Critical factors for implementing sludge processing of the Rome Wastewater Treatment Plants

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Abstract The use of sludge thermal drying after mechanical dewatering implies a sharp increase in capital costs but can be effective in reducing both transport and disposal costs. In this paper the most critical factors affecting economics in implementing with sludge thermal drying the four wastewater treatment plants serving the city of Rome are discussed. As alternatives, replacement of belt presses with filter presses in the plant of Rome East, due to the low concentration of sludge cake (18%) presently produced, and centralised treatment in the plant of Rome South of the sludge produced in this plant and in the plant of Rome Ostia are also considered. Thermal drying appeared more convenient especially when dewatering operation is poorly performed (Rome East), but in the large plants (Rome South alone or with Ostia) the upgrading of the plant is always economical. Other contingent and local situations can also play an important role in this prospect (distance from the landfill site, transport and disposal unit costs), thus making not convenient the adoption of thermal drying for the plants of Rome North and Ostia. For disposal cost lower than 52 ECU/t replacement of the present belt presses with filter presses in Rome East plant is more advantageous than the construction of a drying plant.

Keywords Capital costs; mechanical dewatering; operating costs; sewage sludge; upgrading; thermal drying

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Introduction

The management of sewage sludge is becoming of even greater concern since the generated volumes are increasing as a result of extended sewerage and advanced wastewater treatments due to progressive implementation by different European Union Countries of the Directive 271/91. The typical disposal options face growing difficulties due to sludge contamination, strict disposal criteria and the general lack of suitable sites at convenient distance and costs. Operators of the wastewater treatment plants have to struggle day by day with new restraints and possible opposition from public opinion to activities and operations linked to sludge disposal. Flexibility in sludge management appears, therefore, nowadays very important to open different possibilities in case of crisis of the current disposal system. In this framework thermal drying could be effective in solving several problems, reducing drastically the sludge volume to be disposed of and consequently also the odour emissions, being also compatible both with agricultural use, landfilling and incineration disposal. A technical and economical study was, therefore, carried out to investigate how different factors (size of the plant, performance of dewatering operation, disposal unit cost) affect the possible convenience in upgrading a wastewater treatment plant with a sludge thermal drying process or as an alternative with a new mechanical dewatering system. This study was applied at the situation of the four treatment plants serving the city of Rome.

Design criteria of sludge thermal drying process

The flow sheet of the sludge thermal drying process used for the plant upgrading is shown in Figure 1. The adopted process is based on direct contact of the sludge to be dried and of the hot gases and in the subsequent treatment of the flue gas in a washing column and in a biological filter. After washing, part of the gas is recycled back to a mixing chamber for cooling

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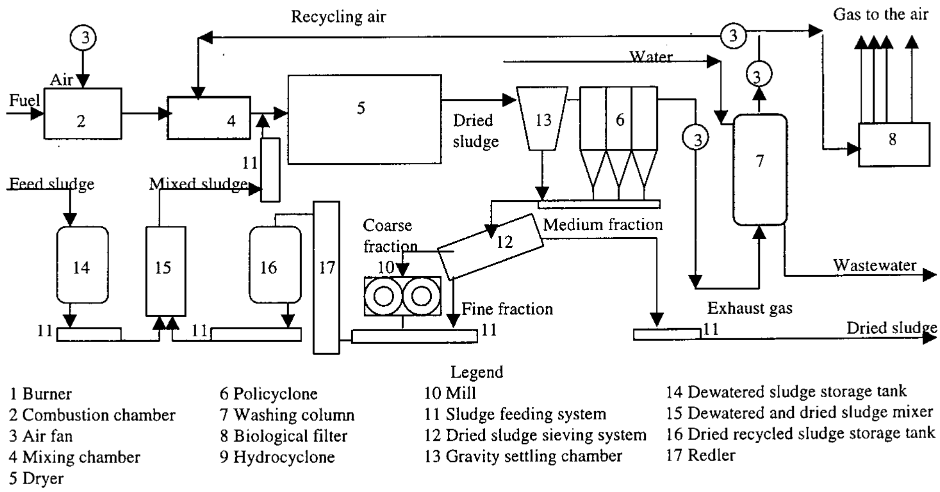

Figure 1 Typical flow sheet of sludge thermal drying process by direct contact

the gases deriving from fuel combustion to a temperature lower than 400°C before entering the dryer. Also part of the dried product has to be recycled to increase the solids concentration of the sludge to be dried to at least 45%. This allows to avoid clogging inside the rotating dryer and also to increase the specific surface, where evaporation occurs, with great advantages in equipment performance.

For design purpose the humidity and the temperature of the exhaust gas from the dryer were kept at 0.245 kg of water/kg of dried air and 120°C, respectively. This guarantees the efficiency of the process avoiding saturation inside the dryer. The gas is treated by a gravity settling chamber and a policyclone where dust is collected. The dried sludge with a residual moisture of 10% by weight is sieved in order to recover three fractions: the coarse and the finest ones are mixed together with the dust and are recycled to a mixing chamber where feed sludge is conditioned to the proper cake concentration. The exhaust gas is washed and cooled to a temperature of about 55°C, thus obtaining also a dehumidification. The great part (up to 80%) is then recycled to the mixing chamber, while the residual one is finally treated by a biological filter to get rid of malodorous substances and discharged to the atmosphere.

For design purpose the following parameters were fixed:

- combustion air: temperature 15°C, humidity 0.008 kg/kg dried air;
- dried sludge temperature from the dryer: 80°C;
- recycled sludge temperature: 70°C;
- excess air for methane combustion: 20% with respect to the stoichiometric value;
- heat losses from the combustion chamber and from the dryer: 1% and 7% of the input heat, respectively.

The drying plant is continuously operated for 24 h/d and 350 d/year.

Upgrading of the wastewater treatment plants of Rome

Present situation

Table 1 shows the main characteristics of the four wastewater treatment plants serving the city of Rome: Rome South, Rome East, Rome North and Rome Ostia.

Costs of chemical conditioning, mechanical dewatering, transport and disposal for the four plants are reported in Table 2. Costs of personnel were evaluated considering the number of people involved in dewatering operation in each plant and the unit costs, which differ for the four treatment plants (higher in Rome East, lower in Rome North). For maintenance

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Table 1 Main characteristics of the wastewater treatment plants of Rome

Treatment plant	Capacity of treatment plant: Millions inhabitants	Capacity of treatment plant: Flow rate (m^3/s)	Dewatering machines: Type	Dewatering machines: Typical parameter	Dewatering machines: No. of units	Conditioner type and dosage (kg/t dry solids)	Production (t/year): Conc. >25%	Production (t/year): Conc. 20–25%	Production (t/year): Conc. <20%	Total product (t/year)	Average conc. (%)
Rome South	1.6	8.5	Filter press Belt press	[a]10 m^3 [b]2 m	3 6	$FeCl_3$ (102) +Lime (372) Cationic poly-electrolyte (9)	59,351	6,523	741	66,615	34
Rome North	0.78	4.1	Filter press	[a]15 m^3	2	$FeCl_3$ (90) +Cationic poly-electrolyte (5)	25,544	1,101	315	26,960	34.5
Rome East	0.8	4.3	Belt press	[b]2 m	4	Cationic poly-electrolyte (12)	542	6,825	26,231	33,598	18
Rome Ostia	0.1	0.5	Centrifuge	[c]25m^3/h	2	Cationic poly-electrolyte (28)	560	6,149	6,441	13,150	20
Total	3.28	17.4					85,997	20,598	33,728	140,323	29

[a] Chamber volume;

[b] Belt width;

[c] Maximum input flow rate

Table 2 Present costs of conditioning, dewatering, transportation and disposal (1999)

Dewatering and disposal costs (Euro/year)	Rome South	Rome North	Rome East	Rome Ostia
<u>Dewatering</u>				
Personnel (42,100 Euro/year/person Rome North, 44,700 Rome South and Ostia, 50,000 Rome East)	541,579	421,053	136,842	243,684
Electric energy (0.053 Euro/kWh)	83,684	13,158	15,263	33,684
Conditioners (44.5 Euro/t lime, 129.7 Euro/t ferric chloride, 3.68 Euro/kg polyelectrolyte Rome South, 2.29 Euro/kg polyelectrolyte Rome North and Ostia)	760,000	271,053	172,632	159,474
Washing water (0.13 Euro/m^3)	5,789	474	54,211	0
Maintenance	210,526	65,789	44,211	4,737
Amortisation of electromechanical units	691,579	153,684	171,579	52,632
Amortisation of civil works	89,474	82,105	25,789	3158
Total costs of dewatering (Euro /year)	2,382,631	1,007,316	620,527	497,369
<u>Disposal</u>				
Transport	834,211	276,842	504,211	125,263
Post conditioning at the disposal site with lime	15,789	0	18,947	16,842
Landfill disposal	2,084,737	826,316	1,460,000	557,368
Post conditioning+transport+disposal (Euro/year)	2,934,737	1,103,158	1,983,158	699,473
Total (dewatering+disposal)	5,317,368	2,110,474	2,603,685	1,196,842
Unit total cost (Euro/t sludge cake)	79.82	78.28	77.49	91.01

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Table 3 Unit costs of sludge transport and disposal in landfill

	Cake concentration			
	>25 %	20÷25 %	<20 %	
Unit cost for disposal (Euro/t)	30.00	41.58	44.21	
	Wastewater plant			
	Rome South	Rome North	Rome East	Rome Ostia
Unit cost for transport (Euro/t)	12.53	10.26	15.00	9.53

a fixed rate with respect to electromechanical costs was considered: 5% for filter presses, 3% for belt presses (Rome East) and 1% for centrifuges and belt presses (Rome South). The other operating costs were evaluated on the basis of the unit costs reported in Table 2. An interest rate of 8% and periods of 25 years for civil works and 15 years for electromechanical equipment were considered for amortisation. Capital costs were provided by the operator of the plants (ACEA). Disposal of sludge cake is nowadays operated at the landfill site of Malagrotta, where a post conditioning with lime is carried out to increase cake concentration if not high enough. The transport costs differ as a function of distance (Table 3) and the disposal costs depend on the cake concentration (Table 3). These costs are generally lower than the medium ones presently charged in Italy. The unit costs for transport and disposal vary between 40.91 Euro/t of wet cake (Rome North) and 59.03 (Rome East). Total unit costs of sludge dewatering and disposal are quite close for the plants of Rome South, North and East (77.49–79.82 Euro/t sludge cake) while in the case of Rome Ostia it is considerably higher (91.01 Euro/t sludge cake).

Upgrading of the plants with sludge thermal drying

Design of drying plant was carried out for each facility considering the peak monthly production of cake together with the relevant solid concentration. Therefore some differences can be observed comparing Tables 1 and 4. For the plants of Rome South and Ostia a centralised treatment in the former plant was also considered as an alternative.

These two plants, in fact, are quite close (about 15 km) and linked by a highway; moreover, the capacity of the Rome Ostia plant is not so large to justify the installation of a small single drying plant. Capital costs of the sludge thermal drying plant were provided by a commercial company and they include materials, construction, pre commissioning, commissioning, start up and engineering. Table 4 shows the main characteristics of the different plants to be applied for the different options and Table 5 the capital and operating costs. The specific costs of sludge drying vary considerably, according to cake concentration, from 66.99 (Rome South) to 252.75 (Rome Ostia) Euro/t of dry solids. The size of the plant also has an effect on total unit cost: in fact the unit costs are higher for smaller plants even if cake concentrations are quite close (Rome South and North and Rome East and Ostia).

Figure 2 shows the different specific operating costs in drying plants (fuel, electric energy, personnel, amortisation and maintenance) as a function of evaporating capacity. While fuel, electric energy and maintenance are quite constant, personnel and amortisation display a sharp decrease thus confirming that plant capacity has a strong influence on total operating costs.

Convenience in adopting sludge drying can be evaluated comparing total present costs with those relevant to the plants upgraded with the new treatment system, considering disposal of the dried sludge in the same landfill site. The upgrading would be still more convenient if

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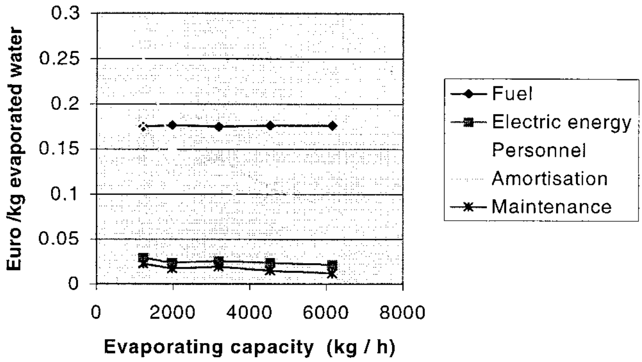

Figure 2 Specific operating costs of sludge drying plant versus evaporating capacity

Table 4 Main characteristics of the sludge drying plants to be applied to the wastewater treatment plants of Rome

Main characteristics of drying plants	Rome South	Rome North	Rome East	Rome Ostia	Rome South +Ostia
Maximum cake production (t/d)	216.74	104.43	132.85	49.24	265.98
Mean concentration (%)	33.58	34.39	16.94	17.66	30.95
Maximum evaporation rate (kg water/h)	5,661	2,689	4,494	1,649	7310
No. of drying units	2	1	2	1	2
Nominal evaporating capacity (kg water/h)	6,000 (3000×2)	3,000	5,000 (3000+2000)	2,000	7,000 (3000+4000)
Maximum production of dried sludge (kg/h)	3,368	1,662	1,041	403	3,771
Maximum production of exhaust gases (Nm^3/h)	7,631	3,626	5,998	2,203	9,810
Mean consumptions					
Methane (Nm^3/d)	12,137	5,302	8,481	3,241	16,461
Electric energy (kWh/d)	4,896	2,136	3,758	1,608	5,910
Washing water (m^3/d)	1,584	686	1,102	420	1,812

an alternative option is available (agricultural utilisation, use in cement factories as fuel, combined incineration with solid wastes).

In Table 6 the comparison of disposal costs of the two options (with and without sludge drying) are reported. It may be seen that implementation of the plant is convenient for Rome South and East where cake production is considerably high. Relative saving with respect to present situation is very relevant for Rome East plant where 7.4 years are sufficient for the pay-back. This situation is strongly influenced by the disposal costs charged when cake concentration is lower than 20% (44.21 Euro/t) which are about 50% higher than those when the concentration is higher than 25% (30 Euro/t). Moreover, transport costs for Rome East plant are the highest ones, thus making the present situation quite critical in this plant. The Rome North plant, whose capacity is the same as that of Rome East, has a very efficient dewatering system and, therefore, does not present any advantage in implementation. The upgrading of Rome Ostia plant is not convenient because of its small capacity but a joint treatment of sludge of this plant and of that of Rome South appears very interesting.

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Table 5 Capital and operating costs of the sludge drying plants to be applied to the wastewater treatment plants of Rome

	Rome South	Rome North	Rome East	Rome Ostia	Rome South +Ostia
Capital costs					
Civil works (Euro)	368,421	263,158	368,421	263,158	368,421
Electro mechanical equipment (Euro)	3,157,895	1,578,947	2,894,737	1,315,789	3,421,053
Total capital costs	3,526,316	1,842,105	3,263,158	1,578,947	3,789,474
Amortisation and operating costs					
Personnel (Euro/year)	294,737	252,632	294,737	252,632	294,737
Electric energy (Euro/year)	90,000	39,474	69,474	29,474	108,947
Methane (Euro/year)	670,526	293,158	468,947	178,947	909,474
Maintenance (Euro/year)	55,789	27,895	51,053	23,158	60,000
Civil works amortisation (Euro/year)	37,368	26,842	37,368	26,842	37,368
Equipment amortisation (Euro/year)	368,947	184,211	338,421	153,684	399,474
Total operating costs (Euro/year)	1,517,367	824,212	1,260,000	664,737	1,810,000
Specific costs					
Specific cost (Euro/t dewatered sludge)	22.78	30.57	37.50	50.55	22.69
Specific cost (Euro/t dried sludge)	66.99	88.61	208.34	252.75	71.60

Table 6 Comparison of disposal costs in present and future situations

	Rome South	Rome North	Rome East	Rome Ostia	Rome South +Ostia
Total disposal costs in the present situation (Euro/year)	2,934,737	1,103,158	1,983,158	699,473	3,634,210
Total disposal costs in the future situation (Euro/year)					
Thermal drying	1,517,367	824,212	1,260,000	664,737	1,810,000+ 94,211*
Transport of dried sludge to the landfill site	309,474	105,789	93,684	23,684	340,526
Disposal of dried sludge in landfill	741,579	308,947	187,368	75,263	815,789
Total	2,568,420	1,238,948	1,541,052	763,684	3,060,526
Annual saving in implementing the plant (Euro/year)	366,317	–135,790	442,106	–64,211	573,684
Relative saving with respect to the present situation (%)	12.48	–12.31	22.29	–9.18	15.78
Pay-back of drying plant= Capital costs/Annual saving (years)	9.63	–	7.38	–	6.61

* Cake transport cost from Rome Ostia to Rome South

Upgrading of sludge dewatering system

An alternative solution in upgrading the wastewater treatment plant is replacement of sludge dewatering machines with new equipment to reach higher concentrations and to decrease disposal costs. This option was studied with reference to Rome East plant where the present situation appears more critical. The possible use of filter presses was considered instead of that of belt presses.

The design of filter press plant was carried out considering a total sludge volume to be processed of 186,393 t/year at 3% dry solids. Lime and ferric chloride are used as conditioners at dosages of 35 and 8% (with respect to dry solids), respectively. A cake concentration of 35% is expected from dewatering and two units are therefore required to treat the total amount of sludge, considering five cycles of filtration each day for about 3 h/cycle (15 h/d×260

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Table 7 Capital and operating costs for the upgrading of the Rome East plant with filterpress units

Capital costs Euro (1999)		
Electro mechanical equipment	**Civil works**	**Total**
2,189,474	257,895	2,447,368

Operating costs Euro/year (1999)	
Amortisation of the old machines	171,579
Amortisation of the new machines	279,474
Personnel	210,526
Electric energy	6,842
Conditioners	232,105
Maintenance	65,263
Total	963,790

Table 8 Comparison of different dewatering systems for Rome East plant

Present situation	
Operating costs of belt pressing (Euro/year)	620,527
Disposal costs (Euro/year)	1,983,158
Total costs (Euro/year)	2,603,685
Upgrading of the plant with filter presses	
Operating costs of filter pressing (Euro/year)	963,790
Transport costs (Euro/year)	338,249
Disposal costs (Euro/year)	676,500
Total costs (Euro/year)	1,978,539
Saving with respect to present situation	625,146
Relative saving with respect to the present situation (%)	24.01
Pay-back = Capital costs/ annual saving (years)	3.91

d/year operating time). Total cake production was calculated as 22,550 t/year corresponding to a volume of 20,295 m^3/year (1.111 t/m^3 of wet cake). A chamber volume of 7.8 m^3 for each dewatering unit was calculated and a commercial unit of 8.1 m^3 was finally chosen. Table 7 shows capital and operating costs for upgrading of the plant with the new dewatering system.

Table 8 shows a comparison of total costs of sludge dewatering and landfill cake disposal for the old and new situations: in the latter case amortisation of the present belt presses was considered as additional cost. Considerable saving (24% with respect to present situation) can be obtained replacing belt presses with filter presses and capital costs can be repaid in about four years. Total saving is much higher than that obtainable by installing a new drying process.

Influence of disposal cost on convenience of plant upgrading

To generalise the conclusion of this study, an analysis of sensitivity of sludge landfill disposal costs on savings obtainable with plant implementation either by thermal drying or mechanical dewatering was conducted. The annual saving with respect to present situation vs. disposal costs are reported in Figure 3. The unit transport costs are considered constant in both the cases for each plant according to those reported in Table 3.

Disposal costs display the major influence on potential saving for the largest plants (Rome South and Rome South+Ostia) where for each increase in disposal costs of 1 Euro/t an increase in annual saving with implementation of the plant of 40,000–50,000 Euro/year can be obtained. In the other situations this incidence is less marked varying the specific annual saving from 10,000 Euro/year (implementation of Rome East plant with filter presses) to 170,000 (Rome North with drying) to 280,000 (Rome East with drying) for each increase of disposal cost of 1 Euro/t. It is interesting to note that the implementation of Rome North and Ostia plants would be convenient with disposal costs over 40 and 55 Euro/t, respectively. As for Rome East plant, thermal drying would be more economical than filter press dewatering at disposal costs over 52 Euro/t.

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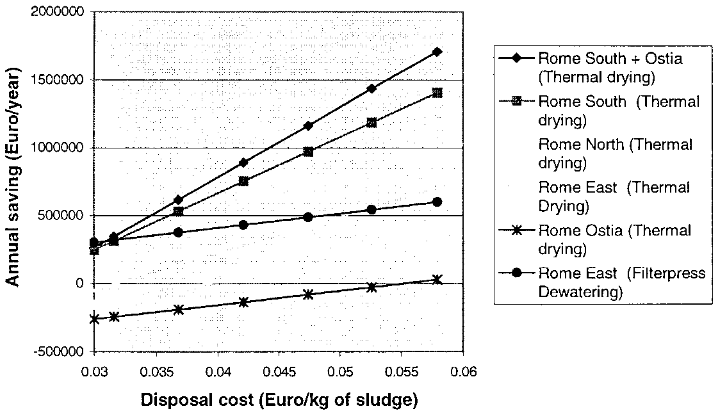

Figure 3 Influence of disposal costs on the annual saving in sludge management by plant implementation

Conclusions

At present Rome is served by four wastewater treatment plants: one very large (Rome South), with a total capacity of 1.6 millions inhabitants, two medium – large (Rome North and East) of approximately the same size (800,000 inh.) and one quite small (Rome Ostia) serving the seaside area (100,000 inh.). The sludge is totally disposed in the landfill site of Malagrotta where the disposal costs are charged according to the cake concentration (30–44.21 Euro/t), being lower then the medium ones in Italy. Mechanical dewatering is performed with filter presses in Rome South and North plants, with belt presses in Rome East (some sludge is also dewatered by belt presses in Rome South) and with centrifuges in Rome Ostia. The huge amount of sludge to be disposed and the poor cake concentration for the plants of Rome East and Ostia suggest to implement the sludge processing to reduce as much as possible disposal costs. This study put in evidence that sludge thermal drying is an advantageous option for the plants of Rome South (in this plant the sludge produced in Rome Ostia can also be treated) and East, while at the present disposal costs it is not convenient for the plants of Rome North and Ostia. If disposal costs increased over 40 and 55 Euro/t, sludge drying would be economical also for these plants. Replacement of the present belt presses with filter presses in Rome East plant is also a good solution with higher savings with respect to thermal drying up to disposal costs of 52 Euro/t.

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