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THE STRATIFIED FACULTATIVE LAGOON FOR THE TREATMENT AND STORAGE OF HIGH STRENGTH AGRICULTURAL WASTEWATERS

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ABSTRACT

A research and development programme at The University of New South Wales and a large intensive piggery located on the outskirts of Sydney, Australia, has culminated in the successful commissioning of an odour control process for the storage and treatment of wastewaters from the piggery. The stratified facultative lagoon utilises surface aeration of an otherwise anaerobic lagoon to provide a non-odorous cover for the anaerobic contents. The process has filled a need in the pig industry for a non-odorous cost effective alternative to conventional treatment systems, prior to wastewater re-use or disposal by land application. Critical design parameters include lagoon depth, specific energy input and aeration system design. Mean removal efficiencies of biochemical oxygen demand of 75 per cent have been achieved consistently. The development of the process was facilitated by the use of wastewater redox potential testing to indicate the likely presence of odorous compounds in the liquid on the surface of the lagoon and in the surrounding atmosphere. Surface redox potential readings (E_h) greater than -76 mV resulted in non-odorous operation of the process.

KEYWORDS

Stratified lagoon; odour control; piggery; redox potential; surface aeration wastewater treatment.

INTRODUCTION

The intensive pig production industry in Australia is a relatively large agricultural industry, with an annual turnover of Aust.$600 million, and producing 5 million pigs per year. These piggeries, which range in size from 50 sows to 20,000 sows, are frequently faced with environmental pressures to manage their wastewater collection, treatment and disposal practices in a non-polluting and non-odorous manner.

For the most part intensive piggeries in Australia are located away from urban areas, although it is relatively common for smaller piggeries to co-exist with urban development on the outskirts of the major capital cities. Apart from these exceptions most piggeries have sufficient land available to enable land disposal of effluents without the risk of pollution of surface waters.

By far the greatest environmental pressure on the pig industry in Australia is the increasing need to operate without the generation of nuisance odours. This task in becoming increasingly difficult due to a combination of a decreasing public tolerance of agricultural odours, even in rural areas, and a tendency towards larger, more efficient piggeries. Odours from intensive piggeries may arise from several sources, including the wastewater treatment facilities, the effluent disposal system and from the pig sheds themselves. While totally non-odorous intensive pig production may be difficult if not impossible, it is generally accepted that a well designed and operated wastewater collection and treatment system will result in acceptable odour emission levels which are consistent with the location of the piggery. The challenge to date has been to develop such a system which is both effective and yet affordable to the industry, which tends to operate for long periods with low profit margins.

This paper describes one such system developed at the University of New South Wales. It also includes information on the development of an odour characterisation study which was used to evaluate the performance of the treatment process. The process itself, which has become known as the 'Stratified Lagoon', consists of shallow surface aeration of a deep anaerobic lagoon.

CONVENTIONAL PIGGERY WASTEWATER TREATMENT PROCESSES

In order to evaluate the Stratified Lagoon process it is necessary to consider the alternative treatment processes commonly used in Austraiia.

The simplest method involves direct disposal of untreated wastewater by irrigation onto pastures. This method is commonly utilised by smaller piggeries where ample land is available and where the climate is relatively dry. Fortunately these conditions prevail in many parts of Australia. Where this method is possible it is by far the most efficient and effective wastewater management system available to pig producers.

The most commonly used treatment/disposal system involves the use of anaerobic lagoons for the bulk of the treatment, followed by naturally aerated aerobic lagoons prior to effluent disposal by irrigation. A portion of the effluent is usually returned to the piggery sheds for use as underfloor channel flushing water. For piggeries in environmentally sensitive locations the odours which usually arise from the anaerobic lagoon, frequently prevent the use of this type of system. Certain pollution control authorities in Australia prohibit the use of anaerobic lagoons in these situations.

The alternative to the anaerobic/aerobic treatment process is the fully aerated lagoon process where the wastewater is maintained in a fully aerobic state throughout the treatment and disposal process. Oxygen is typically provided by floating mechanical aerators. The high operating costs of this system usually precludes its use, except in exceptional circumstances.

THE STRATIFIED LAGOON PROCESS DEVELOPMENT

Laboratory Study

While the concept of shallow aeration of deep treatment lagoons is not new (Ginnovan, 1983) the authors have been unable to locate information on the development of the process beyond laboratory scale conditions. This particular laboratory study is believed to be unusual in that the major emphasis on the work was placed on the odour control capabilities of the process rather than on the treatment efficiency obtained. The laboratory study sought to confirm the hypothesis that a shallow aerobic or near-aerobic surface layer on an otherwise conventional anaerobic lagoon would minimise odour emissions by oxidising the malodorous breakdown products from the anaerobic reactions occurring in the bulk of the lagoon.

Using piggery wastewaters and 20 litre column laboratory reactors it was found that a reduction in influent BOD_5 of up to 90 per cent could be achieved without noticeable odour emissions. By aerating the top 200 millimeters of a 1.5 metre deep reactor a positive dissolved oxygen level could be maintained in that layer without apparent disturbance to the remainder of the contents of the column. Samples of air collected immediately above the surface of the reactor and of the surface liquors were analysed for the presence of volatile fatty acids (VFA s) using head space gas chromatography, these compounds having been previously identified from the literature as being principally responsible for piggery wastewater odours (Van de Hoek 1977). Subsequent research indicated that process stability, as measured by effluent quality and observed and measured odour levels, could be maintained by using an hydraulic detention time of 15 days. The results of this study were reported in detail in an unpublished report by Barnes et al. (1984).

Redox Potential

A valuable product of the research was the development of and familiarisation with the parameter Oxidation Reduction Potential (ORP) or redox potential, as an indicator of the presence of odorous compounds in the wastewaters. It was found that the redox potential was superior to dissolved oxygen (DO) as a parameter in that it is better able to identify the existence of reducing conditions which are known to give rise to the generation of odorous compounds, including the volatile fatty acids. The work indicated that piggery wastewaters are not odorous if maintained at a redox potential of at least plus 40 mV with respect to the standard hydrogen electrode (E_h) (Barnes et al. 1985). It was also speculated that odour breakthrough may actually occur at a lower redox value, and this was proved to be the case when the first full scale stratified lagoon was operational.

While the results of the laboratory study confirmed the potential of the stratified lagoon process it provided little information on the basis for the design of the surface aeration system. The short duration of the laboratory study did not permit any optimisation of the aeration system, with the result that specific oxygen uptake rates (SOUR) in the laboratory reactors were not used in the sizing or selection of the first full scale application. In practice it was subsequently found that it was not possible, nor necessary, to maintain positive DO levels in the surface layer of the lagoon . At the time of preparation of this paper research work on the optimisation of the aeration system using the original laboratory reactors is in progress, some four years after the commissioning of the first full scale stratified lagoon.

FULL SCALE APPLICATIONS

Introduction

Due to extraordinary circumstances at the time, the first full scale application for the stratified lagoon process occurred before any pilot scale operation could be installed. In late 1984 it was decided to proceed with the full scale design on the basis of excellent laboratory scale results and a practically based understanding of the requirements for the appropriate aeration system. In order to minimise sub-surface mixing and promote stratification of the lagoon contents the following qualitative design criteria were selected:

- The lagoon should be a deep as practicable (at least 5 metres)
- multiple small aerators should be used in preference to fewer larger units
- the aerators should impart a horizontal or near-horizontal energy input to the surface of the lagoon.

Other design criteria are given in Table 1.

TABLE I DESIGN DETAILS OF THE MENANGLE STRATIFIED LAGOON

LOADINGS		DESIGN PARAMETERS	
Hydraulic Loading	720 kL/d	Lagoon Dimensions	130/100 x 50/40 m
Influent BOD_5	3000 mg/L	Lagoon Volume	23000 m^3
Organic Loading	2160 kg BOD_5/d	Lagoon Depth	5.5 m
		Hydraulic Detention	32 days
		Aeration Equipment	6 x 7 kW floating aspirators
		Specific Energy Input	1.8 Watts/m^3
		Inlet Location	floor of lagoon
		Outlet Location	surface of lagoon

Case One - Menangle Piggery (3000 sows)

A previously unsuccessful minimal aeration, odour control treatment lagoon was replaced by a stratified lagoon in February 1985. This piggery had a long history of odour problems by virtue of its proximity to a nearby village and freeway. The existing aeration basin was emptied and deepened to 5.5 metres, filled with stored anaerobic liquor and equipped with six 7 kilowatt floating surface aspirators. Those units were modified from their standard design to alter the discharge angle from 45 degrees to 30 degrees from the horizontal. It was felt that this measure would further minimise unnecessary disturbance of the anaerobic zone. The raw piggery wastewater was screened to remove gross solids, using 200 micron vibrating run down screens, before entering the lagoon.

Four weeks after the commissioning of the lagoon a series or redox potential readings was taken over the lagoon surface. At the time of the testing it was apparent that the system was generating offensive odours - a fact confirmed by subsequent odour complaints from local residents. The results indicated surface redox potentials in the range -54 mV to -191 mV, with a mean value of -144 mV. These values were subsequently shown by Swan et al. (1987), to result in the production of odorous volatile fatty acids and other compounds. Depth testing for redox potential showed that stratification of the lagoon contents was not taking place. Flow patterns in the lagoon were such that opposing streams of aerated wastes were converging along the longitudinal axis causing a vertical drop of the surface material to the lower sections of the lagoon. Further testing two weeks later produced similar redox potential readings and a similar unsatisfactory flow pattern.

The aspirator configuration was then modified to the present layout shown in Figure 1. This resulted in an immediate reduction in odours and an increase in the redox potential readings over the lagoon surface. The surface flow pattern changed to one of counterclockwise flow, with a stationary 'dead spot' evident in the centre of the lagoon.

As a further refinement to the system the outlet pit was fitted with a coarse bubble aeration system in an effort to reduce the prevalence of odours in the vicinity of the travelling irrigator. The aeration blower is interlocked with the irrigation pump as an energy saving measure. This system resulted in positive redox potentials in the wastewater leaving the effluent pit, and a significant reduction of irrigation area odours.

In June 1985 the six aspirators, when tested for compliance with the specified energy consumption of 7 kW, were found to be drawing approximately 11 kW. The lagoon was continuing to perform well despite an actual specific energy input of 2.8 watts/m^3. Each aspirator impeller was progressively modified from July to November to consume the required power. There was no visible affect on lagoon circulation patterns and the system remained non-odorous.

The final modification to the system occurred in early 1989 when the aspirator outlets were further modified to produce a horizontal energy input to the surface of the lagoon.

The detailed results of the Menangle lagoon are given in the following section. In qualitative terms the lagoon has operated for 4½ years without major disturbance or instability, and has resulted in the virtual elimination of wastewater treatment based complaints of odours from the premises. The improved quality of lagoon effluent returned to the piggery sheds as flushing water has seen a decrease in odour levels within and around the sheds.

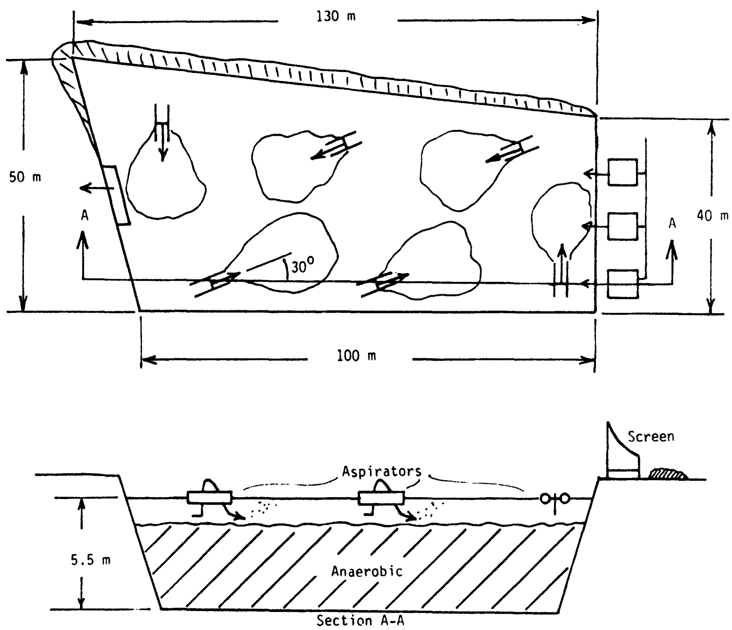

Figure 1 Stratified lagoon (Menangle) - schematic

Case Two - Corowa Piggery (5000 sows)

The second full scale installation occurred in late 1988 at a new 5000 sow piggery at Corowa, New South Wales. The use of a stratified lagoon in this application was a condition of the development approval granted by the local municipality.

In this case a lagoon was constructed with dimensions 120 metres long, 60 metres wide and 8 metres deep. The specific hydraulic and organic loadings (per pig) on this lagoon are slightly less than for the Menangle lagoon, due to the modern design of the pig sheds and wastewater collection system. The overall design loadings are 1500 kilolitres per day and 4500 kilograms of BOD_5 per day respectively. The aeration system comprises eight 5.9 kilowatt Flygt ejector units, configured in a similar arrangement to that used at Menangle, and shown in Figure 1.

At the time of writing this lagoon had been operating for six months, with indications that its performance is exceeding that of the Menangle unit. At this stage this improved performance is believed to be due to a combination of greater lagoon depth and more directionally effective and perhaps efficient aeration system.

RESULTS

The following results refer mainly to the Menangle lagoon which has been extensively monitored since commissioning. Where available the results from the Corowa operation are also included.

Odour Control

The assessment of odours has traditionally relied upon olfactory determinations rather than analytical techniques (Swan et al. 1987). At Menangle both approaches were utilised to assess the performance of the stratified lagoon in particular and the waste treatment/disposal system generally.

Prior to the installation of the lagoon complaints were regularly received from local residents and passers-by of offensive odours emanating from the piggery. Since the commissioning of the lagoon the number of complaints has drastically decreased to the point where these complaints tend now to be related to piggery shed odours rather than to the waste system. This improvement in odour levels has been confirmed by the authors during their numerous inspections of the premises. The odour level immediately adjacent to the lagoon is now very slight, and far less than the piggery shed-related odours in the area. The lagoon odour cannot be detected at the piggery boundaries. Spray irrigation odours which were severe prior to the commissioning of the lagoon, and still at nuisance level for a short time afterwards, were eliminated by the aeration of the outlet pit of the lagoon.

The olfactory assessments were confirmed by Swan et al. (1987) who analysed air and wastewater samples collected on the premises using headspace gas chromatography. Their results indicated low concentrations of odorous volatile fatty acid compounds adjacent to the lagoon and far higher concentrations in the piggery sheds. This confirmed the opinion that the piggery sheds were now the principle source of any complaints received after the commissioning of the lagoon. Significantly a series of aerator failures in the months prior to September 1985 were accompanied by an elevation in detectable volatile fatty acid concentrations in the atmosphere adjacent to the lagoon, despite the lack of obvious odour in the area.

Redox Potential

The full scale results confirmed the laboratory conclusion that a strong correlation exists between liquid redox potential readings and observed odour levels.

Large negative redox readings are known to result in odorous wastewaters. Prior to the commissioning of the Menangle stratified lagoon the previous aerated lagoon was tested for redox potential and produced readings in the range of -240 mV to -190 mV. The odour adjacent to that lagoon was generally offensive. Extensive testing of the stratified lagoon has indicated that the process is very stable and consistently produces mean surface redox potentials within the range -76 mV to +10 mV, with a mean of all readings of -30 mV. These results are depicted in Figure 2. Further improvement has been evident since January 1989 due to the previously mentioned modifications to the aerators.

The redox potential results for the Corowa installation have been an improvement on the Menangle results. The most recent testing indicated a range of redox potential readings at the surface of the lagoon of 0 mV to plus 10 mV, with a mean value of plus 6 mV. Improved surface coverage by the Corowa aerators contributed to this result.

Stratification

The redox potential testing at Menangle also confirmed that excellent stratification between the surface and subsurface layers was being achieved.

Figure 3 shows the results of redox potential depth testing. It clearly illustrates that the contents of the surface of the lagoon to a depth of one metre is in a more oxidising state, to the extent of 100 mV, than the wastes at lower levels. The sawtooth pattern of the surface readings reflects the impact of each aspirator. Samples of the waste collected at depths greater than one metre were found to be odorous, illustrating the importance of stratification. The ability of the lagoon to stratify at specific power input levels of up to 2.8 watts/m^3 is thought to be largely due to the excellent directional capability and shallow impingement quality of the aspirators selected.

The lagoon at Corowa did not display the same sawtooth redox potential characteristic as Menangle, due to the improved surface coverage of the Flygt aerators. While redox potential depth profiles were not carried out, stratification was evident from circulation velocity testing which indicated that the surface velocity was approximately four times greater than that measured at a depth of one metre.

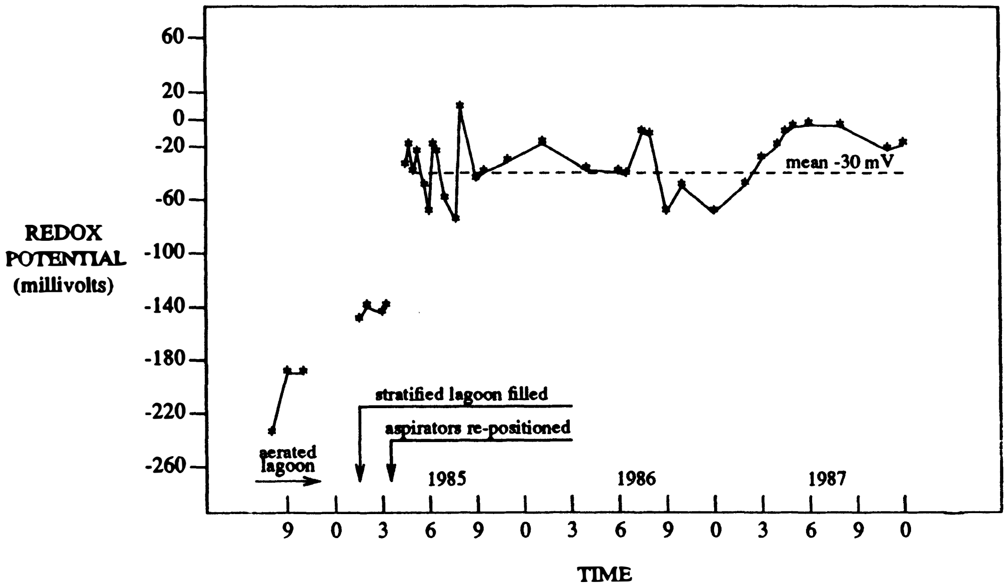

Figure 2 Stratified lagoon (Menangle)- mean redox potential results

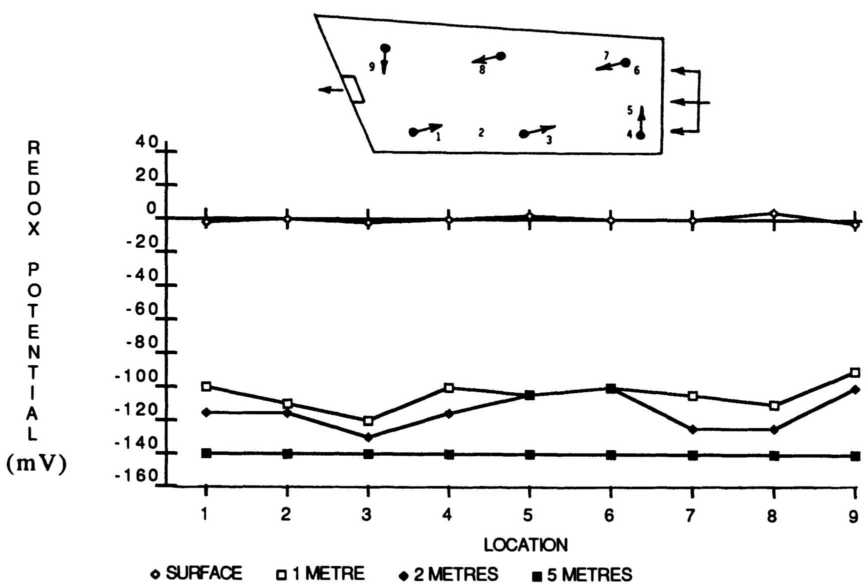

Figure 3 Stratified lagoon (Menangle)- stratification profile-Feb. 1989

Treatment

The treatment efficiency of the stratified lagoon is similar to that of conventional anaerobic lagoon loaded at the same rate. Removal efficiencies at Menangle for BOD_5 are typically around 65 to 75 per cent, although better performance was achieved in the first year of operation. Raw wastewater BOD_5 is typically 3000mg/L. Treated effluent BOD_5 and suspended solids concentrations typcially range from 800 mg/L to 1200 mg/L.

The relatively well treated and non-odorous effluent has had a beneficial effect in reducing odours from both the irrigation area and piggery sheds.

Sludge Accumulation

Since the stratified lagoon is a one lagoon treatment system it was imperative to maximise the sludge storage capacity of the lagoon and thereby minimise the frequency of desludging operations. It was for this reason that fine screening of the raw wastewater is practised at both Menangle and Corowa.

Sludge depth monitoring has been carried out on two occasions at Menangle, after two and four years of service. While the data varied at different locations around the floor of the lagoon, the overall results after four years indicated a mean sludge depth of 1.5 metres. The earlier testing indicated a sludge depth of 0.5 metre. Based on these results the lagoon will need to be desludged in another four to five years.

Economic Considerations

When compared to the fully aerated lagoon treatment process the stratified lagoon is most cost effective, in terms of both capital and operating costs. Both systems would have similar capacities for minimising treatment odours. Capital cost comparisons would depend upon conditions specific to each site, but in Australia would normally favour the stratified lagoon. The principal attraction of the stratified lagoon for pig producers is the lower operating cost, by virtue of an installed aeration power requirement one third of that for an aerated lagoon. Under Australian conditions this represents a saving for producers of approximately A$1.00 per pig produced (A$0.50 compared to A$1.50).

CURRENT RESEARCH

While developmental and refinement work on the stratified lagoon is continuing, the major research emphasis is now placed on two aspects associated with odour emissions from intensive piggeries. Firstly the odour characterisation and quantification study has been expanded, following a research grant from the Australian Pig Research Council, to develop operational correlations between odour emissions and piggery management practices. Secondly the resultant odour source data from the original research is being utilised in a mathematical model of odour generation and dispersion from intensive agricultural operations.

CONCLUSIONS

The stratified lagoon has been shown to be a reliable and effective process for non-odorous storage and treatment of piggery wastewaters. The two lagoons at the Menangle and Corowa piggeries have demonstrated that the process can effect up to 75 per cent removal of organic material without generating nuisance odours, and using only one third of the power required for fully aerobic treatment. Design details of the process require careful attention, particularly lagoon depth, specific power input and aerator selection. While to date the process has been applied only to piggery wastes, it appears to be ideally suited to other high strength organic wastes produced in areas where nuisance odours are not acceptable.

The development of the stratified lagoon has relied heavily upon the parallel development of and familiarisation with the parameter redox potential as an indicator of potentially odorous wastewaters. This parameter is easy to measure in situ using a rugged and reliable industrial quality electrode. Experience to date has indicated that mean surface redox potentials (E_h) in piggery wastes as low as -76 mV are not accompanied by the emission of objectionable odours, despite the absence of measurable dissolved oxygen. The rapid decrease in redox potential readings following the cessation of aeration has shown that aeration systems for this process should be designed for continuous operation. The use of routine redox potential testing should enable the managements of piggeries and many other industries to monitor both the performance of their waste treatment systems and compliance with statutory and social expectations.

REFERENCES

Barnes, D., FitzGerald, P.A., McFarland, R.M. (1984). Treatment of wastewaters from small/medium piggery. Report for the State Pollution Control Commission.

Barnes, D., FitzGerald, P.A., McFarland, R.M., Swan, H. and Schulz, T. (1985). Redox potential/basis of measurement and application. Effluent and Water Treatment Journal pp 232-236.

Ginnovan, M.J. (1983). Shallow aeration of piggery waste treatment lagoons (1) Removal of organic pollutants and indicator bacteria. Agric. Ecosystems and Environ. No. 10, pp 23-29.

Ginnovan, M.J. (1983). Shallow aeration of piggery waste treatment lagoons (2) Odour Control. Agric. Ecosystems and Environ. No. 10, pp 31-36.

Swan, H., Barnes, D., FitzGerald, P.A. and Schulz, T. (1987). Detention and determination of odours from waste treatment facilities. Proceeding of the 12th Federal Convention, Aust. Water & Wastewater Assoc., Adelaide.

Van De Hoek, K.W. (1977). Odour control of liquid swine manure by aeration. Agric. Environ Vol. 3, pp 183-188.