NEW CHALLENGES FOR ENVIRONMENTAL PROTECTION IN TERMS OF INTENSIVE ANIMAL PRODUCTION

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SUMMARY

Modern livestock require the proper handling of the large volumes of manure produced. The main concerns are nutrients which are often in excess of the capacity of the local environment resulting in air and water pollution. Treatment can play a key role in the removal of these surpluses either by breakdown or by exporting as useful products – a wide range of technologies is already well established. However it is the hygienic aspect of manure handling that may pose the greater challenge as concerns grow over the spread of disease and the potential contamination of water and food crops. Thermal treatment represents an effective and versatile option but it is often overlooked due to the anticipated expense. Heat recovery may yet make this approach accessible to the farming systems especially if the process is coupled to an anaerobic digester which can potentially produce an energy neutral process.

Keywords: manure management, thermal treatment, anaerobic digestion, food safety, disease transmission, pollution

INTRODUCTION

Food safety and environmental quality are foremost topics in the public's mind. The two are intimately linked because food production cannot be separated from the land, itself an integral part of the natural environment. In the late twentieth century, farmers were encouraged to intensify in order to remain profitable. However, concerns on hygiene issues have been raised by a series of food scares from the microbiological contamination of agricultural food products (salmonella, e-coli, campylobacter and also BSE). In addition there have been notable outbreaks of diseases affecting the animals themselves including foot and mouth, classical swine fever and more recently, avian influenza. Policies that aim to encourage efficient production of inexpensive food may threaten animal health, food safety and the natural environmental. However, ill-considered legislation to reduce pollution and/or promote food safety can significantly damage farming activity whilst also failing to achieve the intended purpose. Furthermore, moves to protect food quality by restricting the use of livestock manures on crops can undermine measures for environmental protection by limiting the opportunity to usefully recycle and thus aggravating the problem of nutrient excess.

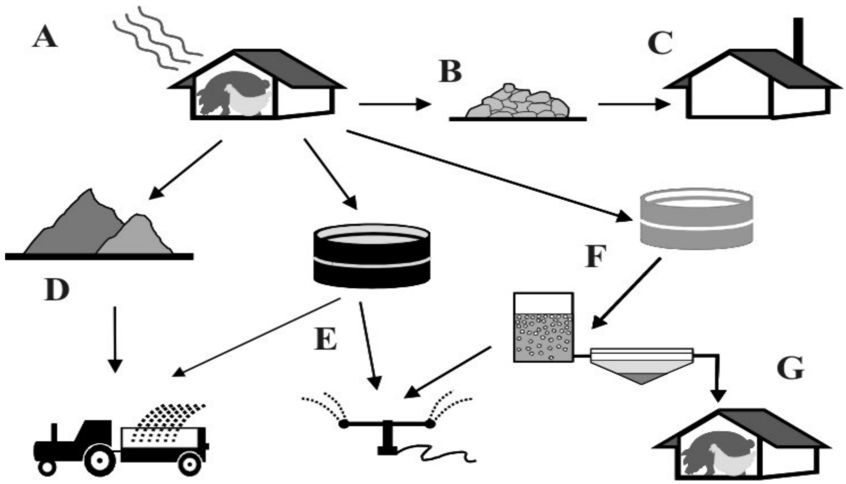

Figure 1. The principal wastes streams from livestock farming: A – emissions, B – fallen stock, C – wastes related to the rendering process, D – solid farm wastes including bedding, E – liquid manures, F – other wastewaters and G – water reuse

The wastes produced from livestock farming are summarised in Figure 1. In terms of volume, fallen stock is a very small percentage but it is often the cause of particular concerns over hygiene. The largest volumes are often of liquid manures that present the main problems to the environment due to the mobility of the nutrients contained. Solid wastes (including farmyard manures or FYM) are considered to be more stable but can present problems in handling. On some farms, there is the separate collection of a more dilute wastewater (also known as dirty water). This can be potentially treated to enable use around the farm for a limited number of duties – an important consideration where water is a limited resource and recycling is encouraged. There is no shortage of research effort or of available techniques to deal with the manure management which lies at the heart of the problem (Burton and Turner, 2003; Burton 1996 and 2006). Rather it is an issue of *strategy*: trying to meet multiple targets in the absence of clear procedures to evaluate and compare the methods available along with their unwanted consequences.

THE ENVIRONMENTAL IMPACT FROM LIVESTOCK FARMING

There are many papers that cover in detail the various environmental effects from raising animals (e.g.: Burton, et al, 2000). Such impacts are from the wastes produced along with the related emissions and odour nuisance.

- The impact on air quality: effect of the management technique on emissions including ammonia, methane, nitrous oxide and particulate matter.

- Impact on water quality (surface and underground): effect of management technique on release of nutrients (nitrogen, phosphorous and organic materials). Risk of water contamination by pathogens.
- Impact on soil quality: changes in soil structure as a result of implementing the proposed measures both short and long term. Expected accumulation effects including phosphorous and heavy metals.
- Effect on nuisance factors including offensive odours and impact on local community.
- Contribution to animal and farm hygiene. Effect on the farm bio-security and on the spread or abatement of infectious animal diseases. Risks to farm staff and local people.
- Impact on the quality of food produced. Contamination risks of crops from zoonotic pathogens – both by direct applications of manures and by indirect routes (via air, soil or water).

These can be more simply grouped as nuisance, pollution or hygienic concerns. In the case of odour nuisance, this implies both revised management practices such as timing or method of land spreading, or the introduction of an effective treatment regime such as aeration (Burton et al, 1998). Although odour has only a small effect on the environment, it is often the principal factor behind local complaints of livestock farming.

The greater concern in terms of the environment is from water, air and soil pollution. This includes emissions of ammonia, methane and nitrous oxide to the air, the release of ammonia, phosphorous and organic matter to surface waters and contamination of underground water by nitrates. Many of these unwanted effects are often the result of the poor use of nutrients – sometimes good housekeeping measures alone such as improved collection and storage and/or manure management plans can greatly help. In cases where there are local or regional excesses of manure nutrients such as phosphorous or nitrogen, some form of treatment is required with the removal of surpluses as a concentrate or (in the case of nitrogen) as the products of the nitrification / de-nitrification process (Pahl et al, 2003).

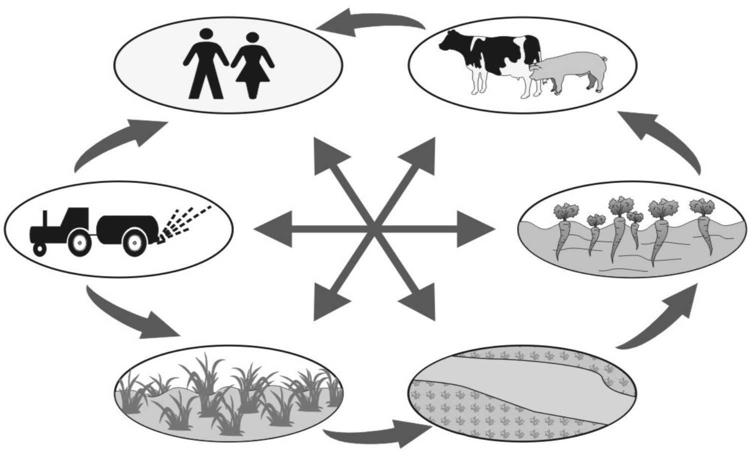

Figure 2. There are many transfer routes for pathogens moving through the environment. Some of these may be minor yet still cause considerable public concern.

In recent years, hygienic issues resulting from the pathogens invariably present in animal wastes have been the cause of increasing concern. The resulting impacts include health risks to the animals and people either directly or indirectly via water or food produced (Figure 2). The extent of such risks is the source of much research and discussion but it may be that public fears of ill health are greater than the actual risk presented. Hygienic impacts can be grouped under four headings:

A: direct risk to farm staff and people nearby. The perceived risk in this case may be much higher than the actual risk and there have been few verified cases of illness as a result of this route. Farm staff in regular close proximity with animals are at highest risk but this can also be the result of the internal environment of the animal buildings (e.g.: dust inhalation, high ammonia concentrations etc) as much as from a direct infection from the waste materials present. However, the recent cases of avian flu generating illness in local people emphasises the problem and bio-security at least will need to be reviewed. Outside the farm, the main impact on local people will be via the land spreading practice and the aerosols sometimes produced as a result. The fact that this can cause offensive odours is not disputed but this should not be confused with an exposure to an infective dose of a zoonotic disease. Nonetheless, public pressure evoked from odour concerns can quickly turn to health matters and scientific argument alone may not be enough to resolve such disputes.

B: contamination of food crops. Again the perceived risk may be higher than that in reality. Furthermore, the avoidance of land spreading manures on certain vegetable crops will be no guarantee that they will not be contaminated from other environmental sources such as wild animals or birds. One might add that there may be equal or greater concerns over the practice of irrigating river water onto food crops. Clearly though, the application of manures to certain vulnerable crops such as lettuce can increase the risk of contamination from a range of common pathogens such as salmonella, e-coli or campylobacter. The issue is that, despite the organic credentials, there may be increasing reluctance to apply untreated manures to a much wider range of vegetable crops including those for which there is little evidence of contamination. Land spreading potentially represents the most environmentally-friendly method of manure disposal so long as suitable cropland is available for the purpose; the areas available may be greatly reduced if fears of food contamination from pathogens are not calmed.

C: contamination of water supplies. There have been cases of drinking water becoming contaminated by effluents from agriculture with the resulting illness affecting local people including fatalities (e.g.: Walkerton, Canada: Guan and Holley, 2003). Such incidents are relatively few and often the result of accidental discharge. However, it is all too apparent that manures can enter surface waters adding a bacterial load to the system – e.g.: from run-off especially if heavy rainfall follows land applications. Various methods can be proposed for better management of land spreading practice to protect rivers and streams but in some high risk areas this may not be considered enough and the farmer may find himself with greatly restricted options. If water quality is likely to be effected, the reaction of local people and politicians can be expected to be very determined and restrictive measures may well follow.

D: disease spread amongst farm animals. The spread of zoonotic diseases to people will always cause the greatest reaction, but often, it is the risk to animals that is the greatest. Within the farm, the transfer of disease via manure is both easily understood but there is an additional dimension in the case of grazing animals and land spreading on grassland. In this case, there is a real transmission risk to neighbouring farms. Fortunately, many of the main notifiable animal diseases of concern are rarely present. Nonetheless, in cases of disease outbreak amongst farm animals and in the absence of good bio-security and good waste management there is a much increased rate of spread. Furthermore, following the outbreak of a notifiable disease at a livestock farm, there is the additional problem of safely disposing of any waste material collected or already in store which must be deemed contaminated.

THE ROLE OF TREATMENT PROCESSES IN COMBATING HYGIENE RISKS

In response to disease related risks, one can consider either storage, drying or treatment of the various wastes to reduce or eliminate the pathogenic agents. Storage represents the simplest option but care must be taken to prevent re-contamination from further addition of raw wastes. The typical farm store can fulfil this role once full and left for a period of time. However, the length of time can be considerable especially during cold weather; for example, 20 days storage was found to be enough time to inactivate *Cryptosporidium* oocysts in cattle slurry at 20 ºC but this increased to 90 days at 4ºC (Svoboda et al, 1997). Some bacteria, viruses and other pathogenic agents have shorter survival times in dry conditions and/or when exposed to oxygen although the process of drying itself may be a factor. Survival in solid manure has indeed been reported as less than for liquid manure and once land spread (especially during warmer weather), but other results contradict this trend possible the result of conditions allowing the formation of spores (Burton and Turner, 2003). The net effect of such uncertainty is to specify storage times running into months when there is a particular disease risk present.

Various studies have concluded that the treatment options come down to either chemical use (such as disinfectants) or heat application (Turner and Burton, 1997). In some cases, the exposure to pathogens to biological treatments (especially aerobic systems or at temperatures above 50ºC) also results with a substantial reduction in numbers. The main limitation with such processes lies with the concept of back-mixing which is almost invariably present – as such; there is almost inevitably the re-inoculation of treated wastes by the raw material entering the system which partly negates the benefit of treatment. The problem is largely avoided in batch processes but at the price of a system that is very difficult to control and unsuitable for large volumes; sequential batch reactors (SBR's) represent a useful compromise. Biological treatments (both aerobic and anaerobic) will remain an important option because of their effectiveness in removing reactive organic matter and (in the case of nitrification and de-nitrification) the removal of nitrogen as well (Beline et al, 2004). Furthermore, the related settling options enable the removal of phosphorous.

The use of chemical disinfectant on farms is commonplace but unpopular because of (a) the implied costs (b) the hazards of handling and (c) the detrimental environmental impact. It is noted that chemicals are less effective within solid material where penetration is inhibited – bacteria within such material might survive such treatment. For manures where there is almost always the presence of ammonia, a bactericidal effect from the chemical can be expected in addition to that of heat, oxygen or biological activity whichever is the principle agent of the process (Turner et al. 1999).

Raising the temperature is almost universally effective in accelerating the reduction of pathogenic agents; the higher the temperature, the faster and further the decline in numbers. Above 50ºC, the time required is down to hours and above 70ºC, minutes may be enough to ensure total removal of a pathogenic agent. The attractiveness of thermal treatments lies with its inherent effectiveness – given time, all the treated matter can be brought to an inactivation temperature where the microbes and spores contained are destroyed. Modelling of heat transfer systems is generally easier and more reliable than of chemical (mass) transfer and both much easier than of biological systems. In addition, depending on the method of heat application, a rapid temperature change is possible adding a thermal shock factor that further enhances the effectiveness of the process.

The clear disadvantage to thermal processes lies with cost and the related implication of an environmental penalty in the energy consumed. This may be addressed in two ways: firstly by the use of heat recovery technology and secondly by utilising the heat already available within the livestock waste. In some cases, a cost neutral process (in energy terms) may be possible which would be a crucial pre-condition before such technology could be considered for general use within the farming system.

THE AVAILABILITY OF ENERGY FROM LIVESTOCK WASTES

Aerobic biological treatment processes for livestock manure are exothermic and are accompanied by a rise in temperature. However, in many cases, the availability of this "free" heat is not translated into any real benefit although general warming can be expected to enhance microbiological activity. Some composting systems do reach 70ºC to enable a final pasteurisation of the product but others struggle to reliable reach 50ºC. For liquid manure systems elevated temperatures are note easily achieved and the general preference to operate at mesophilic temperatures (20 to 40ºC). Some anaerobic digesters have been run at 55ºC with the benefit of enhanced pathogen reduction and possibly also increased degradation, but sustaining the elevated temperatures can consume a high proportion of the biogas in cold regions.

The potential heat from the aerobic degradation of pig manure is around 14.5 MJ per kg of oxygen *consumed* (Evans et al, 1982). This reflects similar values measured for a range of organic compounds – 16.7 for methane, 12.8 for n-octane and 13.0 for benzene (Perry, 1973). Typical organic matter in manure is hard to define but assuming a ratio of 2:1 H:C, one kilogram of pure organic matter fully oxidized will typically need 3.4 kg of oxygen. Various studies (e.g.: Williams et al, 1989) indicate that one kilo of the dry matter in pig slurry will contain reactive organic matter needing around 400g of oxygen for complete oxidation in five days (i.e., its BOD_5 or biological oxygen demand content) – this implies a readily available heat output of 5.8 MJ per kg of dry solids fed to the reactor. In reality, the presence of other oxidizable components in manure, especially nitrogen, will enable a slightly higher value.

In the case of anaerobic digestion, there is little heat of reaction and sometimes, heating must be provided to sustain an adequate reactor temperature. The equivalent energy in this case is released as biogas. Keeping with pig slurry, this can yield 340 to 550 litres of biogas per kg of volatile solids (VS) fully digested (Burton and Turner, 2003). Taking a median figure of 450 and a biogas containing 60% methane and pigs solids containing 70% VS, the maximum methane yield is around 190 litres per kg of total dry solids fed to the digester. In combustion, one volume of methane will require one and a half volumes of oxygen or 285 litres which is equivalent to 342g if we take the gas density of 1.2g/litre. Applying the previously cited figure of 16.7 MJ per kgO_2 consumed for methane gives the energy from the methane produced from the one kilogram of manure solids as 5.7 MJ. This is not surprisingly similar to the figure of 5.8 MJ of heat released per kg of dry piggery solids fed to an aerobic reactor. The implication is that the anaerobic process is barely exothermic with around 95%+ of the potential thermal energy available going into the methane produced – this is indeed what is generally observed. However, the biogas that can be produced is a usable source of fuel equal to 290 MJ per tonne of typical piggery slurry with a dry matter concentration of 50 kg per tonne.

MANURE PASTEURISATION AND STERILISATION SCHEMES

The application of heat alone in a thermal process has been demonstrated as an effective treatment against a range of pathogens. Tuner et al (1999) demonstrated a reduction by four log10 units of a range of viruses exposed to temperatures between 55 and 65ºC for a nominal 5 minutes. The same research demonstrated the option of heat recovery in excess of 80% by the use of heat exchangers in which the treated effluent warmed that entering the system. Taking the specific heat capacity as 4000 kJ per deg.C per tonne, the heat required to warm an aqueous effluent from an ambient of 15 to 65ºC is around 200 MJ per tonne (or m^3 on the basis that the liquid density is close to unity). Energy costs if available at 10 cents (euro) per kWh would be a prohibitive 5.60 euros per tonne treated. If the effluent in question was 5% piggery slurry, then there would potentially be enough energy via the potential biogas production to provide this requirement allowing for some losses and inefficiencies. However, if there is 80% heat recovery, then the energy demand falls to 40 MJ per tonne reducing the energy cost to around one euro per tonne. Moreover, this could easily covered by the potential biogas produced. The broad scheme is set out in Figure 3:

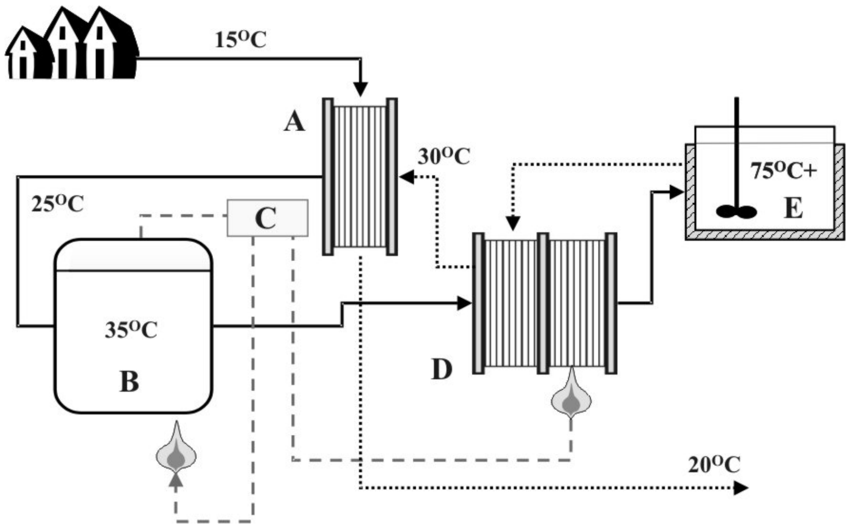

Figure 3. Schematic of a thermal treatment plant for effluents produced from a livestock farm. Heat exchanger (A) is for the optional pre-heating of effluent prior to anaerobic digester, B. The biogas (C) both sustains the digester and the principal thermal process (E). Heat recovery is via the second heat exchanger, D.

The scheme is based around anaerobic digestion with no aerobic stage and thus no removal of nitrogen; such a scheme may be of greater interest for farms wishing to utilise the full agronomic value of the manure but with a reduced risk of crop contamination. Here there is the additional consideration of maintaining the temperature of the digester. On the basis that the final treatment temperature will be over 70ºC, it’s quite possible that once the process is established, heat recovery will reduce the demand for gas for thermal treatment and some will be left over for external uses leaving the system as a net gas generator. There are several alternatives including a combined approach with an anaerobic digestion unit followed by an aerobic treatment system.

The drawbacks of these schemes lie principally with the cost and running of the equipment, especially the heat exchangers. These exist in many designs but all are prone to blockage and fouling over the course of time. Pre-screening (and even centrifugation) of the raw effluent may be required with the removed solids being separately added to the digestion processes. Fouling will progressively reduce heat transfer performance, and periodic cleaning will be required to remove deposits.

CONCLUSIONS

- The principal environmental concerns from livestock farming are related to the management of the wastes produced. The main negative impacts are the pollution of air, water and soil, health and hygiene issues and odour nuisance.
- A wide range of management techniques already exist that enable the safe handling and disposal of livestock wastes. Observing good practice in the collection and targeted application of manures represents a first step for all farmers. Where there are surpluses of nutrient over local crop needs, treatment may be required to enable the removal of the excess. This includes aerobic treatment, anaerobic digestion, composting and separation processes with the export of manure products.
- The patchy uptake of manure treatment across Europe demonstrates some reluctance to use this option which is often due to cost. Difficulties in meeting legislation and local pressures are the main reasons why some farmers have been adopting such technologies. However there are also some benefits that offset the costs including biogas production, the reduced need for chemical fertilisers and the option to sell manure products as organic fertilisers.
- It is concerns over hygiene that ultimately may determine the strategy followed for manure management. From the farming point of view, such fears encompass the spread of notifiable diseases amongst livestock. The greater pressure may come from the risk of water or crop contamination. This last factor may create new problems in the safe disposal of manures onto farmland; the use of treatment may again become an important step in the process.
- Decontamination of manure can be achieved by storage, drying, chemicals, raised temperature or biological systems. Thermal treatment of effluents represents the most reliable system especially if there are particular disease risks. The implied costs can be reduced by heat recovery and if coupled with anaerobic digestion, an energy neutral process is theoretically possible.

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