INTEGRATION AND OPTIMISATION OF URBAN SANITATION SYSTEMS

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ABSTRACT
This article presents the programme of the Swedish-Polish research project and some possibilities of future activities. This project is realized in co-operation between Royal Institute of Technology (Sweden) and technical universities in Krakow, Gdansk, Bielsko-Biala and Gliwice (Poland). Increased integration, regional approach and material and energy recovery are new trends in development of wastewater and solid waste handling systems in urban areas. Costs and benefits associated with the implementation of new methods, technologies and systems have not yet been fully evaluated. The goals of this presented project include performing such cost-benefit analysis, definition of new approaches to sanitation system integration, evaluation of the existing techniques for material and energy recovery, and developing the theoretical basis for new technologies.

KEYWORDS
Energy recovery; product recovery; municipal solid waste handling; sanitation systems; system integration; wastewater treatment

PROJECT PROGRAMME

Background

Urban sanitation systems comprise wastewater and solid waste handling which both are strongly connected to energy management. Biogas produced in digestion chambers at wastewater treatment plants and at municipal landfills may be used for electric power and heat generation. Incineration of municipal solid wastes, possible together with municipal sewage sludge, is another important source of electric power and heat. Heat pumps are more and more often used for heat recovery from municipal wastewater. Electric power produced can be supplied to the distribution nets and the heat can be supplied to district heating systems.

Traditional approach to wastewater, municipal solid waste, and heat management is to perceive them as separate systems. In larger communities these functions are even administrated by separate departments. In smaller ones, such functions may be integrated within one technical department, but even then with limited coordination with other communities.

For recent years it has been recognized that existing systems of wastewater, solid waste and district heating management within a single community are not operating in optimal way, and they could be improved through:

- Increased integration of municipal wastewater and solid waste handling and their combination with energy sector (biogas, district heating). Important benefits may include improved technical functions through reducing barriers between various sectors, opportunity of setting up larger organizations with possibility to employ highly qualified specialists, simplification of fee collection system, less environmental impact due to more effective operation and more opportunities for reuse of resources.
- More regional approach to wastewater and solid waste handling in combination with energy recovery, especially in regions with small municipalities and in districts with the low population density. This would allow for creation of larger institutions for ensuring better technical and administrative capacities for performing those functions. For example, economic effects of an incineration plant depends directly on the plant's capacity.

Involved universities

The project on "Integration and optimisation of urban sanitation systems" is realized within the Visby Programme, which has the general objective to strengthen co-operation and links between the countries of the Baltic area, Belarus and Ukraine in the field of education and research.

The network of researchers from five participating universities have been created in order to cooperatively study the problems pointed out in the project programme.
The involved universities are:

1. Cracow University of Technology:
   - Institute of Water Supply and Environmental Protection
   - Institute of Heat Engineering and Air Protection
2. Technical Humanistic Academy (ATH) at Bielsko- Biala:
   - Institute of Environmental Engineering and Protection
3. Technical University of Gdansk:
   - Center for Environmental Studies
4. Silesian University of Technology:
   - Department of Environmental Biotechnology
5. Royal Institute of Technology (KTH):
   - Department of Land and Water Resources Engineering

Project goals and objectives

Increased integration and regional approach are the present trends for making municipal wastewater and solid waste more effective and to coordinate them with energy recovery systems. Advantages and disadvantages of such trends have not yet been evaluated in detail. The goal of this project is to analyse them and to evaluate these trends from the following standpoints:

- permitted emission standards
- the need for resources' reuse
- environmental effects
- economy
- public acceptance

Polish-Swedish cooperation will help in dissemination of the results obtained in this project.

In Sweden, especially much attention is paid to phosphorus recovery from wastewater and solid waste. The national goal has been set in the report to the government that by year 2001 at least 75% of phosphorus should be recovered without any harm to human health and natural environment. This goal has been, after evaluation by the Swedish Environmental Agency, changed to the national goal of phosphorus recovery of 60% before year 2015. Sewage sludge incineration will require such technologies, which would allow for phosphorus recovery before incineration or from the ash after incineration. European Chemical Industry Council (CEEC) set a goal that at least 25% of recycled phosphorus should be reused. This goal will have an effect on many European countries.

Especially, the interesting research areas in Swedish-Polish research cooperation are: (i) evaluation of costs and benefits of integration of phosphorus recovery from solid waste and sewage sludge; (ii) development of alternative ways of phosphorus recovery; (iii) estimation of energy demand for phosphorus recovery. Biological removal of phosphorus during wastewater treatment processes eases phosphorus recovery. The process depends on supply of organic acids and such acids can be produced for example from organic fraction of solid waste. Alternatively, for this purpose wastewater from food industry may be used. Sulphide and sulphate reactions might become alternatives for presently used phosphorus recovery methods. They are similar to the phosphate holding and releasing reactions occurring in sediments.

As biological removal of phosphorus eases phosphorus recovery it is increasingly more important to better utilize existing models of biochemical reactions occurring in activated sludge (including biological phosphorus removal).

Product recovery from wastewater, solid waste and from the combined systems is much dependent on presence of toxic substances. Such substances limit utilization of sludge in agriculture. Therefore, it is important to better know the strategies to control inputs of toxic substances and the effects of their presence for product recovery.

The integration of wastewater and solid waste handling system increases complexity of the entire treatment system. Regional approach to sanitation systems helps to achieve the integration.

Research areas

In order to achieve the project's objectives (i.e. obtain new knowledge about the effects of increased integration and regional approach to wastewater and solid waste handling for optimisation of sanitation systems), some subprojects have been specified related to research activities carried out at the technical universities in Krakow, Gdansk, Bielsko-Biala, Gliwice and Stockholm. It was planned that the researchers from the participating Polish and Swedish universities would jointly research the problems grouped into the following three research areas:

1. Phosphorus recovery from sewage sludge and solid wastes:
   - Use of organic acids from solid waste for improvement of biological phosphorus removal in wastewater treatment plants.
   - Complementary phosphorus recovery from iron-rich sludge with the use of hydrogen sulphide generated in biological reactions.
   - Energy demand and energy recovery in sludge and solid waste handling systems with phosphorus recovery.
   - Modelling of wastewater treatment systems with biological phosphorus removal.

2. Toxic substances and product recovery:
   - Model system of solid waste handling for minimization of risk associated with toxic wastes.
   - Risk minimization in sewage sludge disposal and utilization.

3. Effects of regional approach to integrated sewage sludge and solid waste handling:
- Treatment of leachate from solid wastes and supernatant from dewatering of digested sludge.
- Modelling of integrated solid waste and sewage sludge disposal systems.

INTEGRATION OF WASTEWATER, SLUDGE AND SOLID WASTE HANDLING

The complex structure of wastewater, sludge and solid waste handling systems is illustrated by Figure 1. Wastewater and wastes are supplied to treatment systems that as a simplification may be divided into local, municipal and regional systems. For the treatment is needed raw materials (as chemicals) and energy (for instance for pumping and air supply). As a result of the treatment rest products may be used or disposed and emissions are obtained. The use or effects may be on a local, municipal, regional or even global levels. Wastewater, sludge and solid waste handling interacts with several other sectors in society, interest organizations and the public and many means of assistance have been developed to improve the possibilities to evaluate and improve the systems. Examples are material flow analysis (MFA) and substance flow analysis (SFA), energy and exergy analysis and different evaluation methods as environmental impact assessment (EIA), life cycle analysis (LCA) and various economical tools (including "green" economy). Different computer programs have been developed as ORWARE to evaluate different alternative system configurations.

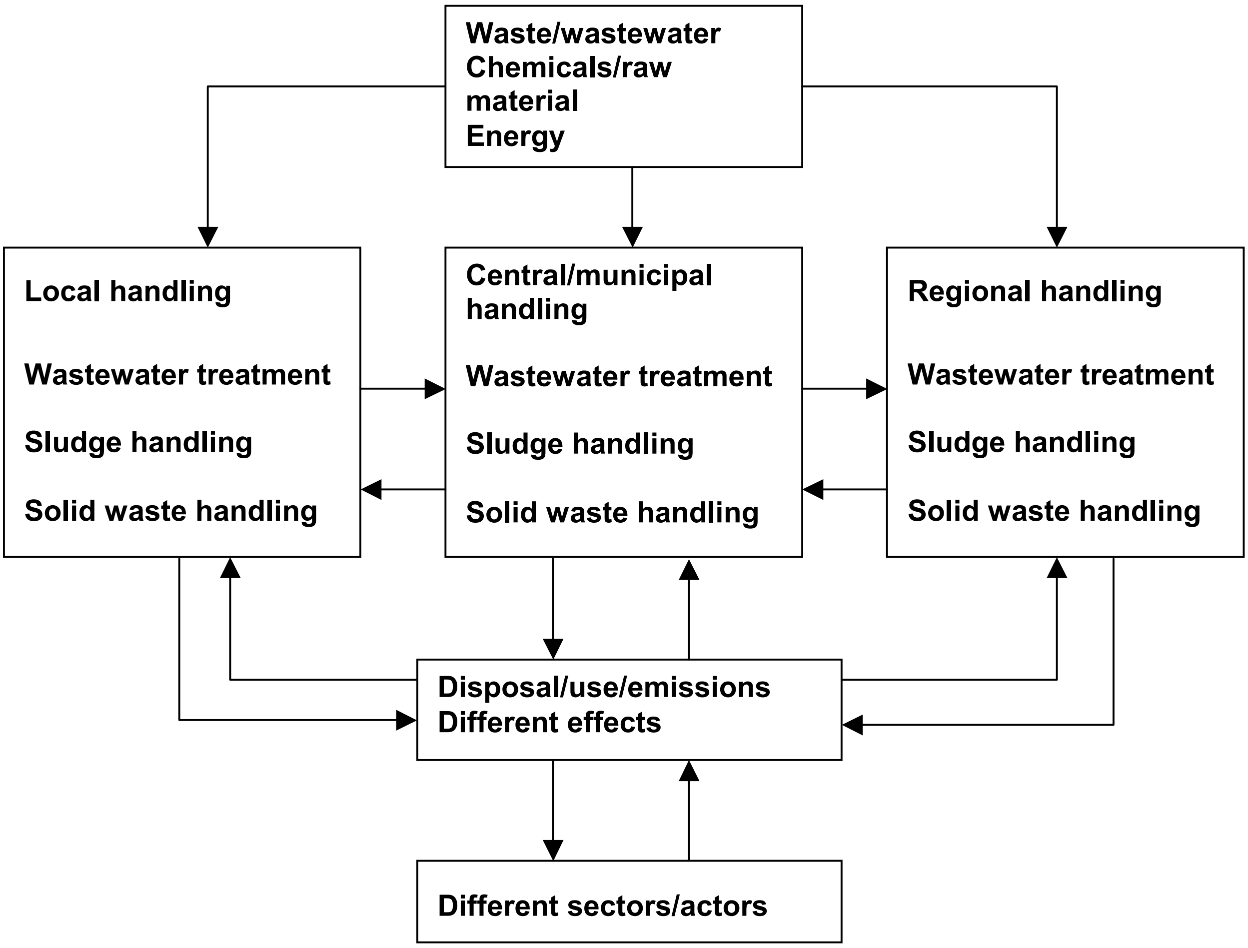

Figure 1. Different possible approaches to waste/water disposal systems.

Most efforts have been given on design and operation of central treatment of wastewater, sludge and solid waste in which the municipality has been the main actor. However, it is a tendency to increase the consideration of the relationships between local and central/municipal handling and between central/municipal and regional handling. The adoption of Agenda 21 is an example of increased awareness of the role of local handling and participation. The role of human life style has become much more in focus as well as willingness to pay and environmental awareness (including education for young children in schools). The well established practice in industry to sort different streams (as process waters, cooling water, storm water and sanitary wastes) for separate treatment, reuse or product and energy recovery has its analogy in present interest to separate wastewater and waste in households. Many suggestions have been given on separate treatment and handling of "grey", "brown", "black" and "yellow" water with the use of separate treatment of toilet wastewater and water from bath, dish and washing, the interest of urine separating toilets, etc. Separate collection of paper, glass, metals, plastics, and toxic waste (batteries, medicine rests etc) is today a common practice in Sweden.

There is also an increased interest to look at regional (and also global) effects on wastewater, sludge and solid waste handling. The need to reduce the emission of carbon dioxide makes energy saving or use an important issue. Forbid to put organic wastes on landfills is much caused by the need to reduce emissions of methane gas. The EU Water Framework Directive is focused on water as it flows through river basins to the sea and water management is based on river basins. It applies to all waters as inland surface waters, groundwater, estuarine and coastal waters and is an example of changing the focus on individual municipalities and point sources to the river basin with its combination of point and diffusive pollutant sources. Regional handling may be a suitable choice for complex treatment facilities as incineration plants or for sludge disposal on productive soils.

Integration of wastewater, sludge and solid waste handling is, thus, needed on local, municipal, regional and global levels. Another way of integration is to better consider the interactions between wastewater and sludge treatment and wastewater/sludge and solid waste treatment. A wastewater treatment plant has normally focus on removal of pollutants in order to obtain an effluent that will not harm the recipient. Wastewater treatment may involve process stages for oxidation of organic material into carbon dioxide, destruction of pathogens, transfer of ammonium into nitrate or nitrogen gas, i.e. reactions in which environmentally disturbing processes are transformed by biological or chemical methods into less harmful products. However, a wastewater has much the function to separate pollutants in the form of sludge from the water phase in order to reach certain effluent requirements. The sludge contains both valuable materials such as nutrients, organic compounds (for energy production) and possibilities exist to use the inorganic fraction as a raw material for the building industry. The sludge also contains different pollutants (toxic metals, organic micropollutants and pathogens), and this makes its use and final disposal problematic. Therefore, a treatment plant must consider both effluent requirements and requirements to eco-cycle the sludge. Figure 2 illustrates possibilities to use the effluent and sludge for different beneficial purposes. Efficient source control and sorting of flows facilitates later uses of the effluent and sludge. Consideration of both requirements for the effluent and eco-cycling of sludge makes it important to better take into account the interactions between wastewater and sludge treatment.

Examples include:

- Possibilities to minimize the sludge amounts and to improve its thickening and dewatering properties

- Possibilities to recycle back certain constituents from the sludge treatment in order to improve sludge sedimentation properties (role of the sludge as a weighting agent), soluble easily biodegradable material obtained during certain sludge treatment methods for improvement of biological phosphorus removal and denitrification, and seeding of nitrification bacteria from a separate stage for nitrification of supernatant from dewatering of digested sludge.

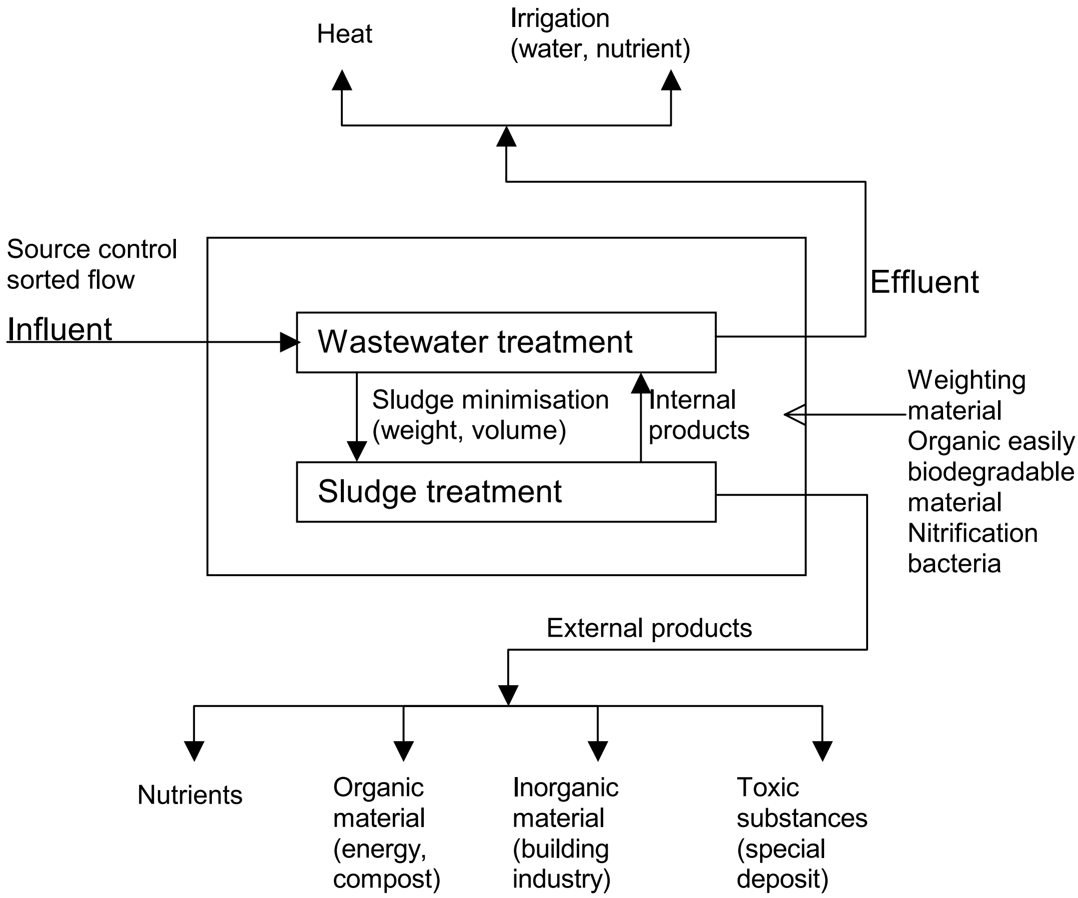

Figure 2. Material flows and different interactions in wastewater and sludge handling.

Interactions between wastewater sludge and solid waste disposal systems

The wastewater and solid waste disposal systems have some common features. They both help to keep the community hygienic standards and both are in the local governments management structures. To achieve this goal the two systems apply the same methods of treatment:

- delay and decay (wastewater treatment technology, composting of sludge or organic solid waste)
- concentrate and contain (sanitary landfills, monofills, leachate irrigation)
- dilute and disperse (attenuate landfills, WWTP effluent discharge)

Generally, both two systems are the energy intensive often non-profit activities of municipalities. The investment costs in the two systems are also very high. And the social acceptance of the facilities is negative causing NIMBY (Not In My Back Yard) syndrome and forcing the two to cooperate to reduce to social and economic impact on the society.

The potential for cooperation are numerous:

- use of the municipal incinerator for disposal of WWTP sludge
- use of WWTP sludge for improving the solid waste composting process
- use of WWTP sludge for the landfill final cover
- meeting new strict regulations on reduction of the landfilled biological fraction of MSW.

There is a growing concern what to do with the sludge from the WWTP. The simplest solution of applying it to the ground meets, in some countries such as Sweden, the strong resistance from the farmers, who do not want it, not believing that it is contaminants free. Sometimes it is not accepted, because the soil in the neighbourhood of the WWTP is phosphorus rich. Communities in such cases look at the local municipal solid waste incinerator as a solution.

Sludge can be mixed with the waste and incinerated and extensive flue gases purifying equipment ensures the removal of the remaining pollutants. The high heating value of sludge varies from 12 to 18 MJ/kg of dry solids. Depending on the dewatering the sludge requires or not the additional fuel. If the concentration of dry solids is 20 to 30% the auxiliary fuel is needed, but if DS concentration is in the range 30 to 50% sludge will burn unaided.

With conventional sludge/MSW co-combustion methods, moisture level in the sludge affects the efficiency of the combustion process - furnace temperatures are lowered, incomplete combustion occurs, and feed rates are reduced whenever the amount of sludge exceeds 2% to 3% of the MSW being burned. One solution to help solving this problem is co-combustion of sewage sludge and MSW in the oxygen enrichment environment. In such oxygen rich environment (25%) the combustion kinetics change favourably. At the same time, the rise in combustion temperature that normally accompanies oxygen enrichment is tempered by the high moisture content of the sewage sludge. The method was successfully tested in Worcester, Massachusetts where in the Riley-Stoker pilot unit designed to mass-burn 205 kg/h of processed MSW was fuelled with MSW/sludge and 25% of oxygen. (EPA page).

The combination of enhanced combustion kinetics and combustion temperature control enabled co-combustion at sludge/MSW ratios of up to 10%, a full five-fold increase in sludge compared to current practices.

One of the ways of solid waste and sludge disposal is composting. To make the process a successful one a few key parameters have to be within the proper range. One of these parameters is a correct carbon to nitrogen ratio. Carbon is needed in the composting process by the new micro-organisms for the life processes and nitrogen for building the new cell bodies. The composting proceeds most efficiently when the carbon nitrogen ratio is between 25:1 to 35:1. Unfortunately both in MSW and in sludge the ratios are not within this range. Table 1 (Kiely, 1997; EPA, 1994) presents the carbon to nitrogen ratio for different materials often used for composting.

MSW is rich in carbon while the sludge has rather low carbon content. This means that by mixing these two one can control the proper ratio. The other advantage of combined composting of waste and sludge is that sludge particles are rather small and that is also not good for the composting process. If the composting is going to be conducted in the optimal conditions, the free access of oxygen to each particle has to be guaranteed. Solid waste helps in this supplying the structural material.

The disposal of digested sludge is a problem. On of the options is to use it for the construction of the landfill final cover. Such cover consists of five layers one of them is the fertile soil. The main problem with this method of sludge disposal is that the amount of the produced sludge and the amount of needed top cover are incomparable.

Table 1. Carbon to nitrogen ratio of various materials

Type of feed	Ratio
Foilage	40-80:1
Leaves and Weeds (dry)	90:1
Mixed MSW	50-60:1
Paper	170:1
Sewage Sludge Activated	6:1
Sewage Sludge Digested	16:1
Kitchen waste	25:1
Wood	700:1
Grass clippings	20:1

The EU Council directive 1993/31/EC lays down the following specific targets for the reduction of landfilling of biodegradable municipal waste:

- in 2006, biodegradable municipal waste going to landfills must be reduced to 75% of the total amount of biodegradable municipal waste produced in 1995.
- In 2009, biodegradable municipal waste going to landfills must be reduced to 50% of the total amount of biodegradable municipal solid waste produced in 1995
- In 2016, total amount of biodegradable municipal solid waste going to landfill must be reduced to 35% of the total amount of biodegradable municipal waste produced in 1995.

To meet these targets the countries introduce the command and control measures such as bans on landfilling the biodegradable municipal waste. Table 2 presents some of the examples from the EU. The other countries introduce the economic tools by introducing the tax on landfilling of the biodegradable waste. The Scandinavian countries (without Finland) introduced the highest tax (between 25 to 75 Euro), while the rest of the EU countries with the exception of Germany, Iceland, Ireland, Spain, Portugal and Greece introduced the tax between the 5 to 20 Euro. Such tax will only be effective if the producers are provided with the alternative way of waste disposal. Otherwise it will only be a fiscal tool. The alternatives are normally composting, incineration or recycling. The problem is that introducing these methods sometimes has a very significant capital cost (in case of incinerators) approximately 1-2 million €/tonne of MSW per hour. The cost of treatment for different countries are also high: Austria - 176 €, Denmark, - 21 €, the Netherlands 70-125 €, Sweden 22-33€ (White, 1997). The cost of recycling, which is the other option of detouring the organic fraction of the waste stream increases with the recovery rate. The Netherlands and Austria, among others, introduced the organic household waste programs that enforce the separate collection of this fraction in the municipalities. The landfilled MSWBF has been significantly reduced, but the technical problems remain particularly in the centres of old towns (Jacobsen, 2002).

Table 2. Countries with a ban on landfilling of biodegradable municipal waste (Jacobsen, 2002)

Country	Ban on landfilling of biodegradable municipal solid waste
Austria	To be introduced 2004
Belgium (Flanders)	Yes
Denmark	Yes
Finland	To be introduced 2005
France	Yes
Germany	To be introduced 2005
Italy	Yes [1]
Norway	Yes
Sweden	To be introduced 2005
The Netherlands	Yes

[1] Only non-recoverable waste and inert waste are allowed to be landfilled

On the other hand, application of the grinders seems to be the option. Grinders are placed under the kitchen sinks and help to dispose all kitchen waste in the drains. This solution is extensively used in the States and the statistics of the MWS composition seem to support the theory of its impact on the MSW compostion. Table 3 presents the typical composition of domestic waste by country (Kiely, 1997)

There are many factors influencing the waste composition. Among others these are standard of living, climate, and consumer's behaviour. These differences occur among the presented countries, but the common use of the grinders in the States seems to be an important factor.

Table 3. Typical domestic waste composition (%) by country.

Component	US (1993)	Denmark (1992)	UK (1991)	London (1991)	Poland (1992)	China (1992)	Ireland (1992)
Food wastes	9	35	25	26.7	24	36	34.2
Paper, carboard	40	35	29	35.5	11	2	18.7
Plastics	7	6	7	5.2	2	1.5	16.1
Glass	8	8	10	10.8	6	1	5.4
Metals	9.5	4	8	6	2	1	2.9
Clothing	2	8	3	3.4	10	1.5	2.6
Ashes, dust	3	4	14	5	45	57	17.2
Unclassified	21.5		4	7.1			2.9

If grinders are used one can expect higher organic load at the WWTP, but significant reduction of cost of the solid waste collection and disposal. The amount of waste is not only to be reduced, but the waste is going to be far more stable allowing seldom waste collection. Such solution is attractive for the communities suffering the lack of landfill sites and unused WWTP capacity. The careful and detail study of this problem seems to be worth time and effort.

The other option of integration of MSW and wastewater systems is a combined anaerobic digestion of MSWBF and sludge (Del Borghi, 1999; Rintala, 1996). Several experiments were conducted giving promising results. In case of Rintala experiments the production of methane was up 90% of theoretical value and the sludge was more active comparing with the WWTP alone. In this example again the biological fraction was utilized without the high investment cost.

CONCLUSIONS

The municipal infrastructure is successively becoming more complex. Both from a technical and administrative point of view integration of water, wastewater and municipal solid waste handling and its integration with other sectors in society may increase significantly the efficiency of the systems. Integration means that better competence is achieved due to that larger organisations can employ different specialists. A larger organisation facilitates the possibilities to better consider handling methods on a local, municipal and regional level. Integration and optimisation of urban sanitation systems is a large research area suitable for international co-operation such as the Polish-Swedish co-operation project supported by the Swedish Institute.

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