CHEMICAL ENGINEERING TRANSACTIONS
VOL. 57, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Sauro Pierucci, Jiří Jaromír Klemeš, Laura Piazza, Serafim Bakalis

ISBN 978-88-95608- 48-8; **ISSN** 2283-9216
DOI: 10.3303/CET1757097

Determination of Physicochemical Characteristics of Solids of Urban Drainage Systems for Potential Use: Case Study in Bogota-Colombia

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Sediments in sewer systems present an environmental issue associated with their poor disposal and the contaminants that exist within them, so knowing their physicochemical characteristics would allow finding a potential treatment and/or reuse potential. This paper aims to identify the physical and chemical characterization of sediments from the urban drainage system in a stormwater sub-basin of Puente Aranda in Bogotá city, to determine its possible use in engineering applications. Characteristics such as pH, temperature, depth of the sludge, laboratory analysis of volatile solids, particle size, and moisture were measured. In addition to determination of chemical compounds was performed with x-ray fluorescence spectroscopy; from which it was established that the sediments analysed could be used in the manufacture of Portland cement and pozzolans. The compounds found in rainwater sewer systems such as alumina and iron oxide meet the limits stipulated in the Colombian technical standard (NTC 30) ranging from 3% to 8% and 0.5% to 6%, to be constituents of Portland cement.

1. Introduction

Solids in sewage systems are one of the major problems in hydraulic terms due to reduction in pipe area and a risk to the environment and human health (Rodríguez et al., 2012). Sediments can absorb some chemical contaminants like phosphates, pesticides and also tend to be associated with other pollutants such as heavy metals and hydrocarbons (Faram et al., 2007; Li et al., 2013; Romero-Barreiro et al., 2015; Sereyrath et al., 2016).

The sources of these sediments are very diverse; in fact, any particulate material generation or activity in the urban environment is a potential source(Spence et al., 2015). Ashley, et al. (2004). The main sources are presented in five items: (i) atmosphere, (ii) catchment area, (iii) residual sewage, (iv) industrial, commercial and solid effluents from buildings, and (v) environment and processes within the system of drainage.

The disposal of solids Is carried out in specific areas such as landfills or debris disposal lots, however, the capacity of these sites has been depleted and authorities are looking for disposal alternatives (Jiménez B., 2004). One of these alternatives is searching for a potential use of these sediments, for example Petavy et al. (2009 and 2009a), who proposed a treatment system to achieve sediment utilization of rainwater sanitation systems on embankments and roads. Likewise, Jang et al. (2010) proposed that this sludge can be used for road construction and maintenance. In the large Colombian cities, the characteristics of rainfall runoff sediments have not been studied and their potential use is unknown. According to the above, this article

Please cite this article as: Cardenas J., Perez A., Pena-Guzman C., Torres A., Fonseca A., Cabeza Rojas I.O., 2017, Determination of physicochemical characteristics of solids of urban drainage systems for potential use: case study in bogota-colombia, Chemical Engineering Transactions, 57, 577-582 DOI: 10.3303/CET1757097

presents a first approach to the subject based on physical and chemical analysis of sediments collected in the town of Puente Aranda in Bogotá city.

In the concrete industry, hydraulic cements such as Portland cement have the ability to set and harden in the presence of water. They are usually manufactured from calcareous raw materials containing silicates, aluminates and iron oxides (Neville, A. M. 1995).

Pozzolanic cement is a ground product of a mixture containing 20-40% natural pozzolan and 60-80% Portland clinker with the addition of a small amount of gypsum. Increase in the natural pozzolans content of cement would reduce the permeability of the paste with the implication of a high resistance to chemical attack, and increase in durability (Sideris, K. K., Savva, A. E. & Papayianni, and J. 2006).

2. Materials and methods

The sampling locations selection was carried out by three factors: (i) separate stormwater networks, (ii) different land uses and (iii) length of study sections. The selected sections covered the largest number of branches, which expand from the Comuneros channel located in the street 3 # 53 B to the avenue 53 C Bis # 5 C, and the section II that begins in the street 3 # 50 and ends at the transverse 46 # diagonal 5 C Bis. Within this zone, thirteen (13) sampling locations were selected: seven (7) for section I composed of one (1) point on the Comuneros channel in which it receives rainwater discharges from the stormwater drainage system, one 1) gully pots for its industrial, residential and commercial influence and five (5) manholes. For the second section, six (6) locations were selected, consisting of two (2) gully pots affected by workshops and restaurants, and four (4) manholes. This distribution of the sampling locations in each of the sections is presented in Figure 1.

Section 1		
Sampling locations	N (Latitude)	W (Longitude)
Manhole 1	4°37' 01.11"	74°06' 59.23"
Manhole 2	4°37' 1.95"	74°06' 55.32"
Manhole 3	4°37' 7.29"	74° 06' 53.20"
Manhole 4	4°37'12.42''	74°06'48.86''
Manhole 5	4° 37' 15.74	74° 06' 51.69"
Manhole 6	4°37' 19.71"	74°06' 48.35"
Manhole 7	4° 37' 24.98"	74°06' 44.18"
Gully pot 1	4°37' 24.77"	74°06' 44.23"
Section 2		
Sampling locations	N (Latitude)	W (Longitude)
Manhole 8	4°36' 56.53"	74°06' 51.41"
Manhole 9	4°37' 2.06"	74°06' 49.10"
Manhole 10	4°37' 4.56"	74°06' 47.96"
Manhole 11	4°37' 8.91"	74°06' 45.89"
Manhole 12	4°37' 14.12"	74°06' 41.53"
Manhole 13	4°37' 12.03"	74°06' 38.98"
Gully pot 2	4°37' 13.81"	74°06' 41.25"
Gully pot 3	4°37' 2.36"	74°06' 49.33"

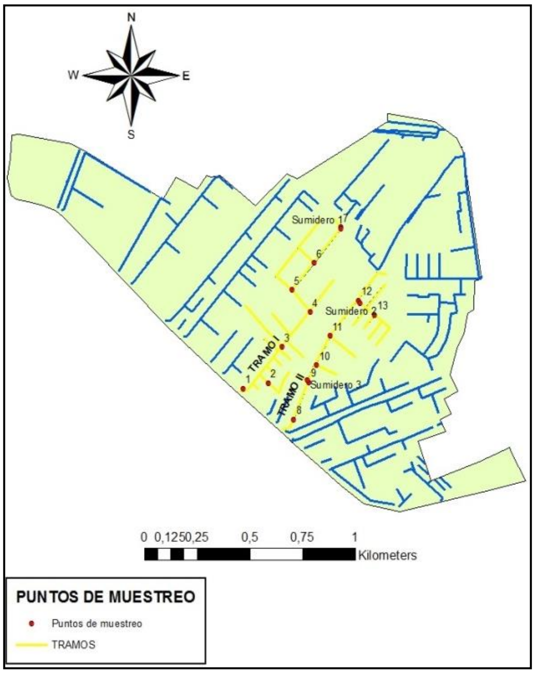

Figure 1: Sampling locations Section 1 and Section 2.

Analyzes were carried out during the months of February, March and April of 2015. The methods for measurements of humidity, and volatile solids used, were from the manual of analytical procedures of Flores and Alcalá (2010). Granulometry analysis was realized to through the Bouyoucos method, in order to determine the sediment texture with the percentage of sands, silts and clays. On the other hand the chemical characterization was carried out is an x-ray fluorescence spectrometer. The pH and sludge temperature were measured in situ.

Finally, a statistical analysis was carried out, which included the Kruskal-Wallis tests; identifying the significance of each representative variable with three place qualitative variables, soil use and precipitation level (Low and High). In addition, a t-test was performed.

For the identification of possible uses of the sediments, a global search was made of the standards and technical guides of different construction materials. The CTS 30 (Colombian technical standard) regarding Portland cement was used for classification and nomenclature. It is based on the COPANT 3:1-009 standard. The CTS 31 is applied to pozzolans and it summarizes definitions related to the manufacture of different types of cements, some of their properties, by-products and components. The CTS 4913 states the specifications for additions in cement processing. Lastly, the other standards used are ASTM C150 Standardized Specification for Portland cement and the UNE 80303-3: 2001 low heat cements of hydration, UNE 80304-3:2001 calculation of the potential composition of Clinker Portland, UNE 80 305: 2001 for white cement UNE 80 302: 85 cement, chemical specifications for its constituents and the ENV 197-1: 1992 composition specifications and conformity criteria for cement.

3. Results and Discussion

For the granulometry, it was found that the sediments are composed mostly of silts in a range of 50% to 90%, followed by sands with a percentage of 6% to 35% and finally clays with a percentage of 1% to 17%, these values depend mainly on the location and month of sampling. According to the textural triangle it is evident that for February it presents a slit loam texture, whereas for March and April the texture is mainly loam.

As for the percentage of volatile solids found in the sediments in section 1,they are in the range of 0.03% to 0.14%, while for section 2 these are in a range of 0.03% to 0.17%, these values are very low, which can occur in the area because there is no abundant vegetation or green areas. This is normal because in the sewage no organic matter is generated; however, according to the results in section I, the site with the highest content of organic matter is the well 1 corresponding to the Comuneros channel. This is the result of the channel being simultaneously fed from sanitary sewers and rainwater sewers.

For pH, it was found that for section I, during February and April, manhole 1 had an acidic pH lower than 6.5, as well as well 3 in February and 7 in March; On the other hand well 2 in march has a basic pH higher than 8.5; while the other wells have a neutral pH, just as it does in section II. The system temperature is in the range of 17.8 ° C to 25.4 ° C.

From the analysis of the x-ray fluorescence spectrometer the following components were found in greater proportion SiO_2, Al_2O_3, Fe_2O_3, CaO, SO_3, on the other hand, P_2O_3, TiO_2, K_2O, RuO_2, ZnO**,** CuO, CrO, SrO, MnO_2, V_2O_5, Ni_2O_3, Pb_3O_4, Ac_2O_3, Au_2O_3, GeO, Rb_2O, Y_2O_3, Sm_2O_3, ZrO_2, Cs_2O, PoO_2, Eu_2O_3, BaO, Ta_2O_5, Lu_2O_3 were in smaller proportions. Table 1 shows the average percentages of compounds that are found to be the highest proportion by sampling site.

As for the statistical tests, the Kruskal test showed that the presence of most of the representative compounds is due to the sampling location, except for the iron oxide, titanic oxide and zinc oxide that, in addition to the dependence on the location, their presence varies with the rainfall. Additionally, this test identified that the presence of the majority of pollutants is not influenced by the climatic dynamics, whereas the granulometric variability is. Regarding the T-test, it was identified that the highest content of RuO_2, P2O3, K_2O and TiO_2 occurs in the sampling locations closer to residential land, therefore it is more convenient to collect the sediments in the wells at these locations. The percentage of theses oxides vary according to the sampling location, even though the sludge flows mix into confluent waterways. In fact, the percentage of SiO_2 and CaO is more affected by residential areas than commercial areas, and industrial areas show variations of its influence on these compounds. Whereas the percentages of Al_2O_3, ZnO, Fe_2O_3 and SO_3 are mainly affected by commercial zones.

4. Possible Uses

From the search and the chemical and physical characteristics it was determined that their application could be in the manufacture of Portland cement and pozzolans. It is worth mentioning that Portland cement is hydraulic glue, that is, a material that in certain conditions is able to set and harden over time, sticking the other heterogeneous concrete materials (coarse and fine aggregates) together. The chemical composition for Portland cement is observed in Table 2, according to the Colombian standard CTS 30 and the international ASTM C150.

Table 1: Average% of Compounds

Point	$\%SiO_2$	$\%Al_2O_3$	$\%Fe_2O_3$	%CaO	$\%SO_3$
Manhole 1	63.39	7.87	11.97	8.11	3.54
Manhole 2	42.07	8.61	9.20	34.01	1.86
Manhole 3	71.42	10.40	4.31	4.04	3.90
Manhole 5	65.47	11.79	8.19	7.10	1.67
Manhole 6	59.67	10.14	8.03	12.79	1.79
Manhole 7	68.24	10.82	6.26	7.81	1.37
Gully pot 1	60.15	8.39	8.06	12.29	3.42
Manhole 8	71.77	9.25	5.37	5.80	1.91
Manhole 9	70.63	9.35	5.35	6.56	2.71
Manhole 10	74.77	6.55	3.59	7.00	2.92
Manhole 11	81.92	4.96	2.51	2.91	4.25
Manhole 12	68.64	9.18	5.12	6.88	4.55
Manhole 13	68.06	11.84	6.49	5.48	2.22
Gully pot 2	62.50	9.78	7.73	10.76	1.74
Gully pot 3	51.82	10.12	13.53	12.99	3.50
Manhole 1	65.61	8.69	6.71	10.48	2.13
Manhole 2	33.79	9.24	7.69	43.76	2.60
Manhole 5	69.27	12.53	6.22	5.71	1.33
Manhole 6	58.83	10.54	6.48	16.27	2.30
Manhole 7	65.86	11.67	6.89	8.63	1.30
Gully pot 1	61.41	10.58	7.70	11.53	2.65
Manhole 8	71.98	9.10	5.50	5.53	2.32
Manhole 9	69.38	9.80	5.95	7.18	3.09
Manhole 10	75.71	7.76	3.53	5.91	2.54
Manhole 11	82.87	5.09	2.00	2.81	3.67
Manhole 12	72.75	8.47	4.64	5.21	3.72
Manhole 13	67.99	11.98	6.23	6.02	2.53
Gully pot 2	60.40	9.33	8.04	12.70	1.62
Gully pot 3	56.63	10.97	9.82	12.47	2.53
Manhole 1	65.74	9.56	6.66	9.36	2.14
Manhole 2	33.95	9.24	7.66	43.65	2.62
Manhole 5	66.67	12.84	6.64	6.87	1.46
Manhole 6	60.64	9.13	6.56	15.63	1.87
Manhole 7	63.29	12.65	6.96	8.65	1.32
Gully pot 1	61.09	10.36	7.36	11.28	2.74
Manhole 8	70.48	9.78	5.77	5.70	2.31
Manhole 9	68.34	10.20	5.63	7.28	3.24
Manhole 10	77.30	6.69	3.40	5.82	2.73
Manhole 11	79.67	6.02	3.03	4.12	3.42
Manhole 12	74.57	8.15	4.50	4.95	3.66
Manhole 13	69.13	10.67	5.75	5.83	3.25
Gully pot 2	65.96	10.29	6.85	8.40	1.83
Gully pot 3	56.36	11.22	10.23	12.00	2.73

Table 2: Composition of Portland cement.

Compound	Limits (%) According to CTS 30	Limits (%) According to ASTM C150
CaO	60-67	60,6 - 66,3
SiO_2	17-25	18,7 – 22
Al_2O_3	3-8	4,7 – 6,3
Fe_2O_3	0,5-6	1,6 – 4,4
MgO	0,1-7	0,7 – 4,3
SO_3	1-3,5	1,8 – 4,6

When comparing these values with the values in Table 1, it can be seen that in the case of lime it does not reach the necessary concentration to be a component of Portland cement, while for silica it exceeds the limits of the two standards. However, the limits established by CTS 30, are met for: alumina in manholes 10 and 11, iron oxide in manholes 8, 9, 10, 11 and 12. Sulfuric anhydride concentration is fulfilled in all wells for the International restriction. Therefore it is inferred that the sediment has some characteristics that make it applicable to use in this type of cement. For compounds that do not comply with the standards, a prior treatment such as dilution could be included before being used.
According to the characteristics of the sediments, they could be given use in pozzolans in Colombia. The sediments found, can be used in pozzolans rich in silica and alumina. As evidenced in table 3, the sediments found contain more silica, which makes them resistant to sulfates. While alumina is contained in lower percentages compared to silica, it turns out to be a good component for aluminum-rich pozzolans. Comparing table 3 with Table 1, it is evident that the sediments found have a chemical composition similar to the volcanic pozzolans, since silica, alumina, ferric oxide, potassium oxide and lime comply with the established limits. However it's not the case for lime in manhole 2 and sulfuric anhydride in none of the manhole. For this reason when using sediments as a source of processing of pozzolans, it wouldn't be necessary to add volcanic extracted rock.

Table 3: Values of the limit and average chemical composition of pozzolans of volcanic origin.

Compound	Limit	Measured
SiO_2	42 - 85	65
Al_2O_3	20-05	12,5
Fe_2O_3	14-01	5
CaO	0 – 12	3,5
K_2O	0 – 5	2
Na_2O	0 – 5	2
MgO	0 – 11	1,5
SO_3	0 – 1	0,5

5. Conclusions

The physical and chemical characteristics of solids are mainly influenced by land use, which shows us the need to identify them and avoid possible environmental and health impacts. Statistical analysis allowed us to conclude that alumina, ferric oxide; sulfur dioxide and zinc oxide can be found in wells with commercial land use; and lime, silica, phosphorous anhydride and potassium oxide in the residential zones.
According to the triangle of textural classification it was evidenced that all the wells and sinks present a silty texture in the three months sampled; For the case of the application in construction sediments are not recommended, since the silts are more unstable than the clays and the sand; therefore it is advisable to carry out a pretreatment before using them.
The sediments that accumulate in the sewage systems of the town of Puente Aranda in Bogotá can be used in the manufacture of pozzolans and Portland cement, although in some cases adding lime would be required. In the case of pozzolans, silica, alumina, iron oxide, potassium oxide and lime may be used according to the limit value of volcanic pozzolans. In addition, the sediments must be dried and pulverized to be more efficient in the potential utilization for the manufacture of pozzolans. As for Portland cement, adding sediments is possible since compounds such as iron oxide and sulfuric anhydride comply with standards CTS 30 and ASTM C150.

Acknowledgments

The authors give thanks to Bogota's Waterway, Sewer and Hygiene Company (Empresa de acueducto, acaltarillado y aseo by its Spanish name) for the technical assistance received for the sampling of the sediments in the sewage system.

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