DEVELOPMENT AND TESTING OF A SLUDGE PELLETIZER

J.K. Sial, Ijaz A. Randhawa, Ahmad Shafi and Khwaja Altaf Hussain
Faculty of Agricultural Engineering, University of Agriculture, Faisalabad

Large quantities of sewage sludge are available in Pakistan annually. Nutrient value of the sludge for soil fertilization is recognized. However, technology for conversion of the sludge into bio-solids acceptable for land applications does not exist. This provided bases for development and testing of a sludge treatment cum pelletization machine in the present study. The machine got capacity to sieve, grind, elevate, mix additives and palletize the sludge apart from drying the product to satisfy pathogen as well as vector attraction reduction requirements. The pilot-scale machine developed and tested in the present project can fill more than 160 bags of 20 kg each in a day of 8 hours. Each bag costs nearly rupees thirteen.
Keywords: Sewage sludge, pelletization machines, development, sludge treatment

INTRODUCTION

Conventionally treated municipal wastewaters contain 10-40 mg of nitrogen per liter and from a few to 30 mg of phosphorus per liter (Asano *et al*, 1985). The treated sludges got 1 to 6 percent nitrogen on a dry weight basis (Metcalf and Eddy, 1991; Dean and Smith, 1973). Rich in nitrogen and phosphorus, two elements essential for crop growth, biosolids (treated sludge) also contain micronutrients such as copper, boron, molybdenum, zinc and iron. However, heavy metals and other toxicities can have detrimental effects on crops and human health if allowed to accumulate beyond established safe limits. Both the treated wastewaters and sludges are being internationally used for soil fertilization. Spreading sewage and / or sludge in forests is time tested under European soils (Council of European Communities, 1986).

In Pakistan, only 1% of the wastewater generated is treated before returning to the rivers, which has resulted in deterioration of water quality to the extent that most rivers are now badly polluted (Anonymous, 2005). Most surface water pollution is associated with urban centres. Typically, nullahs and storm water drains collect and carry untreated sewage which then flows into streams, rivers and irrigation canals, resulting in widespread bacteriological and other contamination. It has been estimated that around 2,000 million gallons of sewage is being discharged to surface water bodies every day (Anonymous 2006).

In the area of municipal sewage treatment, only the major cities of Pakistan like Karachi, Islamabad, Faisalabad and Peshawar are providing biological treatment to a part of the municipal sewage generated. All other cities discharge their untreated sewage into the water bodies thus, heavily taxing their oxygen resources and posing a serious threat to human health and environment.

It has been estimated that presently about 24,000 dry tons of sewage sludge is annually produced by Faisalabad Wastewater Treatment Facility alone (Randhawa, 2007). Unfortunately, the sludge is disposed as landfill material in Faisalabad, whereas after necessary treatments, it can be potentially used for agricultural land applications. In view of the availability of large quantities of sewage sludge in the metropolitans as well as countless townships of Pakistan, the present research was planned with the following specific objectives:

The major objectives of the study include:

1. To develop a small-scale sludge treatment-cum-pelletizing machine in accordance with socio-economic conditions of a developing country.
2. To test the pelleting machine and its pellets to meet international standards for biosolids production.

MATERIALS AND METHODS

The sludge produced at Faisalabad Wastewater Treatment Plant (FWTP) carries a variety of objects like bits of plastics, debris, straw etc, apart from pathogens that are to be removed prior to land applications. Therefore, present project was planned for processing the sludge for its conversion into environmentally safe pellets to be used as a bio-fertilizer for field crops. The conversion processes selected for the local sludge are discussed in the succeeding sections. In view of the available literature, physics and chemistry of the local sludge, following steps were selected for processing of the material.

Processes for treatment of indigenous sludge

For beneficial use of biosolids they must meet all of the applicable requirements contained in 40 CFR Part 503, subpart B of US-EPA (US-EPA,1999c). Therefore, it is important to characterize biosolids relative to following three key regulatory parameters:

a) Pollutant concentrations
b) Pathogen reduction
c) Vector attraction reduction (VAR).

(a) Pollutant concentrations

Pollutants' concentrations of the sludge from Faisalabad Wastewater Treatment Plant (FWTP) were established prior to its processing for land applications. Data for the concentrations obtained over a period of one year have assured a continued acceptable quality of the sludge except the presence of pathogens that need to be cleared before the sludge is land applied (Randhawa, 2007).

(b) Pathogen reduction

One objective of this research was achievement of pelleted Class A biosolids with pathogens at an accepted level. For this, "Process to Further Reduce Pathogen (PFRP)" as per 40 CFR 503 biosolids rule US-EPA (1999c) was used. The employment of PFRP to Faisalabad sludge yielded that for assured control of pathogens from "biosolids in the form of small particles and heated by contact with either warmed gases or immiscible liquid must be heated to 50 ºC or higher for 15 seconds or longer". The dryer in the sludge processing line of present project was so designed to create these conditions.

(c) Vector attraction reduction (VAR)

For vector attraction reduction, US-EPA rule "Reduce moisture content of biosolids with unstabilized solids to at least 90 percent" was adopted for the vector attraction reduction. Drying system should be so designed as to achieve the desired moisture level that would be verified in the testing phase.

Selection of process combination

Keeping in view the scope of study, major objectives of the project and regulatory requirements, sludge processes were designed and machine according developed (Randhawa, 2007) using local materials and workmanship as shown in Figure 1.

Description of machine operation

The sludge processing machine (Figure 1) was developed and it is installed at the Workshops Faculty of Agricultural Engineering & Technology, University Agriculture, Faisalabad-Pakistan. Raw sludge is transported on tractor trolleys from the sludge lagoons. The machine operates in batches. For initiating the process, raw sludge is manually shoveled into the sump at the footing of the elevator, which conducts material into pan of vibrating sieve. The oversized material including plastic, metallic / glass pieces, debris, etc are separated and disposed. However, the sieved product enters into hammer mill where it is crushed into almost a powder form. This is cut off point for a batch.

The material received above is again manually shoveled into same sump at the footing of elevator. A chain-controlled lever is pulled to actuate other side of the elevator, which then conducts the material into hopper of the mixer. At this point, moisture / desired additive for moistening / enrichment of the material is added and mixed with the material for uniformity. Moistening the material is undertaken to facilitate formation of pellets. Additives can be poured in for improving the nutrient value or some physical properties of the final product. After mixer the product moves into extruder, which converts the moistened material into pellets and passes them into the drum dryer. A gas fired blower-assisted burner located at outer end of the dryer helps heating the inside of dryer where pellets move outward on the auger flights and get dried. In the dryer, pellets are given a time - temperature treatment i.e., heating the product for 72 seconds at 80ºC. This treatment satisfies the US-EPA regulatory requirement for both Pathogen Reduction and Vector Attraction Reduction criteria. The end product is considered as Class-A biosolids. Finally, a conveyor (Figure 2) conducts and stockpiles the pellets for air cooling, bagging and marketing. A pile of pellets is shown in Figure 3.

Performance evaluation of pelleting machine

Machine performance was tested under variety of operating conditions. Effects of varying levels of sludge moisture, dryer retention times and dryer temperatures on quality and quantity of the final product/pellets were examined for gain of information. Machine testing helped establishing various parameters for production of ideal quality pellets. Finally, the operational capacity of machine along with the operational cost per unit weight of material was determined to precisely understand the economic feasibility of sludge processing activity.

Testing uniformity coefficient of material

Product uniformity coefficient (UC) was evaluated for quality assessment of the processes. The diameter d_{60} and d_{10} were taken directly from the uniformity graph (granulometric curve) of the material for few samples (Jumikis, 1983). Present experiment included determination of uniformity coefficient (UC) for raw sludge and final product/pellets.

In general, three samples of materials were taken and subjected to sieving in a set of eleven mechanical sieves. For each sieve, empty weight of sieve, weight of sieve and sample, weight of material retained, percent material retained, percent material passed were all recorded. Percent material passing through a

Figure 1. A view of sludge pelleting machine
(Mechanical system developed by graduate student for his Ph. D dissertation)

Legend: 1. Sludge sump 2. Elevator 3. Chute leading to screener 4. Vibrating screen
5. Hopper on hammer mill 6. Hammer Mill 7. Screened and grinded material
8. Sludge sump (same at No.1) 9. Second leg of the Elevator in No. 2 above.
10. Chute leading to mixer 11. opper over mixer 12. Mixer 13. Extruder/Pelletizer
14. Drum Dryer 15. Burner

Figure 2. Pellets Conveyor for Stockpiling

Figure 3. A view of Pile of pellets

sieve was graphed against the mesh size of sieve on a granulometric graph / semi log paper. This provided a curve, which was used to determine two diameters i.e., d_{60} and d_{10}. Later, uniformity coefficient was calculated from the ratio of the two diameters (Figure 4). This procedure was repeated for all the other three samples and consequently an average value of the uniformity coefficient was determined.

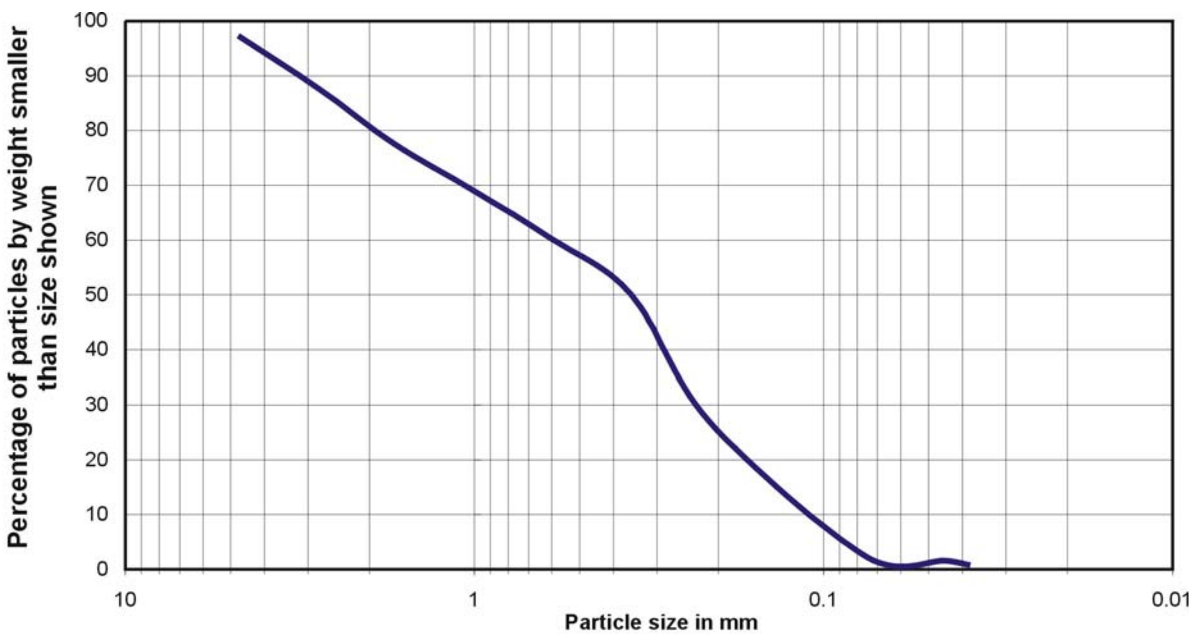

Figure 4. Uniform Granulometric Curve for Sample No. 1
[d_{60} = 0.6, d_{10} = 0.12 UC = d_{60} / d_{10} = 0.6 / 0.12 = 5]

Machine efficiency and capacity

Machine efficiency can be defined in terms of time taken by an activity / process, and both quality and quantity of the output material. Thus efforts were made to record time, measure quantity and evaluate the quality of output for different operations. Following points may be kept in view for better appreciation of the test trials.

Batch size: 150 kg for a trial
Moisture determination: Sample heating at 120 °C for 24 hours
Initial moisture levels of sludge used in testing: 22, 18 and 15 percents

Variables measured

(i) Percent recovery of material from sieving-milling and extruding-drying assemblies and times consumed
(ii) Quality and quantity of pellets for samples with varying initial moistures.
(iii) Quality and quantity of pellets for samples with varying dryer temperatures (80, 75, 70 °C).
(iv) Quality and quantity of pellets for samples with varying dryer retention times (105,100 and 98 seconds).
(v) Quality and quantity of pellets for samples with varying water levels as additive (12, 10 and 8 liters for 150 kg samples)

Machine capacity and cost analyses

There were nine batches/samples tried. Inputs and outputs of all samples along with times in total processing were gathered, and average capacity of the machine in terms of kg/hour was calculated. Similarly, capital and operational costs of the machine were considered for determination of total cost of machine for producing unit weight of material.

RESULTS AND DISCUSSION

A pelleting machine was locally developed using indigenous materials and workmanship for treatment of the sludge to satisfy the regulatory requirements for Class-A biosolids. The machine was tested for its performance as discussed next.

Performance evaluation of the pelleting machine

Investment in a mechanical system can be justified by its performance alone. Therefore, several aspects of the pelleting machine required for quality and quantity of the final product were evaluated. Performance parameters of various processes in addition to overall efficiency of the unit, were determined for the machine developed (Figure 1). Time consumed, quality and quantity of material produced and economic analyses of the sludge treatment processes were thoroughly examined for ascertaining technical viability, social acceptability and economic feasibility of this system in a developing society.

Uniformity coefficient of raw sludge

Three samples of the raw sludge were randomly taken from the piles; sun dried and put to a set of mechanical sieves. Data of each sample were separately used for Uniform Granulometric Curves as given in Figure 4 (drawn for one sample), and uniformity coefficients determined (Randhawa, 2007). Uniformity coefficients for the raw sludge were 3.31, 5.00 and 12.00. Jumikis (1983) interprets the uniformity coefficient; UC < 5 (material is very uniform), UC = 5 to 15 (material is of medium uniformity), and UC > 15 (material is very non-uniform). This suggests that the raw sludge at Faisalabad varies from very uniform to medium uniformity demanding sieving and grinding prior to pelletization.

Evaluation of pelleting performance and machine capacity

The operation of pelleting machine is distinctly divided into two parts; firstly elevating the raw sludge into vibrating sieve followed by its milling, secondly again elevating the material into mixer-hopper for mixing additives followed by extruding and drying of pellets. As the same elevator has to be used for both stages, total operation has to be split in two steps and accordingly the overall performance had to be studied in two steps.
As initial moisture content of the material may affect the machine performance, sludge samples varying in moisture content (22, 18 and 15 percent dry bases) were selected for trials. There were three samples belonging to each moisture level. Thus, there were nine-samples, each weighing 150 kg, to be used during trials for investigating machine capacity and related parameters.

Performance of sieving-milling assembly

The effect of sludge moisture on the efficiency of sieving process is apparent (Figure 5). The residue at the sieve decreased with the decreasing sludge moisture. This suggests that sieving efficiency improves by lowering the sludge moisture. However, it may be kept in view that decreased moisture would later need additional water or other additives for formation of paste in the mixer-extruder assembly. The residues at sieve were 1.25, 1.13 and 1.08 kg for 22, 18 and 15 percent moisture levels respectively. The difference in the values of residues is quite insignificant compared with the respective difference in the moisture levels. It also means that reducing the moisture in the sludge from 22 to 15 percent is not paying compared to the labor, space and inconvenience involved in sun drying of the sludge. Therefore, sludge at higher moisture (22%) should be preferred to that of lower one.

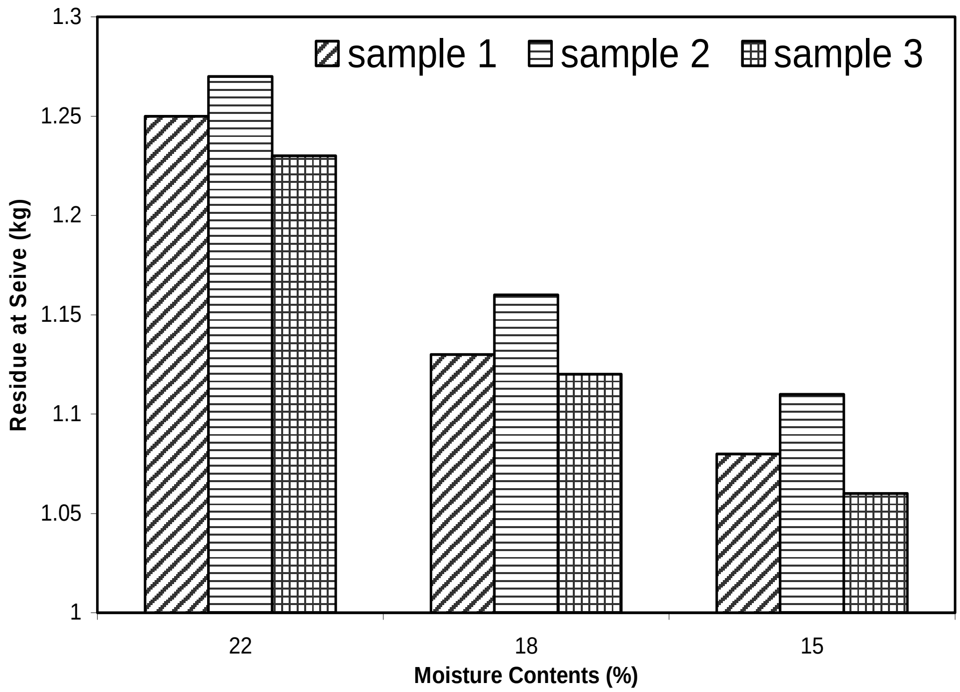

Figure 5. Moisture level versus residue at the sieve

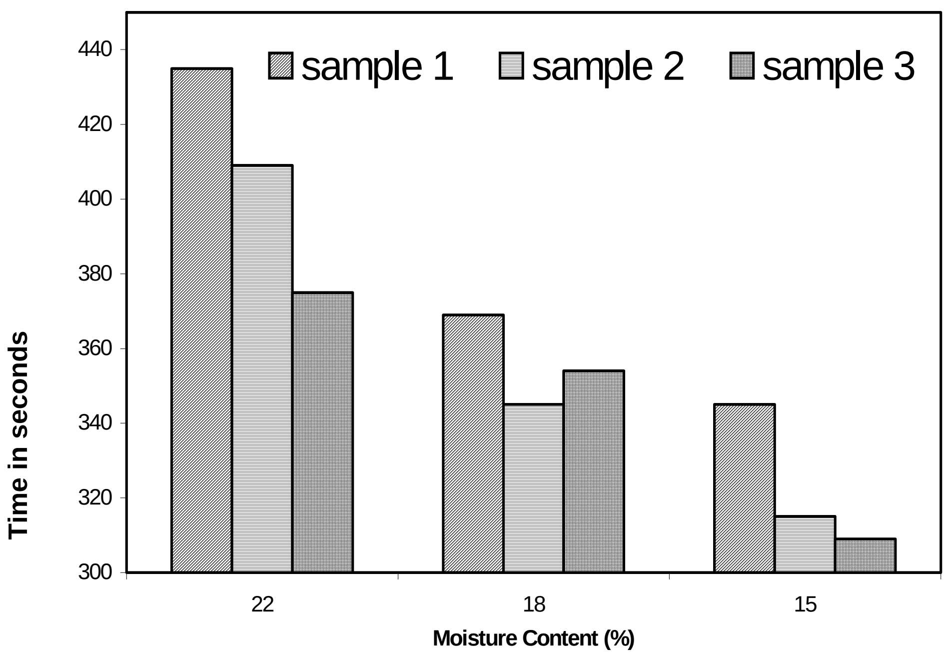

Figure 6. Moisture level versus time for completion of operation

The average times consumed in sieve-milling assembly were 406, 357 and 323 seconds for the samples with 22, 18 and 15 percent sludge moisture (Figure 6). It is obvious, time decreased with the decreasing moisture, in turn improving the machine efficiency. The time saving for one ton of sludge during sieving-milling assembly cannot be more than ten minutes for the samples with 22 and 15 percent moisture levels. Energy consumption of the motors driving the assembly is few kWh for one ton of material, and therefore unimportant. Thus time saving is not convincingly large to justify the efforts involved in drying the sludge to level like 18 or 15 percent before processing.

Performance of Mixer, Extruder and Dryer Assembly

All the nine samples grinded by the sieving-milling assembly were stacked for next operation. There were already three distinct groups of nine samples, that is, as per initial level of moisture in the sludge. Each group was further studied for investigating the effects of new variables in the succeeding operations. The end products (pellets) were analyzed for product output, time for batch completion, uniformity coefficient, bacterial count and vector attraction reduction (Table 1).

The major reasons for treatment of the Faisalabad Wastewater Sludge were to satisfy Class-A biosolids regulatory requirements of 'Pathogen Reduction' and 'Vector Reduction'. Results indicate that a non-detectable level of bacterial counts for all the samples (Table 1), and moisture levels of the final product being less than 10 percent satisfy the regulatory requirements for land application of the sludge pellets.

(b) Effect of dryer retention time on quality parameters of pellets

There is always a chance to increase / decrease the retention time of the drying pellets by adjusting angle of inclination of dryer. A change in the angle modifies the retention time of the pellets resulting in varied drying. For this purpose, three retention times (105, 100 and 98 seconds) were arranged. The drying times selected here were higher than the designed time of 72 seconds in this project. The reason for selection of the higher times was gain of additional information in terms of the quality of final product i.e. pellets.

Table 1. Product quality parameters as affected by variable conditions

Sample moisture (%)	Sample weight (kg)	Dryer Temp. (°C)	Time in dryer (s)	Water added *(l)*	Output from unit (kg)	Time for batch	UC** of pellets	Bacterial count (MPN/g)	Moisture in pellets (%)
22	148.45	80	72	10	124.32	11 Min. 55 Sec.	9.13	ND*	8
	148.33	75			127.69	12 Min. 35 Sec.	8.33	ND	10
	148.47	70			127.80	12 Min. 45 Sec.	10.47	ND	11
18	148.64	80	105	10	127.35	11 Min. 55 Sec.	16.65	ND	7
	148.37		100		128.76	12 Min. 15 Sec.	12.44	ND	7
	148.48		98		129.26	12 Min. 36 Sec.	11.39	ND	8
15	148.32	80	72	12	133.20	12 Min. 37 Sec.	15.00	ND	9
	148.59			10	133.30	11 Min. 30 Sec.	9.00	ND	7
	148.54			8	131.72	11 Min. 18 Sec.	13.00	ND	6

** Not detectable, ** UC = Uniformity coefficient*

(a) Effect of dryer temperature on quality parameters of pellets

The product outputs from mixer-dryer assembly were 124.3, 127.7 and 127.8 kilograms for 80, 75 and 70 ºC in the dryer respectively (Table 1). A higher temperature of 80 ºC reduced the product output compared with other two temperatures and the reduction was obviously due to reduced moisture content.

Output of pellets from the assembly slightly decreased with increasing time due to over drying of the material (Table 1). Uniformity coefficient increased with the increasing retention time. This is suggesting that an increased retention time results in additional drying of pellets consequently deteriorating the quality of final product. The bacterial counts are once again in the non-detectable range. Moisture contents of the end product / pellets for all the three samples are less than 10 percent, which is also in conformity with regulatory requirement for vector reduction criterion.

It is interesting to observe that the dryer retention times selected over and above the designed time of 72 seconds are undesirable due to non uniform end product in spite of the fact that all three samples fulfill regulatory requirements. Observations suggest that the retention times higher than 72 seconds may be avoided in practice.

(c) Effect of water quantity on quality parameters of pellets

Generally moistening the sludge is required for formation of cake and consequently pellets in the extruder. For this purpose, water / molasses are added during mixing operation. However, the quantity of water definitely determines the quality of final product. In view of this, three levels of water (12, 10 and 8) were selected and studied for their effects on quality parameters of the end product i.e. pellets in order to make some useful conclusions for future practice.

Effects of changing the water levels during mixing of the sludge on various parameters are given in the (Table 1). Considerable discussion on various parameters and their relationships has been made in the earlier sections. However, the parameter of major interest here is uniformity coefficient (UC), which significantly varied with the changing water levels. The UC values were 15, 9 and 13 for 12, 10 and 8 liters of water respectively. At higher water level (12 liters), the formation of pellets remains incomplete, as the paste is perhaps thinner than desired. At lower moisture (8 liters) again the consistency of paste seems inappropriate for formation of pellets. the difference in the appearance of piles for two levels of water are shown in Figure 5.9 and 5.10. In fact, detailed investigations are required to formulate best practices for ideal quality of pellets.

Overall capacity of pelleting machine

Average times for processing 150 kg sludge in the sieving-milling and mixer-extruder-dryer assemblies were 362 and 722 seconds respectively. Thus the total time amounts to 1084 seconds, whereas the average output of the pellets was 129.13 kg. The overall capacity of the machine is, therefore 428.77 kilograms per hour. The pilot-scale machine developed and tested in the present project can fill more than 20 bags of 20 kg each in an hour or 160 bags in a day of 8 hours. Thus the present machine may be regarded as a research-cum-commercial model.

Cost analyses of pelleting the sludge

Although the first requirement of a machine is to perform the intended function satisfactorily, however, economic aspect of the machine plays a vital role in its acceptability by the end user. Economic feasibility of processing and pelleting the raw sludge was, therefore, worked out. Total cost incurred in developing the overall system was Rs. 10, 33,000/- including equipment, civil, electrical, shed and installation costs. Cost of operation was calculated using the procedure described by (Kepner *et al.* 1978*).* The cost per bag of 20 kilograms was 13 rupees for the bio-fertilizer developed using sewage sludge.

CONCLUSIONS

The sludge of FWTP, is moderately rich in macro and micro nutrients, and the pellets produced by employing newly developed machine are very tough and durable and having potential for their marketability in bagged form. The production cost of these pellets is also moderate and for these reasons these pellets may be beneficially used in lawns, gardens, racecourses, grassy lands and silviculture. Being Class A biosolids, these pellets are safe to be applied without any restrictions. The pilot-scale machine developed and tested in the present project can fill more than 160 bags of 20 kg each in a day of 8 hours. Each bag costs nearly rupees thirteen.

REFERENCES

Anonymous. 2005. State of the Environment Report. Ministry of Environment, Government of Pakistan, Islamabad.

Anonymous. 2006. Pakistan Strategic Country Environmental Assessment Report. Rising to the Challenges. Ministry of Environment, Government of Pakistan.

Asano, T., R.G. Smith and G. Tchobanoglous. 1985. Municipal wastewater treatment and reclaimed water characteristics. Pp. 1–26. In Irrigation with Reclaimed Municipal Wastewater- A Guidance Manual. Chelsea, Mich.: Lewis Publications.

Council of European Communities. 1986. Council Directive on Protection of the Environment. Community Legislation in Force. Document 386L0278. On-Line; http://europa.eu.int/eur-ex/en/lif/dat/1986/en_386L0278.html.

Dean, R.B. and J.E. Smith, Jr. 1973. The properties of sludges. In Recycling of Municipal Sludges and Effluents in Land. Proceedings of July 9–13 Conference. National Association of State Universities and Land-Grant Colleges, Washington, D.C.

Jumikis, A.R. 1983. Book on Soil Mechanics. D. Van, NOST RAND Company, Inc., Princeton, New Jersey.

Kepner, R.A., R. Bainer and E. L. Barger. 1979. Principles of Farm Machinery. Third Edition. CBS Publishers & Distributors. 485 Jain Bhawan, Bhola Nath Nagar, Shahdara, Dehli-1, India.

Metcalf and I. Eddy. 1991. Wastewater Engineering: Treatment Disposal and Reuse. New York: McGraw-Hill.

Randhawa, I.A. 2007. Process design, development and testing of Low-cost biosolids pelletizing machine. Ph D Dissertation. Department of Structures and Environmental Engineering, University of Agriculture, Faisalabad, Pakistan

US-EPA. 1999c. Standards for the use or disposal of sewage sludge. Proposed rule. Federal Register. 64(246):72045–72062pp.