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Environmental impact and removal of phosphates in swine farm effluent

(Impak alam sekitar dan pembuangan fosfat dari najis ternakan khinzir)

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Key words: phosphorus removal, quantification of phosphates, turbidity, pig slurry

Abstract

This article describes the results of: a) a case study to determine the loading of excess phosphates to the environment from pig industry in Malaysia; b) an experiment on the effect of phosphorus (P) concentration on turbidity of wastewater; c) field study on effect of waste stabilization ponds on P retention; d) laboratory study on efficacy of biological P removal. Total consumption of P was about 6,145 t of which about 1,255 t originated from inorganic supplements. This amount was about 1.1% of the total amount of phosphatic fertilizers of about 550,000 t used annually in Peninsular Malaysia. Apparent excretion of P was found to be 4,618 t/year or equivalent to approximately 10,566 t of P_2O_5 per year.

The feed supplements used were tricalcium phosphate (TCP), dicalcium phosphate (DCP), monocalcium phosphate (MCP) and MDCP (a mixture of DCP and MCP). The proportions of farmers using TCP, DCP, MCP and MDCP were 25, 33, 9 and 33%, respectively. The apparent digestibilities of TCP, DCP, MCP and MDCP were 48, 66, 81 and 73%, respectively. The P source with the highest digestibility, i.e. MCP was least used by farmers. Turbidity of wastewater was found to increase with increasing total P (TP) concentration. Only 16.5% of TP in raw slurry was in dissolved form. Approximately 90% of TP were retained in the series of anaerobic, facultative and aerobic ponds. The efficacy of TP removal via sequential anaerobic and aerobic digestion under laboratory conditions was found to be 66.4%, while soluble P was almost completely removed.

Introduction

Malaysian pig farmers typically wash down faeces excreted with plenty of water, often twice a day to clean the pig pens as well as to cool the pigs. In this farming practice, about 30 litres of wastewater is generated per pig per day (Teoh et al 1988). Treated or otherwise, these wastewaters, which contain nutrients like nitrogen and phosphorus, eventually enter the river systems. Together with nitrogen, phosphorus in water bodies cause eutrophication, a phenomenon where excessive algal growth is observed. Hypereutrophic water can support the growth of cynobacteria that can produce toxins that are lethal to livestock and humans. Several types of algae are able to fix nitrogen directly from the air. Thus a

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more effective way of controlling eutrophication would be to make phosphorus the limiting factor for algal growth in water bodies.

In the past, monitoring of effluent quality has been the quantification of total solids (TS), total suspended solids (TSS), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The Environmental Quality Act (Sewage and Industrial Effluent, 1979) does not contain parameters on nutrients such as phosphorus (P) and nitrogen (N). In Malaysia, the pig industry has always been regarded as a source of P pollution, due to the fact that P is supplemented in diets of animals to ensure adequate supply for bone development and other metabolism.

The phosphorus sources are commercially available but all of these originate from non-renewable source, being extracted from phosphate-rich rocks around the world. Worldwide, about 140 million tonnes of phosphate rocks are extracted annually. Worldwide, about 80% of phosphates produced are used in fertilizers, a further 5% being used in animal feed supplements (all species) and the rest going into detergent and other industrial purposes. The objectives of this work were: a) to quantify the amount of phosphorus released to the environment by the pig industry; b) to study the effect of phosphates on the turbidity of discharged effluent; c) to study the effect of waste stabilization ponds on phosphorus retention; d) to determine the efficacy of biological removal of phosphate.

Materials and methods

Case study

In order to estimate the environmental fate of phosphorus, the first step was to quantify the input of phosphorus. Since the pig industry has been identified as a sector of concern in Malaysia in terms of pollution potential as well as communal sensitivity, a case study was conducted for the pig sector. This was carried out by way of a farm survey covering 12 farms. During the survey, questions were directed to the selected farmers or their farm supervisors on sources of dietary P used, feed type and feed amount. Feed samples were collected from the farms for P analyses. Annual feed consumption was calculated in the manner shown in *Table 1*. The numbers used for each parameter of *Table 1* are shown in *Table 2*. Farrowing index (2.06) and pig weaned/sow.year (16.6) were abstracted from PigChamp Review (DVS 1998), while sow number was taken as standing pig population of 1,438,580 (DVS 2005) divided by litter size. The other numbers were the results of a survey of 12 farms conducted in this case study.

Apparent digestibilities of the various sources of P were estimated by taking the difference between total P in feed and that in faeces in growing pigs fed the various P supplements, in on-farm situations, where the pigs were kept in colony pens in groups of 10–20 pigs per pen. Random grab samples of faeces were collected from five pens and these were then composited. No statistical analysis was attempted, since the samples came from four different farms feeding a known source of P supplement.

Table 1. Calculation methods for annual feed consumption of various categories of pigs

Animal category	Calculation method
Pre-starters	Litter size x Kg feed/head.day x Days fed x Farrowing index x Sow number
Starters/growers/finishers	Kg feed/head.day x Days fed x Pigs reared/sow.year x Sow number
Gestating sows	Kg feed/head.day x 114 days x Farrowing index x Sow number
Lactating sows	Kg feed/head.day x Weaning age x Farrowing index x Sow number
Boars	Kg feed/head.day x 365 days x Boar number

Table 2. Numbers used for calculating annual feed consumption

	Number
Litter size	10
Farrowing index	2.06
Pigs weaned/sow.year	16.6
Sow number	143,858
Boar number (boar to sow ratio of 1:25)	5754
Kg feed/head.day for pre-starters	0.36
Kg feed/head.day for starters	0.88
Kg feed/head.day for growers	2.03
Kg feed/head.day for finishers	2.17
Kg feed/head.day for gestating sows	2.10
Kg feed/head.day for lactating sows	4.02
Kg feed/head.day for boars	2.64
No. of days fed to pre-starters	40
No. of days fed to starters	38
No. of days fed to growers	55
No. of days fed to finishers	47
No. of days fed to gestating sows	114
No. of days fed to lactating sows	28

The feeds were formulated as if the supplements were the sole source of dietary P. It was an attempt to obtain an estimate of total P excretion assuming that the biological availabilities of all feed ingredients used were equal. Yi and Kornegay (1996) in evaluating response criteria for assessing availability of P supplements in swine, stated that P excretion was a sensitive indicator of apparent digestibilities. Due to the inadequate facilities in the farms, urinary output was not considered. Feed intake was taken from surveyed data shown in *Table 2*. For TP analysis, dried samples were subjected to acid digestion followed by determination using atomic absorption spectrophotometer (graphite furnace).

Effect of phosphorus concentration on turbidity

Seven beakers were filled with 500 ml of water taken from a facultative lagoon. Each water sample was spiked with 0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0% of dicalcium phosphate (w/w), approximately equivalent to 0, 925, 1,850, 2,775, 3,770, 4,625, and 5,550 mg/litre of TP, respectively. All samples were exposed to sunlight and turbidity in each sample was measured daily for a period of 10 days with an infrared turbidity meter (Cyberscan TB 1000), expressed in Nephelometric Turbidity Units (NTU).

Effect of waste stabilization ponds on phosphorus removal

This study was carried out by sampling and analysing influent and effluent wastewater in a series of waste stabilization ponds, which were by far the most common method of waste treatment in pig farms. The first pond was anaerobic, while the second was facultative, where an anaerobic zone existed at the bottom, with a shallower aerobic layer at the top. The third pond was also facultative. Influent and effluent flowed in series from the first pond to the third pond.

Raw slurry as well as effluent from each pond were sampled and analysed for total P to study the effect of these ponds on phosphorus removal. Random grab samples were taken once every 30 min for 3 h, which was the approximate period of time taken to wash down all the waste in the pig barns. The grab samples were then composited and analysed for TP. Soluble phosphorus (SP) was determined by analysing the filtrate of wastewater samples after filtering through glass microfibre filter under suction.

Efficacy of biological phosphorus removal

Two continuously stirred tank reactors (CSTR) of 10-litre active volume were used. The first one was used as an anaerobic reactor, while the second one was kept aerobic by pumping air for aeration. The feedstock was digested anaerobically and then, aerobically, followed by settling in a settler before being recycled into the anaerobic digester. Samples of influent and effluent were taken on alternate days for three days, after operating the digesters for 20 days. The samples were subjected to acid digestion followed by determination of P concentration using atomic absorption spectrophotometer (graphite furnace).

Soluble P was determined by analysing the filtrate of samples after filtering through glass microfibre filter under suction. Temperature for both reactors was kept at approximately 35 °C throughout the experiment. The aerobic reactor was initially seeded with 10% by volume of sewage sludge. The feedstocks in both reactors were mixed mechanically with six-bladed axial impellers. The feedstock consisted of artificially prepared cattle slurry obtained by blending ground dried cattle faeces with water at 8% total solids, spiked with 10 g/litre of DCP, equivalent to 1,850 mg/litre of TP.

Results and discussion

Case study

Table 3 shows the surveyed estimate for TP consumption derived from estimation of total feed consumption per year as well as concentration of P in the diets. *Table 4* shows some data on the amount of P consumed that originated from supplemented P sources, as well as the quantity of excreted P. Total consumption of P was about 6,145 t of which about 1,255 t originated from inorganic supplements. This amount is only about 1.1% of the total amount of phosphatic fertilizers of 549,529 t used annually (Anon. 1998). The TP originating from feed ingredients was about 4,890 t, being obtained by subtracting TP of supplemented sources from TP consumption.

Based on P digestibility of 15% in a typical corn-soybean diet (Cromwell 1996), the P excretion from feed ingredients would be 4,157 t. Based on the proportions of apparent digestibilities, the apparent excretion of P from supplemented sources was 461 t/year, giving the total P excretion to be 4,618 t/year. This was equivalent to approximately 10,566 t of P_2O_5 per year.

Table 3. Total phosphorus consumption in relation to feed consumption in pig feeding

Feed type	Annual feed consumption (t)	TP content in feed (%)	Annual TP consumed (t)
Pre-starter	42,674	0.66	281.6
Starter	79,856	0.83	662.8
Grower	266,625	0.81	2,159.7
Finisher	243,557	0.85	2,070.2
Gestation	70,946	0.89	631.4
Lactation	33,357	0.87	290.2
Boar	5,545	0.89	49.4
Total	742,560		6,145.3

Table 4. Apparent porcine phosphorus excretion of supplemented phosphorus per annum

Source of P	Usage by farmers (%)	Proportion used in diet (%)	Conc. of P source (%)	Consumption of supplemented P per year (t)	Digestibility of P (%)	Apparent P excretion (t)
TCP	25	1.35	16	401	48	209
DCP	33	0.90	18	397	66	135
MCP	9	0.60	21	84	81	16
MDCP	33	0.8	19	373	73	101
Total from supplemented source				1,255		461
Total from feed ingredients				4,890	15[a]	4,157
Total excretion of TP						4,618

[a]Digestibility of a typical corn-soy diet in pigs (Cromwell 1996)

The amount is proportionately small compared with 58,000 t of P_2O_5 reported for the Netherlands where pig population was about 15 million (CEEP 1998).

If poultry and all other classes of livestock in Malaysia are considered, the proportion might approach 5% of total phosphates used in the country, similar to worldwide trend. However, this needs to be confirmed with quantification studies for other species in Malaysia. The raw material used in phosphate production is non-renewable, being mined from phosphorus deposits in several countries.

Phosphorus is the 11th most common element of this earth and is essential to all living things. Very little of the phosphate in wastewater is recycled for agriculture. Some good examples are seen in a few oil palm estates where palm oil mill effluent (POME) are recycled for fertigation or used for composting in combination with empty fruit bunches (EFB). Most of the other phosphate-containing wastewaters end up in soils (in forms unavailable to plants), landfills, surface run-off and finally in rivers and seas. For this reason, governments around the world need to look into the drawing up of regulations to try and reduce the release of excess phosphates into the environment.

The feed supplements used were TCP, DCP, MCP and MDCP, which was a mixture of DCP and MCP. The need to supplement P arises due to the fact that most of the P in feed ingredients is in the form of phytate, which is poorly utilized by non-ruminant animals. Bioavailability of P in corn and soybean for pigs ranges from 10–30% only (Kornegay 1996). The proportions of farmers using TCP, DCP, MCP and MDCP were 25, 33, 9 and 33%, respectively. The apparent digestibilities of TCP, DCP, MCP and MDCP were 48, 66, 81 and 73%, respectively. The P source with the highest digestibility was MCP. However, this source was the least used by farmers, probably due to its higher price. The consequence of this is that the lesser the digestibility of a P source, the more will be the excretion of P in the manure.

Effect of phosphorus concentration on turbidity

The plot of turbidity versus time is shown in *Figure 1*. There was a general trend of declining turbidity with time, due to progressive settling of insoluble P as well as

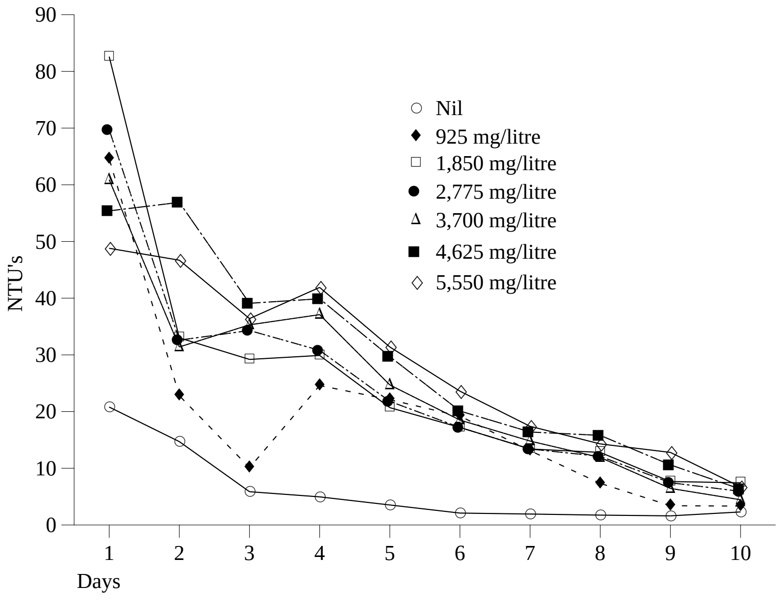

Figure 1. Turbidity versus time

utilization of soluble P by microorganisms and algae present. When the means of NTU's were taken and plotted against TP concentration *(Figure 2)*, it was observed that turbidity tended to increase with increasing TP concentration. This could be caused by increased algal growth with increased TP content, giving rise to increased chlorophyll content, resulting in increased turbidity. Another explanation would be the increased of insoluble P that precipitated out and appeared as suspended particles resulting in increased turbidity.

In general, TP concentration of 25 to 100 mg/litre is already classed as eutrophic (with high nutrient status), while concentrations above 100 mg/litre is classed as hypereutrophic (highly productive and murky). Hypereutrophic water bodies can support growth of cynobacteria that can produce toxins. The other description for trophic status of water is oligotrophic (poorly nourished and clear) with <10 mg/litre of TP, and mesotrophic (intermediate nourishment and clarity) with

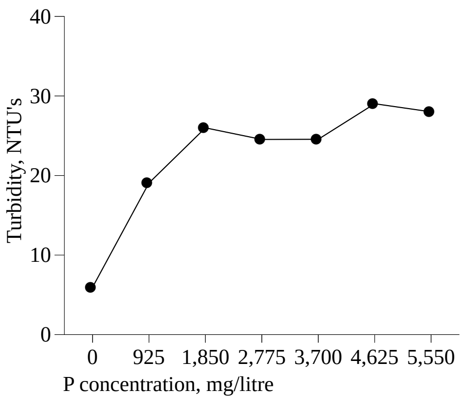

Figure 2. Turbidity vs P concentration

10–25 mg/litre of TP. These descriptions and concentrations are used for classifying the nutrient status of lakes. Since turbidity increases with P concentration, turbidity measurement could be the initial indicator of excessive P loading. Presently the Environmental Quality Acts of Malaysia (1974) covering Sewage and Industrial Effluents (1979) do not include a parameter on P concentration.

Effect of waste stabilization ponds on phosphorus removal

By monitoring the TP of raw slurry and effluents from two of the ponding systems, retention of TP was determined. The ponds were very effective in retaining phosphorus. Almost 80% of TP were retained in the first pond, which was anaerobic. Nearly 90% of TP were retained in the series of ponds *(Table 5)*. Most of it could be retained in the sludge that settled at the bottom of the ponds, particularly the first pond, which represents the primary biological treatment system. This was confirmed when the raw slurry and effluent were checked for soluble P. Only 16.5% of TP in raw slurry was in dissolved form.

Some reports recorded about 90% of pig manure being in undissolved form (CEEP 1998). The observation is similar to that of aquaculture waste, where 77% of the discharged P is in particulate form (Enell 1995). Thus, little phosphorus was being removed; rather, they were retained in the ponds due to settling of particulate matter, so much so the effluents after the second pond consisted mostly of soluble phosphorus. A sizable proportion of TP would be removed if the solids are separated

Table 5. Phosphorus retention in waste ponds (clay soil)

	Raw slurry	Effluent after pond 1	Effluent after pond 2	Effluent after pond 3
TP conc. (mg/litre)	468	95	60	48
TP retention (%)	–	79.7	87.2	89.7
SP conc. (mg/litre)	77	62	47	40
SP retention (%)	–	19.5	39.0	48.1
% SP over TP	16.5	65.3	78.3	83.3

and removed. The efficiency as well as the advantages and disadvantages of solid separation by mechanical means are discussed by Ong et al. (2004).

Since all the ponds were earthen ponds, the environmental fate of P could not be further traced objectively. Different forms of P as well as factors such as soil texture, clay mineralogy, pH and uptake rate of surrounding vegetation affect the final fate of P. Calcium phosphates or apatite phosphates are only sparingly soluble and therefore are unlikely to form complexes with iron or aluminium. Any remaining soluble P would be readily fixed by Fe or Al species in the soil, making it immobile.

So far, very few farmers in Malaysia are known to have lined their waste stabilization ponds. Phosphorus in the soil exists in organic, soluble or attached forms. Retention of TP is higher in clayey than sandy soil, since clayey soils have a higher adsorption potential than sandy soils. P-accumulation is dependent on relative concentration and forms of aluminium (Al), iron (Fe) and calcium (Ca) in the soils, since they are reactive with soluble P. Based on the results obtained, it could be said that if a farmer possesses a series of ponds, only about 10% of TP are discharged into receiving water. Lakes and other bodies of water collect P from influent streams and store them in the sediment, thus serving as phosphate sink. In the case of phosphorus, direct toxicity to fish and other aquatic organisms is not a major concern. On the other hand, when P enters the freshwater environment, it can produce nuisance growth of algae and other aquatic weeds, when other nutrients are also present.

The EPA of USA recommends that TP concentrations in any stream entering a lake or reservoir should not exceed 50 mg/litre (USEPA 1986). The mean TP concentration of effluent after the third pond was about 50 mg/litre, which was a thousand times the USEPA recommendation for lake or reservoir. In the case of Malaysia, discharge of pig farm effluent into water catchments is not permitted. It must be said that the risk of P as a pollutant in water bodies lies not in insoluble P but in soluble P, of which only 16.5% was found in raw slurry. The majority of P is the insoluble part that accumulates at the bottom of the ponds. From the environmental point of view, it is not illogical to suggest that these should be recovered for recycling as fertilizers of appropriate crops, if the economics justify it.

Efficacy of biological phosphorus removal

The rationale behind this work is that biological waste treatment methods are being promulgated among farming communities. Anaerobic digestion may be used as a form of primary treatment. To improve the water quality further, aeration is often employed at the end stage of wastewater treatment. Thus, in the event that the treatment system is to be up-graded to incorporate P removal, additional basins for the sequential digestion of the waste stream under anaerobic and aerobic conditions could be provided to achieve P removal. This is based on the fact that under anaerobic conditions, the aerobic bacteria were under stress and P is released from the cells, making energy available to absorb low-molecular weight organic substances like fatty acids. Upon subsequent exposure to aerobic conditions, the organic matter is oxidised, and energy is made available for growth and re-accumulation of phosphates into the bacterial cells. The net effect is an excess content of P in the sludge, which is withdrawn from the system.

The removal characteristics of this laboratory work are shown in *Table 6*. The efficacy or TP removal was found to be 66.4%, while the removal of SP was almost complete. This indicates that prior settlement of insoluble P followed by sequential removal of SP would almost remove TP completely. However, these were the results of laboratory-scale work, using an artificial feedstock, and some up-scaling work is required to gauge on-farm efficacy using actual effluent. The aim of conducting this

Table 6. Phosphorus removal characteristics

	Value
Volume of anaerobic reactor (litre)	10
Volume of aerobic reactor (litre)	10
Volume of settler (litre)	5
Influent flow rate (ml/h)	400
Return sludge flow rate (ml/h)	800
HRT in anaerobic reactor (h)	2.5
HRT in aerobic reactor (h)	2.5
Mean TP conc. of influent (mg/litre)	1,683 ± 86
Mean SP conc. of influent (mg/litre)	40 ± 14
Mean TP conc. of effluent (mg/litre)	566 ± 18
Mean SP of effluent (mg/litre)	trace
Efficacy of TP removal (%)	66.4
Efficacy of SP removal (%)	~100

experiment was to determine the degree of P recovery that could be achieved, rather than to compare the results of P removal achievable in the ponding system previously described. In the ponding system, there was interaction with the soil eco-system, while in the laboratory such an interaction did not exist.

Additionally, a separate economic-feasibility study is needed to determine viability P recovery. Another negative point of P recovery is that the excreted P of about 4,600 t annually is scattered all over Peninsular Malaysia. If one assumes that future pig production will be sited in only five pig farming areas (PFA), then each site is estimated to produce about only 900 t of excreted P annually. However, the Nipah-virus experience of 1998 has resulted in a re-think on the implementation of PFA. If the option of in situ waste treatment for individual farms is taken, recovery of P would not be viable.

In the ultimate analysis, it is a better option for producers to practise pollution reduction at source, i.e. at feeding stage. Reduction of pollution by phosphorus can be carried out by: a) Avoiding over-specification in feed formulations; b) Using phosphorus sources of high availability: As can be seen from *Table 4*, MCP has the highest digestibility. The work of Cromwell et al. (1996) showed that excretion of P could be reduced by 50–60% by diet manipulation; c) Using phytase in feed: At the time of conducting this survey, none of the farmers interviewed used phytase in feed. All the farmers did not consider the availability of phosphorus from plant ingredients, supplementing sufficient inorganic P to ensure more-than-adequate supply. The P stored in plants is predominantly present as phytate-bound P, which cannot be utilised by non-ruminants. Numerous research reports have shown that phytase is effective in increasing P digestibility, bone mineralization and growth performance of pigs fed low P corn-soybean meal diets (Cromwell et al. 1993, 1995; Veum et al. 1994, 1995, 1996). In general, 500 units of phytase activity are said to increase the amount of digestible P by 0.8 g/kg of pig diet (Coelho 1996). This amount of phytase activity is calculated to be equivalent to 1 g of P from supplemented MCP.

Conclusion

Total annual consumption of P in pig industry was about 6,145 t of which about 1,255 t originated from inorganic supplements. This amount is about 1.1% of the total amount of phosphatic fertilizers of 550,000 t used in Peninsular Malaysia. Apparent excretion of P was found to be 4,618 t/year or equivalent to approximately 10,566 t of P_2O_5 per year. The feed supplements used were TCP, DCP, MCP and MDCP (a mixture of DCP and MCP). The proportions of farmers using TCP, DCP, MCP and MDCP, with digestibility of 48, 66, 81, and 73% respectively were 25, 33, 9 and 33%, respectively. The P source with the highest digestibility, i.e. MCP was least used by farmers. Turbidity of wastewater increased with increasing TP concentration. Only 16.5% of TP in raw slurry was in dissolved form. Approximately 90% of TP was retained in the series of anaerobic, facultative and aerobic ponds. The efficacy of TP removal via sequential anaerobic and aerobic digestion was 66.4%, while SP was almost completely removed.

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Abstrak
Artikel ini melaporkan keputusan yang berikut: a) kajian kes berkenaan dengan pencemaran fosfat yang berasal dari industri khinzir di Malaysia; b) kajian tentang kesan kandungan fosfat pada kekeruhan air buangan; c) kajian berkenaan dengan kesan pengolahan air buangan cara kolam pada penahanan fosfat; d) kajian makmal berkenaan dengan kecekapan pembuangan fosfat dengan kaedah penghadaman biologi. Jumlah penggunaan fosfat dalam industri khinzir ialah 6,145 t setahun dan 1,255 t daripadanya berasal daripada sumber tak organik. Jumlah ini merupakan 1.1% daripada jumlah fosfat yang digunakan sebagai baja. Perkumuhan fosforus ketara ialah 4,618 t iaitu setara dengan 10,566 t P_2O_5 setahun.

Terdapat sumber tak organik yang digunakan iaitu trikalsium fosfat (TCP), dikalsium fosfat (DCP), monokalsium fosfat (MCP) dan MDCP, iaitu campuran DCP dengan MCP. Peratus penternak yang menggunakan TCP, DCP, MCP dan MDCP masing-masing ialah 25, 33, 9 dan 33%. Kadar penghadaman ketara TCP, DCP, MCP dan MDCP masing-masing ialah 48, 66, 81 dan 73%. Sumber yang tertinggi dalam kadar penghadaman, iaitu MCP, didapati paling kurang digunakan. Kekeruhan bertambah dengan peningkatan kandungan fosfat di dalam air buangan. Hanya 16.5% jumlah fosfat larut di dalam air buangan. Lebih kurang 90% jumlah fosfat dapat ditahan dengan penggunaan kolam pengolahan tiga peringkat berjujukan, iaitu kolam anaerob, fakultatif dan aerob. Kecekapan pembuangan jumlah fosfat melalui penghadaman anaerob dan aerob secara berjujukan ialah 66.4%, manakala pembuangan fosfat terlarut menghampiri 100%.

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