CHARACTERIZATION AND SLUDGE VALORIZATION IN CEMENT INDUSTRY

D. Djafari[1], A. Semcha[1], B. Mekerta[1], R. Zentar[2]
[1] Faculty of Sciences and Technology, Ahmed Draya University - Adrar, Algeria;
[2]Ecole des Mines de Douai, *Laboratoire de Génie Civil et géo-Environnement (LGCgE), Lille du Nord de France.*

.

ABSTRACT

Whatever the adopted treatment system, wastewater treatment induces the production of significant quantities of sludge that must be disposed of. Several methods exist for the management of sludge. However, the choice depends on the origin of sludge, the cost of the installation, the added value of the resulting product and the potential impacts on the environment.

In the context of beneficial reuse of the induced sludge, chemical and mineralogical analysis was carried out on the Raw material as on the sludge ashes (after treatment at 550 ° C). The results obtained allow exploring the ability of using the ashes to develop green cement (or eco-cements).

Keywords: Sludge, wastewater and green-cements

INTRODUCTION

During the second part of the twentieth century, the question of water pollution has taken worrying proportions whereas, at the same time, water consumption increased together with the demographic explosion. In industrialised countries the reduction and the control of water consumption is linked to the optimisation of processes for industrial and domestic wastewater treatment [1]. Excess sludge treatment and disposal currently represents a rising challenge for wastewater treatment plants due to economic, environmental and regulation factors. There is therefore considerable impetus to explore and develop strategies and technologies for reducing excess sludge production in biological wastewater treatment processes.[2]

Primary and secondary sludge produced in wastewater treatment plants is composed of a complex mixture of organic and mineral, dead and alive matter that is further treated using specific processes of treatment of this excess sewage sludge. Such processes aim at providing a material usable in the classical fields of conversion of biological wastes such as agricultural reuse [3], dumping, incineration or thermo -chemical conversion [4]. The main goal of the treatments applied to rough sewage sludge is the reduction of both volumes and injuries. At the exit of wastewater treatment processes, sewage sludge is composed of 99% of water and occupies considerable volumes.

During these operations rheological properties of sludge suspensions will strongly influence working conditions and scaling-up calculations of tanks, settlers, pumping stations or installations for sludge transport and storage. For all these reasons, some articles have been devoted to the rheological study of more or less concentrated sludge, in order to optimise such processes of treatment of sewage sludge [5,6,7,8,9].

	Nbre of WWTPs	Capacity (million hab/Eq)	Water vol. treat (million M^3/year)	Quantities produce of sludge (T / day)
ONA	96	6,88	161	106
SPA and others	54	/	/	433
Total	150			539

Table 1 Sanitation situation in Algeria [10]

In Algeria, the National office of Cleansing (ONA: Office National d'Assainissement) manages 96 WWTPs (until 2013). Total quantity estimated of sludge produced summers 196735 T/ year. Capacity for treatment, the number of WWTPs as well as the quantity of sludge produced for are presented in (Table 1) [10].

Rheological characteristics

It was of major importance to be able to measure some wastewater sludge rheological parameters that can be used as tools to investigate the treatment proper functioning. Rheology described the body deformation under shear stress influence. More specifically, the shear stress (τ) determination as a function of the shear rate ($\dot{\gamma}$) was called "rheogram" and this allowed the matter rheological behavior characterization. The rheological parameters recorded from bacterial suspensions in pure culture or sludge depended on the rheological equipment used and the measurement procedure applied [1,8].

Sludge produced in wastewater systems (i.e. from primary, secondary or tertiary treatment) characteristics varied greatly, due to the tremendous difference in wastewater composition, and in wastewater treatment plants design and operation. Sludge rheological properties depended on sludge parameters such as shape (size of particles), dispersion degree, solid components content, chemical constitution, temperature and physical features.

Rheological behavior models

The sludge rheological behavior can be described by Bingham model (Eq.(1)), the Ostwald model (Eq.(2)), the Herschel-Bulkley model (Eq.(3)), and the Sisko model (Eq.(4)) [11, 12, 13].

$$\tau = \tau_0 + k\frac{dv}{dx} \quad (1)$$

$$\tau = k\left(\frac{dv}{dx}\right)^n \quad (2)$$

$$\tau = \tau_0 + k\left(\frac{dv}{dx}\right)^n \quad (3)$$

$$\tau = \mu_B\frac{dv}{dx} + k\left(\frac{dv}{dx}\right)^n \quad (4)$$

Where $\tau(Pa)$ was the shear stress and dv/dx (s^{-1}) the shear rate. The consistency index k represented the fluid cohesiveness, and the flow behavior index n far from one meant high deviation from Newtonian behavior (n = 1 for Newtonian fluids) and the yield stress τ_0 indicated the sludge resistance to the deformation until sufficient stress was applied to exceed the solid phase yield strength. The parameter μ_B was the high shear limiting viscosity where the shear rate imposed on the fluid tended to an infinite value.

MATERIALS AND METHODS

Rheological characteristics

Source and preparation of the samples

Sludge used in the present study came from Sidi Belabbes (Algeria) wastewater purification plant. The sludge dried in a laboratory drying oven under a temperature of 40°C during 24H. Due to the rheological measurement cell size gap, the sludge was crushed then sieved with an 80 μm mesh sieve. Five samples were prepared for different solid matter concentration content 25, 30, 35, 40, and 45 $g.l^{-1}$.

Rheological measurements vs protocol

The apparatus used was a rotational rheometer RS600. The sludge sample volume (v) used for each measurement was 17 ml. The protocol used was to increasing linearly shear rate from 0 to 100 s^{-1} in 210 second. The temperature was maintained constant at 20 $\pm$ 2 °C.

Table 2 Composition in mass proportion of the developed cements.

Cements	Gypsum (%)	Clinker (%)	Ash (%)
EC_0	5	95	0
EC_1	5	90	5
EC_2	5	85	10
EC_3	5	80	15

Chemicals and mineralogical characteristics

For the shutter characterization of ash resulting from the calcinations of sludge of WWTPs, analyses of X-ray diffractometry were undertaken. These analyzes are realized on a calcined sludge with 550 °C so as to delete the matrix organic matters but also to apprehend the phases in presence for an incorporation in eco-cement. In these experiments, the diffractometer used is of the type OXFORD 1000 MDX (Multi-dispersive X-ray fluorescence analyzer element).

For the preparation of the eco-cement; mixtures of clinker, of ash resulting from the incineration of sludge WWTPs and Gypsum are carried out. The compositions of formulated eco-cements are given in Table 2.

To evaluate the performance of the developed eco-cement, prismatic samples (40 mm x 40 mm x 40 mm) of a mortar made of eco-cements were tested compression. The mortar used is composed in mass, of one part of cement (or eco-cement), three parts of standard sand and a half part water (W / C = 0.5).

Each batch for three test specimens comprises 450 g ± 2 g of cement, 1350 g ± 5 g of standard sand and 225 g ± 1 g of water.

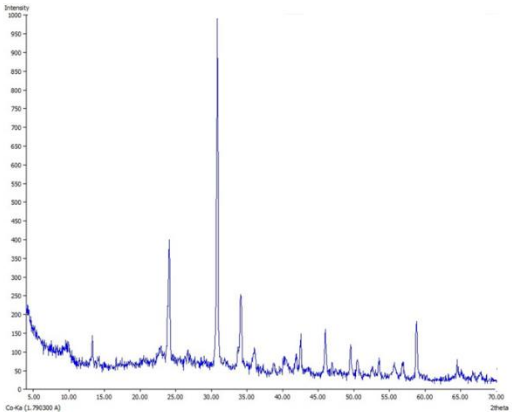

Fig. 1 X-ray diffractogram of the calcined sludge (+550 ° C for 4 hours)). formatting.

Table 1 The rheological parameters of sludge.

TSS(g/ l)	Ostwald de Vaele Parameters		
	K (mPa.sn)	n	r
25	1,162	1,119	0,9993
30	1,149	1,133	1
35	1,017	1,148	0,9999
40	1,223	1,118	0,9996
45	0,933	1,172	0,9999

RESULTS AND DISCUSSION

Rheological results

Figure 1 showed rheograms obtained for sludge wastewater sample at different TSS (Total Suspended Solids) content. It was clear that curves obtained for the application of an increasing shear rate were basically the same. The results proved that sludge belongs to a non-Newtonian family. The most fitting rheological model describing this rheological behavior was the Ostwald model. Different Ostwald's model parameters (consistency index k, and the flow behavior index n) were mentioned in table 1.

Figure 2 illustrated a remarkable increase in the apparent sludge viscosity for different Total Suspended Solid (TSS) content during the shearing imposed history. This increase in apparent viscosity translated the Bernoulien effect and the Waaliennes forces caused particles adhesion. An apparent viscosity summer maximum value reached equal to 2.12 mPa.s for a shearing speed of 100 s^{-1} and for a Total Suspended Solid (TTS) of 30 g/l.

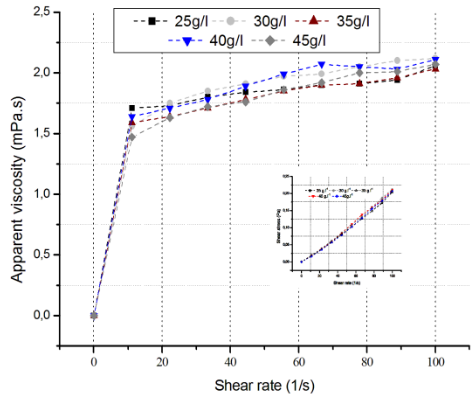

Fig.2 The apparent viscosity vs shear rate.

Eco-cements performance

The mechanical tests of characterization consisted in compressive strength were performed according to standard EN 196-1 on specimens made of a mortar which integrates various eco-cements.

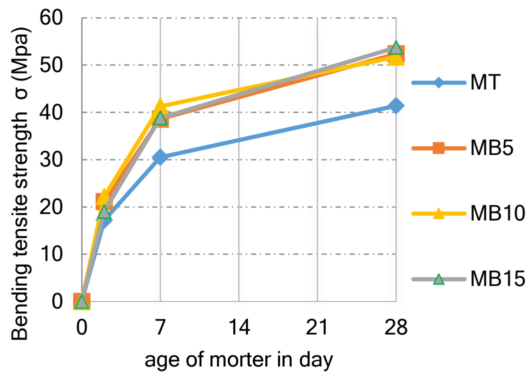

Fig.3 Evolution of the compressive strength.

The mechanical results presented in Figure 3 that eco-cements used make it possible to develop strengths at the early age (7days) and beyond higher than the resistance measured on samples including the standard cement (MT).

CONCLUSIONS

For rheological characterization, sludge studied had shown a non-Newtonian behavior. The rheological model as adopted to describe this behavior was that of Ostwald de Vaele. On one hand, this characterization helped to understand sludge's response to deformation, knowledge essential in developing crystal specifications for handling, transportation, applications, and in determining the optimum conditions for the processing equipments efficient operations.

The results of mechanical tests on specimens containing a control cement and eco-cement make it possible to conclude that they can be doubly valorized: the organic fraction is used in combustion (in the cement kiln) and them ash generated are incorporated in the chemical composition of the finished product (eco-cement). This will qualify our substitute cement as "eco-cement", as one hand it saves the same amount of cement and on the other hand offer a sector of exploitation of this waste.

REFERENCES

[1] Seyssiecq, I. State-of-the-art: rheological characterisation of wastewater treatment sludge. *Biochem. Eng. J*, Vol. 16, 2003, 41–56.

[2] Yuansong, W. Minimization of excess sludge production for biological wastewater treatment. Wat. Research, Vol. 37**,** 2003**,** 4453–4467.

[3] Baudez, J.C., Rhéologie et physico-chimie des boues résiduaires Pâteuses pour l'étude du stockage et de l'épandage, Ecole nationale du génie rural, des eaux et des forets. Engref, France, thèse, 2001.

[4] Islam MR, "Conference proceedings", in Proc. 2nd Int. Conf. on GEOMAT, 2011, pp. 8-13.

[5] Abu-Orf, M.M., Dentel, S.K. Effect of mixing on the rheological characteristics of conditioned sludge: full scale studies, Water Sci. Technol, Vol. 36(11), 1997, 51–60.

[6] Gasnier, L., Florentz, M., Soleilhavoup, S. Utilisation des méthodes rhéologiques pour le conditionnement des boues de station d'épuration. Tech. Sci. Méth., Génie Urbain Génie Rural**,** Vol. 81(1), 1986. 81, 35–43.

[7] Forster, C.F. Preliminary studies on the relationship between sewage sludge viscosities and the nature of the surfaces of the component particules. Biotechnol. Lett, Vol. 12, 1981. 707–712.

[8] Slatter, P.T. The rheological characterisation of sludges, Water Sci. Technol, Vol. 36(11) , 1997. 9–18.

[9] Pevere, A., et al. Viscosity evolution of anaerobic granular sludge, *Biochem. Eng. J*. vol. 27**,** 2006. 315–322.

[10] Ladjel, F., and Abbou, S. Perspective de valorisation agricole et energétique des boues issues des STEP en Algerie, Ministère des ressources en eau, 2014.

[11] Hasar, H., et al., Rheological properties of activated sludges in a sMBR. Biochem. Eng. J, Vol. 20, 2004.20:1-6.

[12] Mu, Y., et al., Rheological properties of anaerobic hydrogen- producing flocs. *Biochem. Eng. J*, Vol. 34, 2007. 87-91.

[13] Forster, C.F.. The rheological and physico-chemical characteristics of sewage sludge. *Enzyme Microb. Technol*. Vol. 30, 2002. 340-345.