Sludge management – future issues and trends

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Abstract 
A review of the literature over the last thirty years shows that while the diversity of unit processes for sludge treatment has increased dramatically, there are still only three basic ultimate disposal routes for processed sludge; land application, landfill and incineration. None of these end-uses are fundamentally either good or bad; each one is simply more or less appropriate for a given situation. Selection of a sludge management option is not immune to popular trends and this may introduce artificial criteria as opposed to having the choice based on a critical evaluation of the needs of each specific project. We must ensure that efforts to promote one approach to sludge management does not inadvertently create new obstacles for alternative solutions. For example, land application of sludge is enjoying a well-deserved period of growth based on good science, cleaner sludges and proactive public education. However, we must not fall into the trap of assuming that this is the only “good” approach and discounting other potential solutions without a unbiased assessment. This paper summarizes the major trends in sludge management from the perspective of both the past and the present. Issues related to current practice and future developments are discussed with reference as to how they may impact on future sludge management decisions. Sludge management alternatives should be selected based on consideration of the following elements: multiple use options provide the producer with flexibility to respond to changing priorities, the solution must reflect the unique needs of the individual community and the public must be incorporated into the decision making process from the very beginning.

Keywords Sludge; biosolids; strategic planning; public education

Introduction

Biological processes are an effective way of treating society’s wastewater and ensuring minimal impact on the aquatic environment but they have one serious drawback; they produce sludge. Generally speaking, the more effective the process is in removing contaminants the more sludge it produces. Historically it was common to see schematics that showed the liquid treatment scheme in detail with all of the appropriate unit processes and an arrow at the end that simply said “sludge to disposal”. The assumption that the sludge would somehow disappear was supported by the fact that only a minor fraction of the engineering design budget related to sludge management. Unfortunately this approach does not represent reality and today the industry is very aware of the fact that the management of sludge, or biosolids as it is now called, represents significant technical challenges and accounts for a major portion of the capital and operating cost of any wastewater treatment facility.

The selection of a sludge/biosolids management strategy is of interest to a wide variety of people including facility owners, engineering consultants, contract operators, equipment suppliers, politicians, regulators, environmental groups and the general public. Each group sees the issue from its own unique perspective and has valid reasons on which to base its views. It is not surprising that these views or opinions often differ widely. Without criticizing any of these positions, this paper addresses the problem from the perspective of the two groups which are most directly affected; the producer of the sludge who must ultimately find a home for it, and the general public who must live with the selected option. Although the terms sludge and biosolids will be discussed in more detail later, the two terms are essentially used interchangeably throughout this paper.
Historical development

Sludge management has evolved over the last fifty years from an approach that could probably be best described as an “afterthought” to a high priority issue today that represents up to 50% of the total wastewater treatment cost and in many ways, is a far more sensitive issue with the general public than the liquid treatment train. Although the variety of individual management techniques that have been implemented is impressive, the vast majority of them fall into three broad categories: application to land, disposal in a landfill and incineration/thermal technologies.

Land has long been a repository for sludge, often with few constraints attached to the practice. In some situations, sludge was applied at extremely high loading rates with no consideration given to agronomic nutrient requirements and in fact, often there were no attempts to even grow a crop. In these cases, the land was functionally used as a disposal site rather than for sludge utilization. In the early 1970’s the focus changed to “sludge utilization” and an intense period of research was initiated to study the long term impacts of heavy metals in sludges. At the same time there was increased effort to develop and enforce industrial sewer bylaws in order to keep contaminants out of the sewage and produce cleaner sludges. The outcome of this period was the development of guidelines, codes of practice and regulations for the utilization of sewage sludge (biosolids) on agricultural land. These guidelines, regulations, etc. allowed for the agricultural use of the nutrient value of sludges with minimal risk to the environment or human health.

Another prominent land-based alternative has been composting. Sludge has been composted using a number of different technologies and a variety of bulking materials including wood chips, bark, municipal solid waste, etc. Initially, composting was embraced, in theory, by the environmental community as a highly desirable “green” technology. In practice, the NIMBY syndrome remained a factor in siting plants and the failure rate for full scale facilities has been high. Control of odours in both processing plants and maturation/storage areas have been problematic and many plants have been shut down as a result of community complaints. The economics of a sludge composting facility have often been based on the assumption that a significant amount of revenue would result from the sale of the finished compost without committing the finances necessary to develop the market. Without this, many facilities failed to achieve their revenue predictions and in some cases did not have an outlet for the finished compost.

The disposal of sludge in a sanitary landfill was traditionally perceived as the simplest and possibly the cheapest form of sludge management available to a municipality. After all, they needed a landfill to handle municipal solid waste so why not use it for sludge as well. This approach began to be seriously questioned in the 1970’s and 1980’s when the problems of siting new landfills became a political nightmare. The evolution of the NIMBY syndrome resulted in vocal resistance of many neighborhoods against siting new landfills within their community. The disposal of sludge in landfills, which would reduce their effective life, began to be seriously questioned, particularly when other options were available.

Apart from public perception, there were also operating issues related to disposing of sludge in landfills. There was concern that the organic content of the sludge would overload any leachate treatment system, particularly in the early life of the landfill. Raw sludge gradually became unacceptable and treatment was required to minimize vector attraction. Landfill operators began to refuse liquid sludge due to problems associated with compacting the sludge/garbage mixture. Dewatering sludge to some minimum solids concentration became the norm. In recent years, many analyses have tended to conclude that landfilling is one of the least desirable options since it does not lend itself to the reuse of sludge in any significant way.

The 1960’s and 1970’s saw incineration emerge as a major disposal route for large municipalities. Energy was cheap and plentiful, incineration produced a minimum volume
of material for final disposal and air emissions were not a priority concern. Over the intervening years this situation changed dramatically. Energy prices escalated sharply and it became obvious that sludge incineration would have little priority in the event of an energy shortage. In order to reduce energy requirements, improved dewatering facilities were implemented to increase the solids content of sludge cakes. Many attempts were made to improve the energy balance around incinerators but many of these efforts met with marginal success because the problem was not addressed from an overall systems approach.

More recently, incineration has become a target of local interest groups and in many communities has evolved into one of the most heated environmental debates of the century. Although many of the issues, such as the production of dioxins and furans, were related to the combustion of municipal garbage and had little relevance to the incineration of sludge, the public image of incineration hit an all time low. Regardless of the material being incinerated, the public perceived the emission of contaminants into the air they breathed as an involuntary health risk and essentially unacceptable, independent of the level of risk determined based on mathematical risk assessment models. Emission regulations were upgraded to address heavy metals, organics, particulates, and nitrogen and sulfur compounds. There was a significant movement from multiple hearth furnaces to fluidized bed combustors which offered increased energy efficiencies and better emission control. The technology to control airborne emissions continued to improve but the public image of incineration did not.

**Current practice**

No discussion of future trends would be meaningful without some understanding of current practice and the driving forces that are expected to induce significant changes in the future. Within the scope of this paper, it is impossible to present a comprehensive global state-of-the-art status of sludge management. However, the IAWQ Global Atlas of Wastewater Sludge and Biosolids Use and Disposal (IAWQ, 1996) does provide this kind of information for 24 different countries throughout the world, with additional overview discussions on the situation in highly urbanized areas and the European Union. This document is an excellent resource that provides information on the current status of sludge management in each country and insights into the philosophy behind the decisions.

While there is a wide variety of specific sludge management schemes in place, with the phasing out of ocean disposal, essentially all processes fall into the three broad historical categories mentioned previously; land application, landfilling and incineration/thermal technologies. It is interesting to compare, on a very broad level the different approaches that seem to be prominent in various countries. In Canada, the majority of plants employ some form of land based system but there is still a significant mass of sludge incinerated at a small number of locations. In the USA there is a strong push towards land application but a number of major incineration facilities are still in operation. In the European Union the distribution between the three options appears to be a function of the individual country as opposed to an overall trend. In Japan, there is heavy reliance on thermal based technologies such as incineration because of the critical need for maximum volume reduction.

Future sludge management trends will be impacted by the decisions and events of today. Some European countries are developing increasingly stringent metal requirements for land applied sludges. This implies that aggressive pretreatment strategies will produce very clean sludges or land application will disappear as an option if these levels cannot be achieved. The proposal by the European Union to limit the total organic carbon of landfilled material to 5% will effectively eliminate sewage sludge from this option. This has the potential to drive the industry towards incineration if land application is not an alternative option. Although public acceptance of land application is increasing due to cleaner sludges and better public education programs, negative publicity surrounding a few localized
problem sites can have widespread implications. A significant fraction of the current wastewater infrastructure expansion is occurring in developing countries and is addressing the needs of some of the largest urban centers in the world. Identifying the most appropriate sludge management strategies for cities such as Mexico City (~24 million) and Sao Paulo (~17 million) must address practical concerns that are unique to huge metropolitan areas and there is little historical information to build on.

**Future issues**

The future strategies that will be acceptable for biosolids management will be based on a combination of sound economics, reliable technology and an understanding of local needs and issues. Since biosolids management involves interaction with the community, public acceptance is a critical factor. In many cases, perception is more important than facts.

The terms “biosolids” and beneficial use” were introduced in an attempt to project a positive image for sludge by identifying that the material has intrinsic value and should be considered as a resource rather than a waste. This approach has been enthusiastically embraced in some areas, particularly the USA, but there are concerns associated with the general application of the terminology. Although it was not the original intention, there is a tendency to use these terms only in reference to options involving some form of agricultural utilization of sewage sludge. There seems to be a reluctance on the part of government and environmental groups to consider alternatives such as energy recovery from incineration, use of incineration ash as a construction material etc., as beneficial uses. The danger in this is that the public may come to view “biosolids for beneficial use” as applicable only to agricultural utilization. Although it is accepted that agricultural use has many positive aspects, it is also a fact that it is neither the only option nor necessarily the best option for any given situation. We must ensure that efforts to promote one approach to sludge management do not inadvertently create obstacles for alternative solutions.

The management of sewage sludge is often susceptible to “fallout” from other environmental issues making headlines in the news media. An example of this is the issue of organics in sludges, particularly PCBs and dioxins/furans. Because these contaminants are present in sludge, any media coverage focusing on the dangers of these substances, even in a totally different context, is presumed by the public to be applicable to sewage sludge. For example, the problems associated with the treatment of soils or transformer oils contaminated with high levels of PCB’s may be equated with PCB’s in sludges even though these levels are generally less than 2 ppm. Dioxins and furans are another issue due to their high profile. The current EPA review will recommend whether allowable levels should be set for sludges applied to land. The public may expect complete elimination but this is not practically possible in the municipal sector since they are not a result of point sources. An approach that is often used in an “environmental expose” is to identify that there are hazardous, toxic, or deadly contaminants present without ever presenting a single value for the concentrations actually measured. With today’s sophisticated analytical techniques, the mere detection of a contaminant is meaningless without an assessment of the associated risk.

The issue of privatization of wastewater treatment facilities in general and sludge management in particular, will continue to be a hotly debated issue as we move forward. Proponents of privatization argue that the private sector can finance and operate these facilities in a much more efficient manner than the public sector and make a profit for the company while reducing the cost to the municipality. Opponents of privatization complain that projected cost savings are rarely realized and that profits are more important to the company than performance. Regardless of the position on this issue, privatization in one form or another is proceeding to some degree in many countries throughout the world. This will add...
an additional element to the already complex task of evaluating and selecting the optimum sludge management strategy for any given situation.

The operational word surrounding sludge is “change”. Since change can never truly be predicted or controlled, it is essential to incorporate as much flexibility as possible into any management strategy. National and local environmental regulations change. We live in a global world; events in one area impact other areas far beyond the original regulatory jurisdiction. The US EPA is evaluating dioxins/furans in the second round of the 503 regulations. The outcome of this evaluation will impact on the direction that other regulatory bodies take. When a major food processor announces that they will no longer accept produce grown on sludge amended soil, farmers around the world get concerned about continued use of sludge. The proposed limit by the European Union on organics in landfills will definitely change the balance among management alternatives. Significant fluctuations in world energy prices will also impact the relative cost effectiveness of technologies. Moreover, sludge management failures are much more likely to make media headlines than sludge management success stories.

Future trends

Future trends will evolve rather than appear overnight. Significant investment has been committed to current practice and this infrastructure will not be discarded without valid reason. Changes will normally be phased in when an existing facility is being replaced or upgraded due to age or lack of capacity. Biosolids will continue to be viewed in the future as a resource with valuable components that should be recycled. This will result in increasing pressure to phase out the disposal of sludge in landfills. However, apart from the issue of sitting, landfills require the least sophisticated infrastructure and will continue to fill a role both as an emergency backup system and as an interim measure in developing countries. The two components in sludge that are technically and economically feasible to recycle are nutrients (primarily nitrogen and phosphorus) and energy (carbon).

Nutrients are recycled through agricultural utilization by direct application of liquid or dewatered sludge, or as components of compost or pelletized organic fertilizer. The agricultural benefit and environmental acceptability of this practice is well documented. As industrial pretreatment strategies are put in place, the levels of contaminants in sludges will continue to decrease and this will broaden the applicability of the practice. Agricultural utilization is expected to remain as a major option in the future for many countries and particularly for smaller plants, may represent the most cost effective solution.

There are many circumstances where land application of liquid or dewatered sludge is simply not viable for a variety of reasons. There may be little land available within economical transportation distances that meet the criteria set out by the local guidelines. The quality of the sludge may not meet the metal requirements specified in the guidelines. Local land use patterns may not be compatible with land application of sludge. The volume of sludge as a liquid or dewatered cake may be of such a magnitude that traffic density arising from its transportation may be unacceptable in that region. In these situations, volume reduction becomes important as a prerequisite to any resource recovery initiative.

The most common approach to volume reduction is incineration. This is not a technology that is popular with the public. Environmental concerns most often cited relate to air emissions and ash disposal. Air emissions are essentially an economic rather than a technical problem. Technology is available to meet extremely stringent air quality standards but it is expensive. Ash disposal does not generally present significant problems because heavy metals in the ash are very immobile and resistant to leaching. Incineration is one of the few technologies that can adequately deal with sludges that do not meet the requirements for agricultural use. Although improved sludge quality may be a widespread objective, it may
still be several years before some communities reduce contaminants sufficiently to allow agricultural use to be implemented. Incineration also results in the minimum quantity of material (i.e. ash) for ultimate disposal. This can be important, particularly for large municipalities, where the number of trucks moving through the neighborhood is of concern. It can be a cost-effective solution in large urban centers where the distance to available agricultural land makes transportation prohibitively expensive. It also represents a consistent year round solution with no requirement for storage facilities during winter or other weather related periods.

The energy recovered from incineration is usually based on recovering heat from the flue gas. This may be used directly in applications such as sludge drying or it may be used to generate steam to produce electricity. The most effective way to use the available energy is very much a function of the specific situation. In Canada, electricity prices are very low by world standards and the capital required to generate electricity onsite is difficult to justify economically. In other parts of the world where the price of electricity may be two to three times higher, the entire equation changes. Even though a very clear case can be made that energy recovery from the incineration of autogenous sludge cake constitutes beneficial use (Haug, 1991), it is very difficult to get both the public and regulators to accept this. Disallowing this designation simply because the process involves incineration would appear to be a complete contradiction of the original intention of the terminology.

A promising approach for efficient utilization of biomass energy is thermal conversion to liquid and solid fuels. This process involves heating dried sludge, in the absence of oxygen, to approximately 450ºC. The organic material is volatilized and when brought into contact with the remaining solid residue or char, the vapours are converted to predominantly straight chain hydrocarbons. The vapours are then condensed into a liquid oil. The key to the thermal efficiency of the system is that the remaining solid residue or char is combusted to provide heat to dry the sludge, thus providing the major energy requirement of the system.

This process has been under development for many years at both bench and pilot scale and the impact of operating parameters on oil yield and quality have been extensively documented (Bridle et al., 1990). The commissioning of a full scale plant in Perth will provide the final verification in terms of capacity, oil yield and quality, energy balances, capital costs and operating costs. The plant will also produce sufficient quantities of oil for full-scale evaluation of alternative end uses.

Thermal conversion of sludge appears to offer a unique approach which eliminates some of the problems traditionally associated with energy recovery scenarios. To begin with, a high percentage of the energy in sludge, approximately 50%, is recovered in the oil. Secondly, the recovered energy is in the form of a liquid rather than a hot gas and can therefore be stored and transported. This fact alone significantly increases the flexibility in how the recovered energy is ultimately utilized. Although use of the oil as an alternative to diesel fuel for electricity production is viable under specific electrical pricing structures, preliminary investigations suggest that there may be other potential end uses. One area that has shown promise is as an anti-stripping compound in the asphalt industry (Campbell et al., 1995). Due to the complex nature of the oil, there is potential for a wide variety of end uses that have not been evaluated at this time. Thermal conversion can provide a high degree of versatility to a sludge management strategy. It is independent of sludge quality, is a year round solution in any climate, produces the minimum volume of material for ultimate disposal and produces a product which may have the potential to generate significant revenue.

In North America and Europe, volume reduction of sludge has generally stopped with destruction of the organic fraction through combustion leaving the inorganic fraction as ash. Although there have been some minor attempts to use it in construction materials, the
ash is typically landfilled. In Japan, the development of melting and slagging technologies has focused on the end use of the inorganic residue. Depending upon the approach, end uses can range from light-weight aggregate, to tiles, to even jewellery and full-scale facilities are in operation (Spinosa et al., 1994). This approach is generally dismissed in North America as being prohibitively expensive. However, the definition of “expensive” is directly related to the options practically available. There is little to be gained by comparing expensive, thermal-based options against inexpensive land-based options when land is not available.

Over the last few years sludge management strategic planning has started to focus on multiple options to ensure flexibility for the operating entity. No sludge management alternative is immune from public opinion, political pressure, regulatory changes and fluctuating prices. The operating authority who has only one system with no contingency plan, runs the risk that if this option is forced to discontinue operation they will be faced with enormous costs for emergency disposal services until they either modify the existing system or construct a new one. Depending on the relative capacities within a multiple option system, it may be possible to switch all of the material between processes or in the worst case, emergency treatment costs would be minimized because only a portion of the sludge would be affected. A multiple use plan also allows the operator to vary the percentage of biosolids being handled by each option based on fluctuating economics resulting from external factors such as energy and fertilizer prices.

The public will continue to play a significant role in determining which sludge management options are acceptable. As sludge managers we really have only two alternatives, if we are not working with the public then we are at least perceived, to be working against them. The public will no longer tolerate the situation where a completed design is presented for their approval without any consultation. Today, the public is educated, articulate, extremely well informed and quite knowledgeable in the art of lobbying. The only acceptable approach is one of openness throughout the planning cycle and a demonstrated willingness to provide factual information to the public. The planner who ignores public opinion does so at his own peril. In many developing countries, this may not appear to be a problem currently but as environmental awareness increases, the public will demand a larger role in making decisions which they see as impacting directly on their health or quality of life.

The most important criterion in the selection of any sludge management strategy, is that the solution must be appropriate to the conditions of the site in question. There is no universal solution to the problem of sludge management. It would be ridiculous to assume that the optimum solution for a city of 20,000 people in the middle of the Canadian prairies would be the same as for a city of 10 million people in Japan. The optimum solution for any municipality will be a function of all factors that define the individuality of that location such as population, level of wastewater treatment, land use of surrounding area, topography, climate, industry, quality of sludge, etc. The selection of a strategy must ultimately be based on a true reflection of the needs of the specific community not on what is popular in another part of the country or world, or what is perceived, by some vocal component of society, as the only acceptable solution.

**Conclusions**

Predicting the future trends in biosolids management is extremely difficult because of the dynamic nature of the wastewater treatment business. The inputs from industry, government regulations and public expectations are continually changing; what is desirable today may be unacceptable tomorrow. There is no magic formula for predicting the optimum biosolids management strategy for five to ten years into the future but unfortunately, this is the time frame that planners and designers must work within. The key to dealing with the uncertainty of future external influences is to maintain an ongoing awareness of develop-
ments and provide as much flexibility in the strategy as possible. A comprehensive
proactive public outreach program will guard against the impact of opposition from special
interest groups. Diversification to multiple management strategies avoids the “all eggs in
one basket” syndrome. Selection of a management strategy based on the actual needs of the
community rather than on some artificial set of criteria is probably the single most
important component in achieving long term sustainability.

References
oil from sludge process, Wat. Sci. Tech., 22(12), 249.
sludge derived fuels, Proc. Second Biomass Conf. of the Americas, Portland, Oregon, USA.
Management Conf., Durham, North Carolina, USA.
IAWQ (1996). A global atlas of wastewater sludge and biosolids use and disposal, IAWQ Scientific and