29,000 metric tons (source: Dutch Central Bureau of Statistics [CBS]), which does not correspond with the data in Table I. One possibility is that chicken manure from previous years was disposed of. It does indicate that almost all manure from the establishments is disposed of.

The export of stackable poultry manure is decreasing. One reason for this is the import restrictions associated with the required quality guarantees. Other factors that have a negative influence on the export of poultry manure include the disappearance of the generic rebate (see Table 1) on 1 January 1998 and the fact that good quality manure yields a better returns on the domestic market.

Manure treatment

Phosphate can be accumulated by separating liquid manure (laying hens) in the same way as for pigs and cattle. As already mentioned, the production of liquid manure is steadily decreasing. The treatment of chicken manure was (thanks to industrial dryers such as Vefinex and Ferm-O-Feed) and is (at the farm level) mainly oriented towards drying the manure to obtain a marketable manure product. There are no treatment techniques for the selective removal of phosphate from chicken manure. The techniques that are now attracting interest in connection with this type of manure have the effect of concentrating phosphate and other non-volatile minerals as much as possible. These techniques are incineration and gasification, and are used at both the farm and the industrial level. The primary objective is to generate energy, and the liberation of phosphate-containing residual products (ash) is a secondary aspect.

Incineration/gasification

A government-subsidised (SVEN) demonstration project in 1983 concerned the incineration of chicken manure to produce the energy to heat a broiler farm (Peco Mesterijen, in Koningsbosch). The project included drying, compacting and incinerating broiler manure (932 metric tons). The expected savings, expressed in terms of cubic metres of natural gas, were 288,000 m³/year [33]. Work on incinerating chicken manure at the farm level, with the aim of producing energy, was also carried out in Belgium during the 1980s [34, 35]. An incinerator with a capacity of 400 kW has been installed by Mercelis in Turnhout, in which compacted chicken manure from two poultry houses, each of which contains 25,000 birds, is incinerated - not without problems [34].

Another Belgian publication reports on the incineration of floor litter to produce energy to heat broiler sheds [35]. The ash from the litter (table chicken manure) had a phosphorus content of 23.2% P₂O₅. All of the above-mentioned plants were closed down because of the excessive pollution caused by the flue gases. It is known that there is also a plant in Bösel (Germany), where manure is incinerated on a farm. The quality of the flue gases probably does not completely conform to the latest standards for waste incineration.

According to recent information from Kasper [44], the small-scale gasification of chicken manure is technically and economically feasible. The gas is used as a fuel for two electricity generators. An important condition is that the residual heat generated during the production of electricity can be used in horticultural greenhouses or (grass) drying plants. This is the result of a study carried out by poultry slaughterhouse Storteboom and Hanze Milieu, which is a subsidiary of the energy distributor, Edon. Consideration is being given to a gasification plant with a processing capacity of 20,000 metric tons of poultry manure per year. This would remove 440 metric tons of phosphate from the animal manure market. The plans are part of the Schone Kip project [36]. Moreover, Van Aspert (MVH) plans to construct a test factory in Zeeland to gasify 25,000 metric tons of poultry manure per year.

At the moment, considerable interest is being shown in the central incineration of chicken manure. Two power plants fired by chicken manure with 60% d.s. are currently in operation in England, while a third is under construction (see Table 22).

Table 22: Chicken manure incineration in England

Place	Capacity (metric tons/year # MW)	Status
Suffolk (EYE)	125.000#12,71	In operation since July 1992
Lincolnshire2)	140.000#13,5	In operation since November 1993
Norfolk	400.000#38,5	Under construction

- 1) Provides electricity to 12,500 households 2) Glanford power station

According to Fibrowatt, maximum economic efficiency would be achieved with a plant capacity of 400,000 tons of manure per year. The manure can be supplied free of charge within a radius of 60 km. This is made feasible under English circumstances through the high returns on the sale of the electricity produced. Fibrowatt handles the sale of the ash produced by the incineration process.

A brochure from Fibrophos [38] gives the following analysis of the ash (referred to as concentrated slag) of the English power plants [38]. Each ton of incinerated manure yields about 100 kg ash.

Table 23: Composition of the concentrated slag (Fibrophos)

Source: Fibrophos [38]

Component	in the form of	%
Phosphate	P ₂ O ₅	24
Potassium	K ₂ O	12
Magnesium	MgO	4
Sulphur	SO ₃	5
Calcium	CaO	23

It is reported that the phosphate is 60% soluble in 2% citric acid. From this, Rijpma [39] concludes that the very poor solubility of the phosphate prevents it from serving directly as a plant nutrient. This conclusion is shared by Van Dijk of the Nutriënten Management Instituut (NMI, Wageningen).

The incineration of chicken manure is the subject of intensive study in the Netherlands. After earlier initiatives in the field of chicken manure incineration (Cofert Beheer B.V./PNEM fluidised bed incineration and Schelde Engineers & Contractors roasting kiln incineration [44]) came to a standstill, Mestac and Kema picked up the trail again. This institute studied the technical and economic feasibility of the incineration of 175,000 metric tons of stackable poultry manure (a mixture of broiler and laying hen manure) per year [37]. The researchers came to the conclusion that such a plant is feasible, requires an investment of 110 million guilders, and can be implemented within three years. The plant would produce an incineration ash that can be used as a feed material for phosphorus production, as an additive/basic material for fertiliser production, and as a basic road-building material. The predicted ash quality is shown in Table 24.

Table 24: Calculated (macro) composition of the manure incineration ash

Source: Kema [37]

Component	% (w/w)
SO ₃	4,4
Cl	1,6
P ₂ O ₅	20,8
K ₂ O	16,4
CaO	38,2
Fe ₂ O ₃	1
SiO ₂	17,6

In the context of the incineration of chicken manure, it can also be reported that CES Milieutechnologie, of Wageningen, recently carried out research on the so-called Torbed reactor. This (fluidised bed) incinerator was developed by the Torftech, an English company [40]. This company recently carried out a preliminary manure incineration trial commissioned by the manure disposal companies, Mestac and OVEM. This system is designed for small capacities. No results have been published.

In the past, work was carried out without success on manure pyrolysis. One of the reaction products was so-called bio-black, which could be used as a valuable filler in the tire industry. Analysis has shown that the phosphate content of bio-black is 98 g/kg [41].

At this moment, Mestac plans to build a power plant based on the English technology, in which 250,000 metric tons of chicken manure will be incinerated each year.

Two Belgian initiatives in the field of incineration deserve mention. One of them is an existing experimental facility belonging to Danis (capacity 70,000 metric tons/year), in which mixtures of chicken and pig manure are incinerated together with other energy-rich waste. The other is an initiative by Biovert, and concerns the large-scale incineration of solid pig manure fraction with chicken manure for the purpose of power generation. This is in the development phase.

To summarise, incineration and gasification are two techniques that are not yet used in everyday practice in the Netherlands, but which could come to be used in the longer term. Both of these techniques are certainly promising in the context of processing chicken manure.

Drying/Composting

One development that is gaining in popularity on farms is composting (also referred to as biological drying) of poultry manure. Poultry farm Te Wierik in Raalte composts 8,000 metric tons of laying hen manure in closed tunnels. The end product is composted manure (about 3,000 metric tons per year) with a dry matter content of 90% (probably post-dried) and a P_2O_5 content of 3.4%. This results in the disposal of 100 metric tons of P_2O_5 per year. It is anticipated that composting of poultry manure on the farm will increase in the long term.

Prognosis

Developments with regard to the production, treatment and processing of chicken manure are largely determined by the following factors:

- * the decrease in the export of stackable poultry manure;
- * the threat of restrictions on production rights (as anticipated shortly in the pig sector);
- * the obligation, under the Dutch "Integral Policy Document" of the Ministry of Agriculture, Nature Management and Fisheries and the Ministry of Housing, Spatial Planning and the Environment, to remove 20,000 metric tons of manure-derived phosphate from the market each year, with effect from the year 2002.

In connection with the first two of the above-mentioned factors, farms are increasingly switching to the production of dried or composted manure, which can be exported under quality guarantees, in exchange for opportunities of expansion. An example of this is the initiative of Zuivere Ei. The last of the above-mentioned factors could provide an additional stimulus for the large-scale incineration or gasification of chicken manure.

To obtain an indication of the amount of available phosphate from the poultry sector, it is assumed that a central incineration facility for 350,000 metric tons (Fibrowatt plan, investment 215 million guilders [42]) and a gasification facility for 20,000 metric tons will be built. If the average phosphate content is 22 kg per metric ton of manure, this will make available more than 8,100 metric tons of P_2O_5 per year. At a processing price (without subsidies, etc.) of NLG 60 per metric ton, these costs amount to NLG 2.73 per kg P_2O_5 . The supply price can be cut back to an acceptable level (no more than NLG 25 per metric ton) by implementing a number of measures, such as increasing capacity, providing subsidies, and raising the feedback price for electricity (for example, from NLG 0.11 to NLG 0.15 per kWh). Only time will show whether this is feasible.

Note

For the sake of completeness, it should be noted that part of the poultry manure is used to prepare mushroom compost (so-called champost). CNC alone disposes of about 1500 metric tons of P_2O_5 per year in this compost (on the basis of a production capacity of 500,000 metric tons). Horse manure and wet poultry manure (and, currently, pig slurry) are used as

the animal manure raw material. With regard to the use of poultry slurry, a rough calculation indicates that 2/3 of the phosphate is derived from this type of manure. CNC plans to increase its production capacity to 750,000 metric tons per year.

4.5 Overview

On the basis of the information provided in this chapter, a global estimate was made of the amount of phosphate (P_2O_5) available from various “manure products” (Table 25). The figures in the table are rounded, and are mainly intended to give an indication of the extent of the possible phosphate streams from animal manure.

Table 25: Available phosphate (P_2O_5) from various “manure products” (in the Netherlands)

Technique	Product	% d.s.	% P_2O_5	P_2O_5 /d.s. NLG/kg P_2O_5	Fictive Costs ²⁾ no	Amount (tons of P_2O_5 /?) ^b	forecast
Cattle manure							
Drying	Granulate	90	1,5	0,016	100	240	0
Veal calf manure							
Biol. treatment	kgbi sludge	10	1,3	0,121	10	940	0/- 1)
Precipitation	Struvite	20(15-30)	3,2	0,160	24	0	+ (400)
Evaporation ⁶⁾	Concentrate	20	1,5	0,075	13	80	+/- (500)
+ drying ⁷⁾	Granulate	90	6,8	0,075	n.k.	0	+? (400)
Pig manure							
Separation	Solid fraction	25 (20-30)	1,5	0,06	2	0	+
Composting	Compost	50 (25-80)	2,3	0,047	5	0	+
Evaporation ⁶⁾	Concentrate	20	0,6	0,03	57	0	+/- (30)
+ drying ⁷⁾	Granulate	90	2,7	0,03	n.k.	0	+? (20)
Chicken manure							
Shed ventilation	Stackable	60 (45-65)	2,2	0,037	0	29.000	+/- 2)
Drying	Granulate	90	3,4	0,037	4	2.2005)	+ 3)
Composting	Compost	80	4,3	0,053	2	100	+? (1000)4)
Gasification	Ash	95	13,7	0,145	n.k.	0	+/ (400)
Incineration	Ash	95	13,7	0,145	3	0	+? (7700)

Explanation:

0 = Little or no change; - = decrease; + = increase; (0/- or +/-) indicates a decrease in the one due to an increase in the other; n.k. = not known; ? = uncertain

a) Fictive; processing costs or cost price completely attributed to P_2O_5 !

b) rounded numbers

c) calculated

1) Including simultaneous precipitation with lime (dephosphorisation)

2) Drying in the shed with the help of ventilation air (adapted “housing”)

3) Further drying on the farm or industrially (e.g. Ferm-O-Feed)

4) 30 farms with 75,000 laying hens; amount of phosphate = $30 \times 75,000 \times 0.023 \times 18.8 \times 10^{-3} = 973$ metric tons of P_2O_5 (rounded to 1,000).

5) Drying: various primary farms 20,000 metric tons of granulate; industrial (Ferm-O-Feed) 40,000 metric tons of granulate; amount of phosphate = $65,000 \times 0.034 = 2210$ metric tons of P_2O_5

6) Van Aspert evaporation:

Veal calf slurry: 5 (plants) \times $67,500$ (capacity) \times $1.5 \times 10^{-3} = 506$ metric tons of P_2O_5

Settled sow manure: $5 \times 67,500 \times 0.1 \times 10^{-3} = 34$ metric tons of P_2O_5

7) Van Aspert drying:

Granulate from veal calf slurry: $244,000 \times 1.5 \times 10^{-3} = 366$ metric tons of P_2O_5 (rounded to 400)

Granulate from settled sow manure: $244,000 \times 0.1 \times 10^{-3} = 24.4$ metric tons of P_2O_5 (rounded to 20)

5. DEVELOPMENTS

This chapter gives a brief overview of the **technical, economic, organisational and social developments that can influence, for better or for worse, the recovery of phosphorus for the benefit of the phosphate industry**. Finally the developments are summarised and an indication is given of the effect of the various developments on the possible future availability of P_2O_5 for the phosphate industry.

Technical developments

- Research is being carried out into the **struvite process, especially with regard to the relatively phosphate-rich veal calf manure**. Substances are added to the effluent to cause the phosphate to precipitate out as struvite (magnesium- or potassium ammonium phosphate).. The effluent from pig manure is, in principle, also suitable for the struvite process, but the costs are very high: because most of the phosphorus is in the solid fraction of pig manure, biological or chemical digestion would be necessary before P-recovery, and this is not economically feasible.
- Especially for veal calf manure and the liquid fraction of sow manure, the technology of **evaporation and drying** is at a more advanced stage of development. At present a plant with a capacity of 25,000 metric tons per year is operational and a 135,000 metric ton plant is in the start-up phase.
- In other countries, experience has been gained in the **incineration of chicken manure**, to which pig manure is sometimes added. In the Netherlands, consideration is being given to the incineration and gasification of chicken manure. This development in particular could have a **favourable effect on the possible future availability phosphate-rich ash**. It is uncertain whether the ash can be used directly as fertilizer or whether its solubility and composition first need to be improved.
- Improvements in animal accommodation in the poultry sector are resulting in drier manure being obtained. This has a positive effect on incineration, because it increases the net heating value of the manure.
- Attempts are being made to improve the quality of chicken manure in particular. Producing drier and certified manure increases export opportunities, and this introduces an element of uncertainty about whether manure will be available for incineration/gasification.
- **The continued reduction in the amount of P in feedstuffs** has a negative effect on the processing of all types of manure, because less P_2O_5 can be made available to the P industry.

Economic developments

- **The standards for spreading manure on the land are being tightened up**. This makes it even more necessary to find other applications/solutions. Trade in P production rights also has a positive effect on making chicken manure available for gasification or incineration.
- The various types of manure are in competition with each other. Because farms are limited in the extent to which they can expand, there is now greater willingness to pay more for manure disposal. Farms are prepared to increase the disposal prices of NLG 15 per metric ton of manure to between NLG 20 and a maximum of NLG 30 per metric ton.
- In the case of pig manure processing in particular, due to the **failure of a number of large-scale manure processing initiatives**, financiers are unwilling to participate in the projects. Pig farmers themselves were not prepared to pay large amounts of money over a long period of time for manure processing.
- All kinds of difficulties, including outbreaks of swine fever and other diseases, have made the export of manure very uncertain.
- The **energy price** is a key factor that influences the economic feasibility of the incineration of chicken manure. The energy market is difficult to predict; deregulation can cause prices to fall in the short term.

Organisational developments

- There has been an **increase in scale in the intensive stock farming sector**. Large establishments are prepared to look for and invest in new processing methods - for example, incineration and gasification.
- Willingness to cooperate and conclude long-term contracts differs from type to type of manure. At the present time, poultry farmers would be prepared to enter into a long-term agreement (for example, 5 years) to supply 260,000 metric tons of chicken manure to an incineration plant. Poultry farmers would be prepared to pay an appreciable price for the manure incineration.

Social developments

- In the Netherlands, it is very **difficult to obtain a licence for a manure processing plant**. The local community can obstruct or considerably slow down the decision-making process. The question of whether or not manure is a waste substance may become the subject of debate in the Netherlands. This can be to the detriment of export opportunities, and can make it more difficult to obtain a licence.
- Specifications for atmospheric emissions are stricter in the Netherlands than in England. The cost of adapting the (English) incineration technology to comply with the Dutch regulations is unknown.
- The Dutch government requires the intensive stock farming sector to remove 20,000 metric tons of P_2O_5 , derived from animal manure, from the market. For chicken manure in particular, this is a stimulus to turn to incineration.
- The Dutch economy is seeking long-term solutions, and sectors of the economy are prepared to cooperate in setting up circuits.
- In the Netherlands, there is considerable interest in sustainable sources of energy. The use of biomass to achieve reductions in CO_2 emissions is being encouraged. Almost all Dutch electricity distribution companies support “eco” electricity and “green” electricity. A proportion of the population is prepared to pay 4 to 7 cents per KWh more for energy generated from wind, the sun or biomass. The levy on energy produced from non-sustainable sources is a stimulus to the use of incineration. The table on the following page summarises the consequences of the identified opportunities and threats.

Table 26: Summary of opportunities and threats with regard to P recovery for the P industry.

Developments	Consequences for:			
	Cattle manure	Veal calf manure	Pig manure	Chicken manure
Technical developments				
• Struvite process		++	+	
• Evaporation and drying		++	+	
• Incineration/gasification			+	+++?
• Drier manure (accommodation and composting) (accommodation/compost)			+	++?
• Quality improvement (export)	-	-	-	-
• Less P in feedstuffs				
Economic developments				
• Tighter standards for spreading manure on the land	+	+	++	++
• Competition between different types of manure	+	+	+	+
• Willingness to pay more (disposal costs NLG 15 to between NLG 20 and maximum of NLG 30)	+	++	++	+++
• Failure of Promest and other test facilities		-	---	-
• Export uncertain				++
• Direct application				--?
• Energy price				+?
Organisational developments				
• Large-scale establishments			+	++
• Willingness to work together and conclude long-term contracts			--	++
Social developments				
• Licensing (NIMBY)		-	--	---
• Strict regulations on atmospheric emissions				?
• 20,000 metric tons P ₂ O ₅ out of the chain		+	+	++
• Chain management/closing the circuit			+	+
• Encouragement of sustainable sources of energy (CO ₂ /biomass environmental levy)			+	+++

++ indicates positive effect on future availability of P₂O₅ to P industry. -- indicates negative effect on future availability of P₂O₅ to P industry. ? indicates uncertainty

6. CONCLUSIONS AND RECOMMENDATIONS

1. In 1995, the total consumption of phosphorus in the Netherlands was 269,000 metric tons. Animal manure was the major waste flow, at 86,000 metric tons of P (about 200,000 metric tons of P₂O₅) and is the waste flow with the greatest potential for closing the phosphorus cycle and reducing accumulation in the environment.
2. Manure is only of interest if there is no way of using it on the farm where it is produced or of distributing it. Of the approximately 200,000 metric tons of P₂O₅ in animal manure in 1998, 15,000 metric tons could be exported or processed. This amount will increase to 20,000 metric tons of P₂O₅ in 2002.
3. The scale of the manure problem is greater in the Netherlands than in any other country. The Netherlands also has the highest livestock density of any European country. Other countries have a manure problem in certain regions - for example, Flanders, northern Germany, the Po delta and Brittany.

4. **Manure from cattle is not a potential source of P for the phosphate industry.** The main reasons are that cattle farms are usually non-intensive, with large areas of land, and cattle manure contains only a small percentage of phosphate. Dried cow manure is exclusively a product for the hobby market, which is of only limited scope.
5. **Half of the veal calf manure could be used for industrial extraction of P.** The following technologies can be used:
 - evaporation and drying to form a concentrate which can be used by the fertiliser industry (Van Aspert)
 - struvite precipitation processes

A maximum of about 400 metric tons of P_2O_5 could be recovered as struvite. In addition to this, evaporation and drying could be used to recover, at most, an additional 400 metric tons.
6. Due to the failure of a number of large test facilities, **centralised processing of pig manure is not anticipated in the Netherlands in the short and medium term.** Manure processing is too expensive for pig farmers. It is expected that the solution for the manure problem will be found in reducing the amount of P in feedstuffs; the distribution of manure; and obligatory reductions in the number of pigs. Conclusion: no or scarcely any P_2O_5 for the P industry from pig manure processing.
7. **Chicken manure is the biggest potential source of P for the phosphate industry.** The high P_2O_5 and energy content and the economic necessity of finding a use for the surplus are a stimulus to incineration or gasification of chicken manure. If 20,000 metric tons were gasified and 350,000 metric tons were incinerated, about 8,000 metric tons of P_2O_5 would become available, which could possibly be processed by the P industry. There are currently 3 or 4 projects in progress in the Netherlands for gasifying or incinerating chicken manure. Partly as a result of experience in England, there is considerable interest in incinerating chicken manure.
8. Fibrowatt has been successful in England, but there would be obstacles to reproducing this success in the Netherlands:
 - the generated energy would fetch a lower price in the Netherlands
 - the regulations governing flue gas are stricter in the Netherlands
 - it is very difficult to obtain a licence for manure processing plants in the Netherlands.
9. There are positive developments that could stimulate the incineration of chicken manure:
 - + there is considerable interest in energy from sustainable sources (reduction of CO₂ emissions, additional payment for biomass)
 - + expansion is possible without buying P production rights NLG 60 to NLG 100 per kg P_2O_5
 - + export of chicken manure is uncertain
 - + government policy is focused on removing 20,000 ton P_2O_5
 - + poultry farm management methods have changed (drier manure)
 - + poultry farmers intend to work together and enter into long-term contracts
10. There are negative developments/obstacles that make chicken manure incineration less attractive.
 - obtaining a licence for manure processing is very difficult
 - due to the failure of many big manure processing projects, financiers are not very interested in large-scale manure processing
 - emission regulations in the Netherlands are very strict
 - drier, certified manure can be more profitably exported.
11. **The maximum potential in Holland, which, however, is absolutely unachievable, is about 29,000 metric tons of P_2O_5 from chicken manure, about 1,000 metric tons of P_2O_5 from veal calf manure and 2,000 metric tons of P_2O_5 from other manure sources. These 32,000 metric tons represent about 15% of the total amount of P_2O_5 in animal manure.** The P_2O_5 can, however, only be made available in very low concentrations and in very widely varied forms (ash, pellets, sludge).

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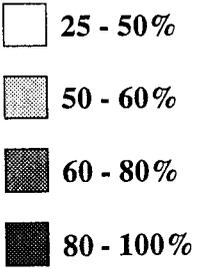
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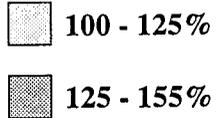
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