The 2012 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM' 12)
Seoul, Korea, August 26-30, 2012

Life Cycle Assessment of Sewer System: Comparison of Pipe Materials

Dongwook Kim[1], Sora Yi[2], Woojin Lee[1]*

1 Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea
2 Urban Infrastructure Labolotory, Daejeon Development Institute, 480 Worldcup-ro, Seo-gu, Daejeon 302-280, Republic of Korea

(*Corresponding author : woojin_lee@kaist.ac.kr)

Key words: Sewer system, Life cycle assessment, Pipe material, Methane formation

Abstract

Sewer system is fundamental urban infrastructure for the public sanitation. Construction of sewer system is needed to invest a huge amount of capitals and labours as well as generates various and wastes and atmospheric emissions, and hence sewer pipes should be appropriately managed in the environemental aspect which is analysis of greenhousegases(GHGs) emissions. In this study, we investigated the environmental impact by focusing on GHGs emission and developed the assessment model to identify the contributions of impacts by the different stages in the life cycle to the system by using life cycle assessment (LCA) as a tool. The developed model was applied to Deajeon city and assessed the GHGs emissions from sewer system in Deajoen. We concluded that the concrete pipe can be the first option than other pipe materials in the environmental aspect and the amount of methane (CH_4) formation estimated by the model cannot be neglected for total emssion of sewer system.

* Corresponding Author : Woojin LEE, Professor of Civil and Environmental Engineering, KAIST, Tel : (82)-42-350-3624 Fax : (82) -42-350-3610 Email: woojin_lee@kaist.ac.kr

INTRODUCTON

Over half of the world's population live in cities and these urban areas become key leverage point as a primary driver of resource comsumption and waste production. The Sewer system plays a significant role as one of urban infrastruture to keep public health and to prevent comtamination of an urban area. According to the sewage statistics in Korea, the 43% of total installed sewer pipeline are older than 20 years and 17% of pipes are older than 30 years(MoE, 2011). Recently, these deterioration of pipes has been occuring serious problems (i.e., decrease in capacity for sewer flowing and destructure of buried pipes). In order to prevent the problems, the government announced the plan to replace and rehabilitate the old sewer pipes over the nation. The installation and rehabilitation of the sewer system demand the huge amount of capital investments and diverse resources (e.g., raw materials for producing pipes, construction materials, and electricity related to material production). Additionally, it could generate various wastes and emissions at the same time. Since the sewer pipes are long-lived infrstructure and the rehabilitation spends lots of costs and labours, sewer system should be managed by an appropriate maintanence plan and continuous monitoring.

Many research for the environmental assessment of sewer system have been performed to improve the sustainability of sewer system to date. The studies concluded that the most envirmentally friendly material is concrete pipe among various available materials (e.g., polyvinyl chloride (PVC), high density polyethylene (HDPE), polypropylene (PP)) due mainly to the less requirement of bedding materials in Europe (CPSA, 2001). In Norway, Venkatesh and collegues developed the model to estimate the GHGs emissions based on years of pipeline network by appling life cycle assessment (LCA) and material flow analysis (Venkatesh, Hammervold et al., 2011). Stokes and Horvath were implemented water-energy sustainability tool (WEST) in California to analyze whole urban water section including water and wastewater treatment plant (WTP and WWTP) and water and sewer system (Stokes and Horvath, 2011). In Japan, there was a LCA study for sewer system and made a conclusion that an activated sludge WWTPs contribute 86% GHGs of total emission from urban sewage treatment system (Yukinori, 2001). A German reasercher focused on the service life of sewer pipe and rehabilitation methods (Lipkow, 2002). All of the previous studies defined different scope and published diverse results depended on the geographical characteristics.

In this study, we investigated the environmental impact (especially, greeenhouse gases (GHGs) effects) associated with the sewer system and developed the assessment model to identify the each contributions of the different stages on whole system with LCA tool. We additionally applied the developed model to sewer system in Daejeon city in South Korea to acquire the solution to reduce GHGs emission from sewer system. Especially, methane (CH_4) gas emission from operating state of sewer pipeline was also estimated to give the significant perception to urban planner, engineer, and policy makers those who are considering the ways to mitigate GHGs emissions in a city. Input and output information related to whole sewer pipeline cycle (e.g., material production, construction, and disposal of pipeline) can provide the meaningful insights into life cycle energy consumption and GHGs emissions to the environment.

Material and Methods

Overview of Sewer Pipe Material

According to sewage statistics listed in Table 1, frequently used pipe materials are polyethylene (PE) and concrete pipes, while cast iron pipe is usually used for the special case. Concrete pipe was installed more than 40% out of total installed due mainly to its easy production process. On the other hand, it has relatively low external pressure strength against a shock (i.e., DN300 concrete pipe has 1,000 kg/m and DN300 PVC pipe has 1,337 kg/m) and poor water-rightness because of many junction point resulted from a short pipe length. The usage of plastic pipes, PVC and PE, has been increasing due to a developed production technique and their various advantages (e.g., strong corrosion resistance, water-rightness against all sorts of chemicals and organisms, relatively light weight to carry, and easy procedure to cut and connect pipes in a construction site). In case of cast iron pipe, it was employed to the transport section under high pressure and has strong tensile strength and low decay resistance.

Table1 Statistic of installed sewer pipe materials (MoE, 2011)

	PVC	*PE*	*Concrete*	*Cast iron*	*Other plastics*	*Others*
Korea						
Pipes length (m)	8,573,693	20,551,550	52,177,262	2,094,408	2,554,762	38,967,738
Percentage (%)	6.9	16.5	41.8	1.7	2.0	31.2
Deajeon city						
Pipes length (m)	10,452	218,483	1,695,796	15,773	203,924	749,922
Percentage (%)	0.4	7.5	58.6	0.5	7.0	25.9

LCA for Sewer System

LCA methodologies were implemented for following purposes 1) to evaluate the environmental performance of a product or system 2) to estimate a potential environmental impacts 3) to analyze trade-offs between alternatives by considering entire life cycle, from its origin to its final destination (ISO, 2006). In this study, we only focuesd on global warming potential (GWP) in the various impact categories; abiotic and biotic resource depletion, ozone depletion, photochemical oxidant formation, acidification, europhication, human toxicity, ecotoxicity and hazardous, and radioactive waste (ISO, 2000).

The main advantage of focusing on GWP is to be more friendly with organizations and decision making contexts, which has poor knowledge on LCA approach, with positive camouflage effect (Finkbeiner, 2009). Besides, public has already became familiar with CO_2 emissions owing to carbon footprint and ecolabeling attached on commercial products (Weidema, Thrane et al., 2008). Therefore, results from this study could be more effective and easier information to the public.

Goal Definition

The main purpose of this study were comparison of both pipe materials and each life cycle stage. For the comparison of pipe materials, four selected materials for sewer pipe were evaluated in terms of the environemtnal performance. For the comparison of each life cycle stage, emissions from whole life cycle (from material production to end of life) was verified to figure out the significant stage. Obtained results from here are expected to provide guidance and information to urban planner for their selection of a suitable sewer pipe material as well as to governmental engineers for their management of GHGs emissions.

Scope definition

The function of sewer system was defined as sewage collection and transporation from household to WWTP. The functional unit (measurable unit to represent a function) was defined as the produced sewage per day transporting through the sewer pipes (i.e., flow rate of a sewage). The reference flow measures the performance of the functional unit and was defined as the length of sewer pipe and its service life (ISO, 2006).

In previous sewer system LCA studies, a length or an weight of pipeline was defined as a functional unit(CPSA, 2001; Venkatesh, Hammervold et al., 2011). However ,In LCA studies dealt with WTP and WWTP, the functional unit were determined as flow rate (Memon, Zheng et al., 2007; Stokes and Horvath, 2009; Stokes and Horvath, 2011; Lee, Yu et al., 2012). Since the flow rate of sewage effluent changes the chmicals and electricity consumption and contributes largely to the results, flow rate was chosen as functional unit. Therefore, flow rate was also selected as functional unit in this study in the same manner with previous water and sewer LCA model. In priciple, the system boundary of sewer system should include an entire life cycle stage (ISO, 1998). This study also includes entire stage and acitvities such as material production, material transportation, construction, operation, rehabilitation and end of life (Figure 1).

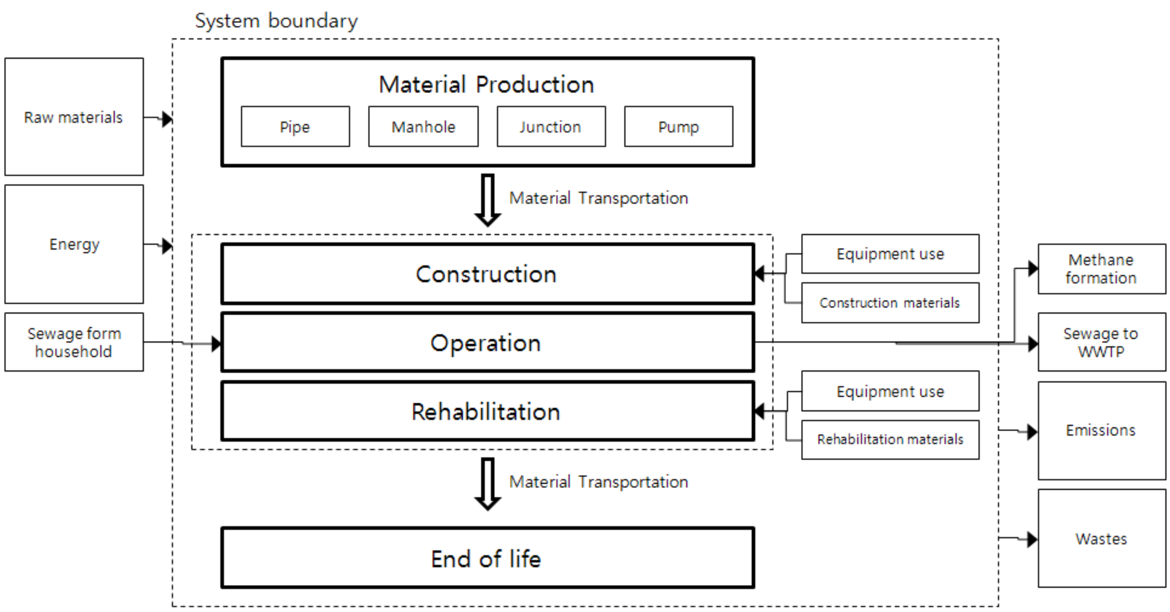

Figure 1 Process tree of sewer system

Inventory Analysis

For life cycle inventory (LCI) analysis, the basis scenario of sewer system was set up and described in Table 2. The material composition and weights of sewer pipes and manholes were mainly obtained by an interview with an expert or a request to the production company. Data including end of life plans was acquired based on the waste statistic report (MoE, 2011). Inventory analysis was performed by adapting input and output data obtained from Korea LCI (KEITI, 2012) and Ecoinvent database (Ecoinvet, 2006).

Table 2 Summary of basis scenario of sewer system

	Summary
Pipe dimensions	300 mm (DN 300)
Number of manholes	1 per 100 meters
Total transportation distances	200 km (15 ton trunk on Highway)
Weight of pipe and addition	PVC: 1,340 kg pipe and 113 kg manhole PE: 930 kg pipe and 113 kg manhole Concrete: 4,600kg pipe and 113kg manhole Cast iron: 5,420kg pipe and 113 kg manhole
Construction method	Open trenching method (installation and rehabilitation)
Sewage type	Mixed household water
Flow rate of sewage	7000 m^3/day
Service life	20 years
End of life plans	PVC: 17.15% recycle, 82.85% incineration PE: 17.15% recycle, 82.85% incineration Concrete: 99.64% recycle, 0.36% incineration Cast iron: 44.44% recycle, 55.56% landfill

Results & Discussion

Comparison of Plastic, Concrete and Cast Iron Pipes

GHGs emissions from sewer pipe materials were estimated as form of CO_2 equivalent emission. Inventory analysis phase and the impact of GHGs emissions on global warming was assessed (Table 3) by characterizing GHGs defined by Intergovernmental Panel on Climate Change (IPCC, 2006). The result of PVC pipe showed that the emissions of material production, operation and end of life stage were 49.3%, 30.7% and 16.9% of total emission, respectively. However, the emissions from material transportation and construction stage were negligible. For improvement of the sustainability of PVC pipe, CO_2 capturing from a chimney and using recycled PVC resin in material production process can be performed leading to GHGs emissions reduction. When it compared to the results between PE and PVC pipe, the usage was quite similar and they were shown as resemble features. In construction stage, PVC pipe was not only relatively easier to connect pipes but also was less impacted by temperature conditions. However, the emission of material production stage of PVC pipe was far larger amount than the emission of the stage of PE pipe. As the previous study reported, the GHGs emissions of concrete pipe were the least among the emissions of other sewer pipe materials. The significant issue of concrete pipe exists in the rehabilitation stage which contributes to 31.2% of entire life cycle emissions due to the assumption that the deteriorated pipes should be digged out for the rehabilitation. In order to enhance the sustainability of concrete pipe, new technologies such as no dig rehabilitation method should be developed and employed. The emissions of cast iron pipe consist of 78.4% for material production, 8.6% for operation and 4.0% for construction stage. Although the cast iron pipe has being used less than other pipe materials, the production process of cast iron pipe should be more environmentally friendly process by implementing CO_2 capture technology and using recycled scraps of cast iron.

Table 3 Global warming impact of four sewer pipe materials (kg CO_2-eq)

	PVC		PE		Concrete		Cast iron	
Stage	kg CO_2-eq	%	kg CO_2-eq	%	kg CO_2-eq	%	kg CO_2-eq	%
MP	4.55E+03	61.7	6.25E+02	19.6	9.99E+02	29.2	8.33E+03	78.4
MT	1.99E+01	0.3	1.69E+01	0.5	6.08E+01	1.8	1.73E+02	1.6
CO	1.06E+02	1.4	1.00E+02	3.2	3.59E+02	10.5	4.23E+02	4.0
OP	9.09E+02	12.3	9.09E+02	28.6	9.09E+02	26.6	9.09E+02	8.6
RE	2.62E+02	3.5	0.00E+00	0.0	1.07E+03	31.2	4.11E+02	3.9
EL	1.53E+03	20.7	1.53E+03	48.1	2.68E+01	0.8	3.77E+02	3.6
Total	7.38E+03		3.18E+03		3.42E+03		1.06E+04	

* MP (Materials production), MT (Materials transportation), CO (Construction), OP (Operation), RE (Rehabilitation), EL (End of life)

Case Study for Deajeon city

To demonstrate applicability of developed model, it was implemented to assess the environmental impacts of sewer system in Deajeon city. The area of the case study site is 539.8 km2 where 1,518,540 persons live in 2010. There are two wastewater treatment facilities (i.e., the one located in Yuseong-gu has capacity of 900,000 m3/day and the other one located in Seo-gu has capacity of 1,000 m3/day) and all of the wastewater from household in Deajeon is collected in these two facilities through the buried pipeline which length is 334,329m. The daily generated wastewater is 64,675m3/day on average (MoE, 2011).

The results of impact assessment for Deajeon sewer system are shown in Table 3. The emissions related to concrete pipe were recorded as the largest, 36.5% out of total, due to the buried pipeline is more than 50% out of total. Although the production of concrete pipe seems to generate relatively a little amount of GHGs, the rehabilitation process of deteriorated concrete pipe emits a more excess amount of GHGs than material production does because concrete pipe can be damaged easier. Another significant insight was delivered from operation stage. The emissions estimated under 1 year-basis contribute to 20.8% of total, which was ranked the second largest amount emissions of sewer system in Deajeon (Figure 2). From the obtained results here, we found out how much amount of CH_4 gas is formed in pipeline and understand the necessity to invest and support the technology of CH_4 gas capture and storage in pipeline.

Table 3 Global warming impact of sewer system in Deajeon

	PVC	PE	Concrete	Cast iron	Other plastics	Others	Manhole
Stage	$kgCO_2$-eq	$kgCO_2$-eq	$kgCO_2$-eq	$kgCO_2$-eq	$kgCO_2$-eq	$kgCO_2$-eq	$kgCO_2$-eq

MP	4.37E+05	1.31E+04	1.20E+07	1.26E+06	4.49E+06	2.45E+07	1.44E+07
MT	9.01E+02	6.46E+04	5.91E+05	9.43E+02	1.49E+04	1.48E+05	1.44E+07
CO	8.91E+03	1.86E+05	1.45E+06	1.34E+04	1.74E+05	6.39E+05	-
OP	1.08E+05	2.26E+06	1.75E+07	1.63E+05	2.11E+06	7.75E+06	-
RE	1.70E+03	2.46E+04	1.95E+07	3.63E+03	2.81E+04	2.25E+06	7.13E+05
EL	6.08E+06	1.82E+05	1.35E+06	1.84E+06	3.50E+06	3.24E+06	-

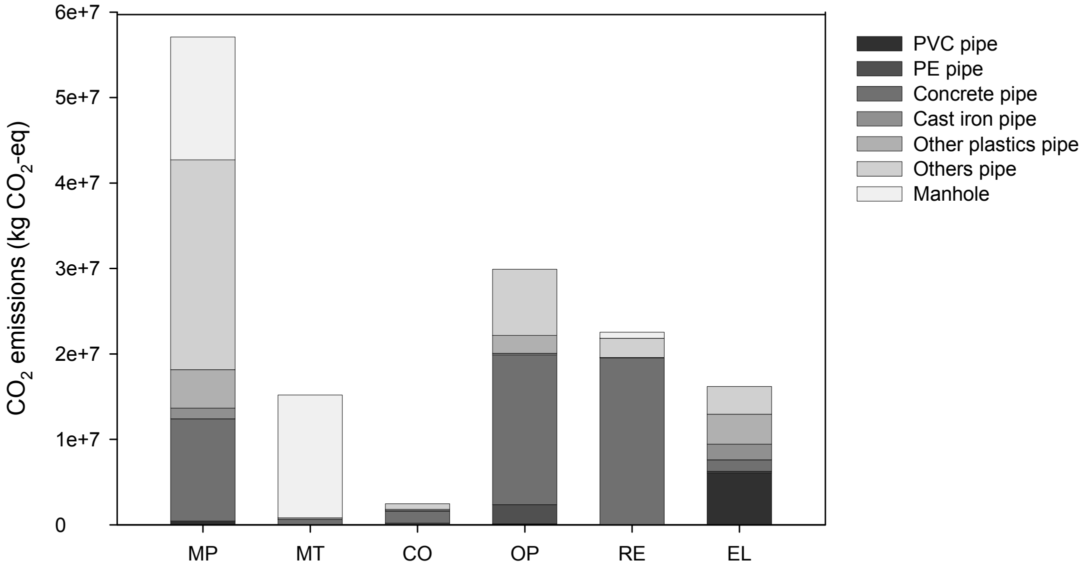

Figure 2 Global warming impact of four sewer pipe materials for each stage

Conclusions

This study investigated the environmental impact of sewer system by considering its life cycle. The results indicate that the concrete pipe can be the first option in the aspect of the low environmental impact (i.e., minimum CO_2 emission in life cycle). The potential solution for CO_2 mitigation as methane capturing in the pipe and the improvement of rehabilitation method was also suggested. By developing clean development mechanism (CDM) business related to these kinds of issues, economic and environmental opportunities could be created in the near future. The developed LCA model can be applied to diverse cases of sewer system which have different geographic, environmental, residential characteristics and etc. Infrastructure LCA can be used as an important methodology with Life cycle costing (LCC) for planners, engineers and decision makers in construction planning. For more widely application of LCA, the researchers should make an effort to solve lack of the LCI database associated with construction material, equipment and method.

Acknowledgement

This work is financially supported by Korea Minister of Ministry of Land, Transport and Maritime Affairs (MLTM) as 「U-City Master and Doctor Course Grant Program」 and as Project named 「Development of Urban Space Decision Support System for Establishing Material Circulation Framework」

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