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Sustainable vacuum waste collection systems in areas of difficult access

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ABSTRACT

Waste collection is the activity of transporting solid waste from the point of production to the point of treatment or disposal. Today, the most common way of waste collection is by road from each individual's house or collecting point. Whilst other services and utilities such as sewage, water, drainage and even modern day telecommunications have wisely been designed to be out of sight in the underground infrastructure, solid waste collection has commonly remained unchanged since the 19th century. Furthermore, traditional municipal waste handling in historical city centres is often made difficult by: old infrastructures; narrow, crooked streets that are not suitable for large waste collection vehicles; little space for rubbish bins, making at source separation difficult, and; high volumes of tourists that make traditional bins less accessible by waste operatives, which often conflicts with the objectives of keeping areas associated with tourism clean and hygienic. In these circumstances, underground vacuum waste collection arise as a revolutionary solution, even in remote areas. This waste management model lets integrate waste collection into the infrastructure of a building, a residential development a district or even entire towns, by transporting waste using vacuum technology through an underground network of pipes. The result, among other positive elements, is an average reduction in CO_2 emissions above 90% compared with traditional collection models by truck.

1. Introduction

In 2010, 50.6% of the world population lived in urban regions and it is projected that by 2050 urban dwellers will likely account for 86% and 67% of the population in the more and less developed regions, respectively (Un-habitat, 2010). Urbanisation is, thus, an irreversible phenomenon that creates the need to expand existing residential areas, consuming, at the same time, neighbouring "green areas". This trend collides head-on with the model of sustainable development that the new EU policies aim to implement.

In this scenario, waste management is one of the major issues to be addressed. The annual generation of municipal waste in the EU-27 reached 477 kg per person in 2015 (Eurostat, 2010). The daily waste production per capita ranges from 0.48 to 2.16 kg, with people in highly developed countries producing more waste. In the coming years, both the increase of global population and the growth in developing countries are expected to create a boost in the municipal waste production. Only for the case of urban food waste, its production is expected to increase by around 45% until 2025 (Mavropoulos, 2010). Thus, cities will be facing new challenges to efficient address the management of solid waste.

Among waste management activities, collection is the most important and costly aspect of the urban waste cycle because of the labour intensity of the work and the massive use of trucks in the collection process. According to Beliën et al. (2012), the collection activity accounts for approximately 80% of all costs associated with waste disposal. Environmental costs associated with traditional collection models are also important and this is why the amount of carbon emissions created by heavily polluting waste collection vehicles has to be seriously considered (Ramos et al., 2014, Sandhu et al., 2015).

The situation in remote areas (islands and rural communities) is even worst. Difficult access when climatic conditions are adverse or remoteness of centralised municipal treatment systems are factors that make remote areas a real municipal waste treatment challenge (Santamarta et al., 2012).

In these circumstances, the subsoil arises as a practically unexploited resource with the potential to alleviate the problems associated with the lack of free areas in modern cities (Kaliampakos and Benardos, 2013).

Underground vacuum waste collection (UVWC) systems for the collection and transportation of municipal waste has been more broadly introduced in urban areas during the last decade as an alternative to

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traditional waste management systems. Powered on electricity, this model is an efficient alternative to waste vehicles since it is less polluting, each collection cycle is quicker and more cost effective and even areas of difficult access (understood as remote areas and historical city centres) can receive the service. Furthermore, this technology improves recycling rates up to 50% by making source separation as simple and profitable as possible for the user. Oh et al. (2016) assessed the difference in per capita generation of household waste according to the different waste collection methods in Korea. The value of generation of food waste indicates that a person in a city using UVWC produces 40% less of the food waste (109.58 g/day), on average, compared with that of a truck system (173.10 g/day). The value of generation of general waste in a city with an UVWC system showed 147.73 g/day, which is 80% than that with trucks delivered (185 g/day).

In the case of remote areas, the application of UVWC systems will depend mainly on the existing population density. It is not the same a rural area with a high dispersion of the population than a rural area or island highly populated due, for example, to touristic reasons. In the first case these systems are unsuitable due not only to logistic (e.g. long walking distance to the nearest collection point), but also economic (e.g. high return on investment period). In the second case, the installation of a UVWC system can solve many of the problems associated with waste management in remote areas, as seasonality or low levels of selective collection, among others (Hidalgo et al., 2016).

This paper aims at presenting the solutions offered by underground vacuum collection systems to different typologies of communities, including those considered as remote. Furthermore, through selected case studies the applicability of this technology is analysed.

2. Underground waste infrastructure: pros and cons

The main difference of UVWC systems with respect to typical waste collection models is that the waste containers are positioned underground, thus, they are developed as a permanent infrastructure.

Littering and hygienic problems are kept to a minimum with UVWC systems as the container overload is decreased and odour issues are better controlled, while at the same time a smooth operation of the system can be achieved 24 h, 365 days a year, even at difficult situations either as a result of severe weather conditions or external events (e.g. strikes, protests, traffic congestion, etc.) (Kaliampakos and Benardos, 2013). Also a reduced number of waste collection trips is required, a fact that positively influences operating cost, traffic congestion, minimises CO_2 emissions from the garbage trucks and presents potential space savings (Kaliampakos et al., 2016). The reasons for the introduction of UVWC in urban areas are also that these systems can be efficient and hygienic. On the other hand, according to Punkkinen et al. (2012), a UVWC system could be less sustainable at global scale than a traditional door to door waste collection due to its high electricity consumption and the manufacture of system components. The origin of the electricity, in this case, can play a decisive role in the sustainable balance of the whole process. Furthermore, the inability of UVWC systems to correctly deal with packaging waste and glass fractions results in the development, in parallel, of small traditional systems that need to be employed in order to collect those waste types. Table 1 gathers the major pros of this waste collection modality, as well as the main cons.

3. Comparative cost assessment

The UVWC systems suppose, in general, reduced operating costs for waste handling compared to traditional systems (Kaliampakos and Benardos, 2013). Although a greater initial investment is required (Teerioja et al., 2012), the more economical operation of the system can actually compensate this disadvantage in the long term (Nakou et al., 2014).

The value of the surface space released with the underground system could potentially have a significant impact on the cost analysis. If the land recovered from traditional waste collection can be put to a valuable use, the pneumatic system could be lower cost than the door-to-door system.

An underground collection system is at a cost disadvantage compared to traditional door-to-door collection when the target area is small, sparsely populated or with low waste production, even six times more expensive according to Teerioja et al. (2012). On the other hand, the economic comparison is positive for underground systems in bigger installations, higher population densities and higher trend to generate waste. Also the installation of UVWC in new residential areas has a better economic performance than in old areas. The main reasons for this are that the installation of a pneumatic system is easier in new construction sites, lowering its cost, and also that the saved space from waste collection activities can be easily put to efficient alternatives, as new apartments or parking space.

An important part of the economic benefits of UVWC structures are latent and are associated with social and environmental externalities, as urban revival, time savings, limited disturbance in the citý́s man-made and natural environment, or environmental protection. This latent cost/benefits has been proof to be the pivotal point in an evaluation process that can render an underground project not only feasible but also favourable (Kaliampakos et al., 2016). In some cases such benefits can also be expressed in monetary terms, either by the more efficient utilisation of the use by itself, or by the more efficient utilisation of the system as a whole. When considering such issues under the whole life cycle of the project, underground facilities in general, and UVWC systems in particular, can become the number one priority for infrastructure development.

Several studies carried out in different parts of the world confirm the costs advantages of UVWC systems compared with traditional waste collection modalities (Kaliampakos and Benardos, 2013; Sterling et al., 2012; Ramos et al., 2014; Punkkinen et al., 2012; Oh et al., 2016). Table 2 shows the results of one of these studies. It can be seen that while the two systems, traditional and underground, are very similar in the CAPEX required, the OPEX associated with underground systems is much more advantageous for the final user, with the cost being three times lower in this case.

Törnblom (2016) compared the economic performance of a conventional collection system and a stationary vacuum system for the development of a new housing project comprising near 3000 dwellings. The annual operating cost of this project using vacuum collection was approximately 3 times lower compared to the manual handling of surface containers (43 €/flat vs 130 €/flat). On the other hand, investment costs resulted 1.6 times higher (2254 €/flat vs 1406 €/flat). Considering a 30 year's depreciation period with 6% cost of capital, the global annual cost per dwelling resulted 232 € for manual waste handling and 206 € for the stationary vacuum system.

There also some studies with negative results for the UVWC system. Teerioja et al. (2012) compared pneumatic versus door-to-door waste collection in an existing urban area of 0.2 km^2, with a population density of 20,000 citizens per km^2 and an annual generation of municipal waste of 2,000 t. In this case, the pneumatic system was estimated to be 6 times more expensive that the traditional system in use in that moment, being the investment cost the dominant factor. However, the derived result was favourable to UVWC for higher population densities, higher propensities to generate waste or considering a new residential area instead an old one.

4. Analysis of selected case studies

Until now, there are close to a thousand systems in operation all over the world, mainly in Europe, China, South East Asia, and the U.S., with this figure continuously growing. Some representative examples are concentrated in Spain: