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SLUDGE DEWATERING: INFLUENCE OF OPERATING PARAMETERS ON DRYNESS LIMIT DETERMINATION

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Abstract

Dewatering process efficiency, classically assessed by a parameter “dryness limit”, is strongly affected by conditioned sludge properties and by operating conditions. The method to measure its parameter is based on a filtration-compression test, which depends significantly on operating conditions. A standard method is under progress in France to develop a better controlled procedure.

This paper presents the impact of solids load, pressure and compression time, filter cloth, flocculation conditions, pre-thickening and storage time on the dryness limit for different kinds of sludge. A comparison with industrial devices was also made.

Keywords: Dryness limit, sludge dewatering, flocculation, filtration-compression cell, drainage, polymer

INTRODUCTION

The effectiveness and cost of sludge treatment and disposal operations are strongly affected by the volume to be treated and the solids concentration (or water content). Consequently, thickening and dewatering are significant steps for the total sludge processing train. They both have a real impact on subsequent operations (storage, pumping, transportation and handling). Sorensen [1] reports that 30–50% of annual treatment operating costs relate to the sludge dewatering stage. Sludge conditioning generally enhances the removal of water during the thickening and dewatering process. Sludge is classically dewatered using centrifuge, filter-press, belt filter or screw filters. In every case, the process efficiency is strongly affected by sludge properties, and strongly linked to organic content, state of water and rheological properties [2]. That is why users and suppliers need a parameter to assess sludge dewaterability and a standard method for its measurement. Correlations were already highlighted between dewatered sludge dryness and simple parameters such as Capillary Suction Time (CST), dry and volatile matters, pH and conductivity, specific resistance to filtration, compressibility index, Mohlman index and centrifugation index, viscosity, drainability index [3]. Limit water content, corresponding to the minimum water content of the sludge cake reached after a constant pressure filtration for an infinite operating time, is another important parameter that can be useful to describe and forecast the efficiency of the filtration process by a single mechanical action.

The concept of the dryness limit was defined in the past French standard XP-T97001 Part 3 [4] developed in the early eighties. Suppliers and users of dewatering equipment need a parameter allowing the comparison of sludge dewaterability in referenced conditions. Despite the fact that “dryness limit” does not represent the dryness reached with industrial equipment, industrials agree that this is a fundamental datum giving guarantees on dewatering devices performances [5]. The problem of the XP-T97001 standard lies on the lack of information concerning main parameters (solids load, expression pressure and time) which strongly affect the dryness limit. A task group was recently created at the French standards authority (Afnor), in the

frame of the French mirror group of CEN TC 308 “Sludge characterization” to improve the method of determination of dryness limit. It gathers French suppliers, users and universities. A first document FD-T 97001 [6] was written listing all the parameters which can influence the measurement and recommends to precise them when a dryness limit value is provided. The objective of the research is to study the role of every operating condition listed in FD-T 97001-1 relative to sludge dryness in order to recommend values for analysts for the development of a future standard. Previous communications [7] [8] highlighted the role of 3 main parameters – solids load, pressure and compression time – on the dryness limit of a mineral and activated sludge and proposed a new procedure to reduce the duration of limit dryness experiments. This paper presents the influence of test duration, pressure, cake thickness, filter cloth, flocculation conditions, pre-thickening and storage on the dryness limit for different kinds of sludge (aerated, digested, water supply, industrial, mineral). Results of dryness limit are compared to the dryness reached with different industrial devices (centrifuge, belt press, filter press).

MATERIALS AND METHODS

Sludge and flocculants

Materials characteristics used in this study are summarized in table 1.

Table 1: Sludge and polymer characteristics

Flocculated sludge	Sludge				Flocculent			
	Type	WWTP	Dry solids (%)	Loss of Ignition (% DS)	Polymer	Supplier	Type	Dose (kg active matters/t DS)
A	Activated	Varenes (03, F)	1	53	EM 640 BD	SNF Floerger	Structured, highly cationic	7
B		Moulins (03, F)	3	72	EM 640 BD	SNF Floerger	Structured, highly cationic	7
C		Rouquet (47, F)	3	61	EM 640 TBD	SNF Floerger	Structured, highly cationic	6
D		Liege (B)	2.8	66	FeCl3 Setfloc 9112	Tessenderlo WVE GmbH	Structured, highly cationic	7
E		Noyal (35, F)	3	61	EM 840 HIB	SNF Floerger	Structured, highly cationic	6
F		Mineral synthetic	Kaolin + CaCl ₂	10.2	0	AN 926 SH	SNF Floerger	Linear, weakly anionic
G	Digested	Tours (37, F)	2.4	64	Zetag 8185	BASF	Linear, high cationicity	13
H		Troyes (10, F)	3.4	60	EM 340 CT	SNF Floerger	Linear, medium cationicity	9
I		Albi (81, F)	3.6	66	Zetag 9018	BASF	Structured, highly cationic	20

Flocculation and thickening

Prior to dewatering, sludges were flocculated to be more representative of industrial operating conditions. Sludge flocculation experiments were carried out with a new kind of device called “Bootest” developed by IFTS. This apparatus was initially used for validation of prEN 14742 standard concerning laboratory chemical conditioning procedure and already described in previous work [9]. Two flocculation tanks of 90 mm diameter each are stirred in similar conditions with measurement and control of time and speed mixing,

impeller position (in function of the sludge volume). Flocs are transferred automatically from the flocculation tanks to the drainage part of the Bootest. Drainage cells are equipped with filter cloth reference Si030904 supplied by Rai-Tillières (French manufacturer).

Sludge dewatering

Dewatering tests were carried out with a filtration-compression cell of 70 mm internal diameter (figure 1). A perforated disk was located at the bottom of the cylinder to support a synthetic filtering medium (most of the tests were performed with the referenced medium 05-25302-SK 025 from Sefar Fyrtis). The pressure was applied by a pneumatically driven-piston.

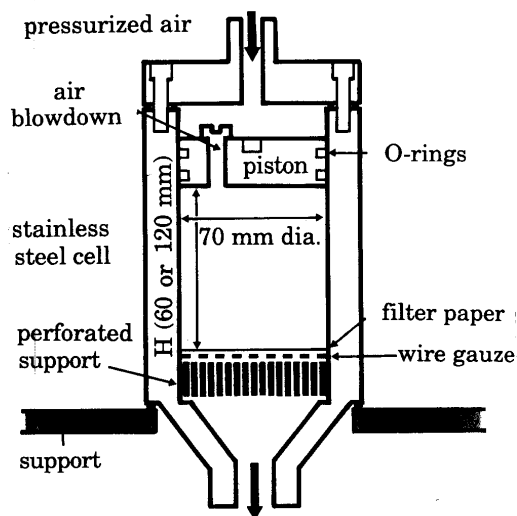


Figure 1: Filtration-compression cell

Flocculated sludge thickened by gravity drainage was used for filtration-compression tests. The mass of filtrate was recorded against time (by a weighing scale connected to a computer). The cake final dry matter content was measured by drying at 105°C.

RESULTS AND DISCUSSION

Choice of operating conditions for a new procedure for dryness limit determination

The dryness of biological flocculated sludge usually slowly increases with compression time, especially for highly compressible sludges. It reaches a constant value after a long compression time, often greater than 16 hours [7]. Consequently, the dryness limit of the filter-cake is generally not reached after a reasonable experimental time as illustrated in figure 2. A long dewatering time is not convenient for analysts and modifications of flocculated sludge properties during one day compression may occur.

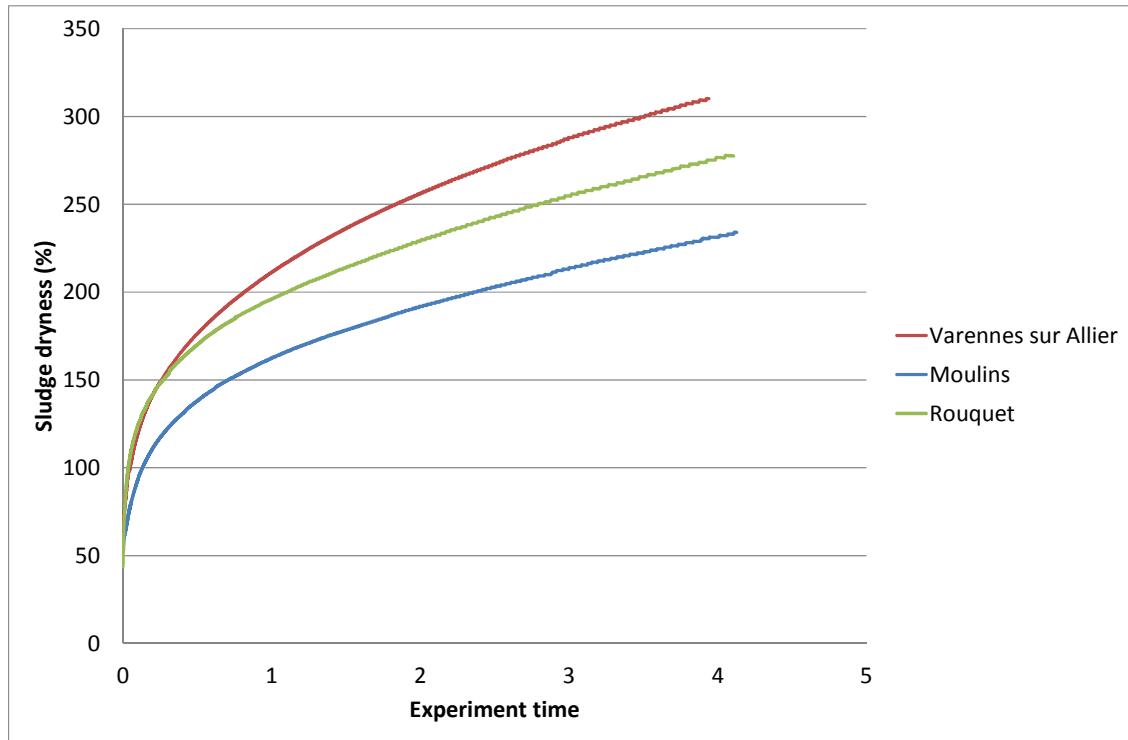


Figure 2: Evolution of different flocculated sludges (A, B, C) dryness versus compression time

The cake dry solids content corresponding to this asymptote is called dryness limit. It corresponds to the cake dryness obtained after an infinite operating time (as defined in FD-T 97001-1 [4]). The standard development aims at determining reference conditions to extrapolate the dryness limit from a 4-hours test. A simple mathematic model, classically used to fit consolidation behaviour [10] [11] is proposed to extrapolate cumulative curves of filtrate mass versus time obtained from a few hours experiment to an infinite time.

$$S = \frac{a * t}{b + ct} = \frac{a}{c + \frac{b}{t}}$$

The determination of the slope of the linearized form of the model enables to assess the dryness limit (S_{∞})

$$\frac{t}{S} = \frac{b}{a} + \frac{ct}{a} \quad S_{\infty} = \frac{a}{c}$$

Previous work [7] showed that the model fits well the compression data obtained with flocculated sludges thickened by gravity drainage. With mineral sludges a good agreement between experimental and model data is obtained over the whole compression time. For flocculated activated sludge (which is more compressible than mineral sludge), model fits better with experimental data when the sludge is well pre-consolidated, that is to say during the last 2 hours of the experiment as illustrated in figure 3. The comparison of sludge of different origins will be carried out on the basis of this method (extrapolation of data obtained after 2 hours of compression).

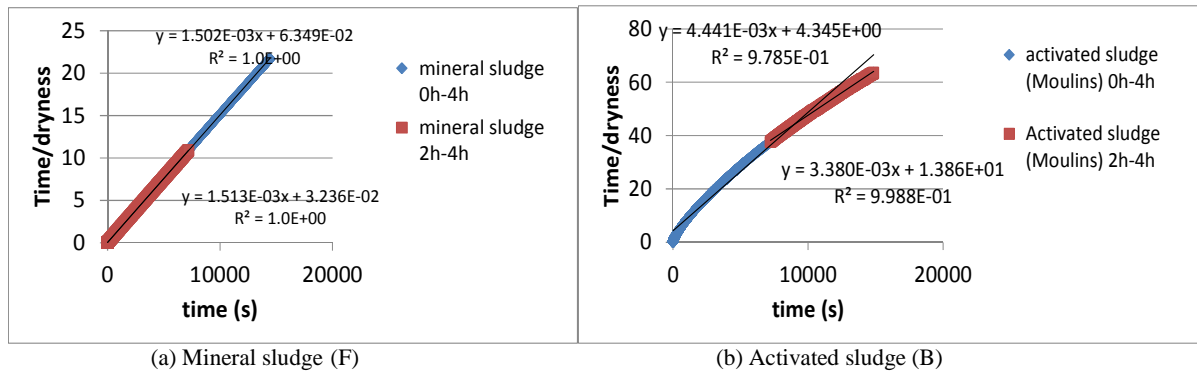


Figure 3: Comparison model (linearized form)/experimental data (a) Mineral sludge (b) Activated sludge

It is well known that sludge dryness is strongly influenced by cake thickness, the higher the cake thickness the lower the dryness. The influence of this parameter is coupled with the compression time [12]. Previous results [7] enabled to draft a new procedure where the reduction of cake thickness from 10 ± 0.5 mm to 5 ± 0.25 mm enables the decrease of compression time from 16 h to 4 h to obtain equivalent results in a filtration-compression cell. Figure 4 shows that cake thickness is a very sensitive parameter as a variation of 1.5 mm generates a variation of 2.5 points of dryness.

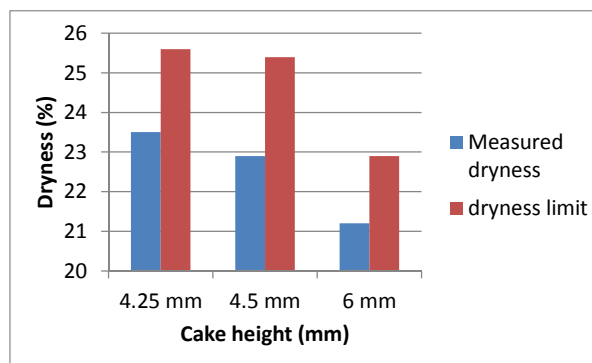


Figure 4: Influence of cake height on sludge dryness (flocculated sludge C)

The difficulty of the procedure lies on the fact that a preliminary test is necessary to adjust sludge mass to obtain the desired cake height (by determining cake porosity and solids density). Another possibility is to impose a given dry solids per filtration area unit but it may lead to different cake thicknesses. For example, the solids mass of sludge E needs to be increased from 1.5 kg DS/m^2 (loaded mass for sludge C) to 2.4 kg DS/m^2 to obtain the same cake dryness of 5 mm owing to differences in cake porosity (75.4% instead of 81.4%) and solids density (2.39 g/cm^3 instead of 1.59 g/cm^3).

Pressure has usually low influence on the final cake dryness obtained with urban sludge dewatering [5]. The behavior is generally different with mineral sludges. For example, the dryness limit of sludge F increases from 68 to 75% while pressure varying from 4 to 15 bar [7]. High pressure (30 bar) can lead to floc breakage if they have a weak mechanical resistance. Similarly, pressure rise has also low influence as illustrated in figure 5 which compares 3 protocols for 4 hours compression time.

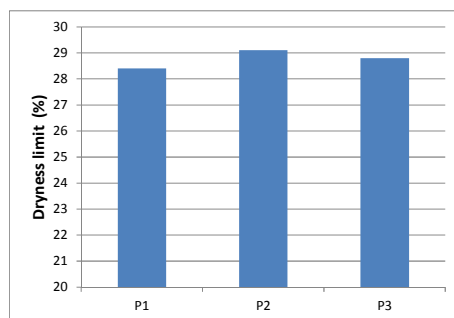


Figure 5: Influence of pressure rise on dryness limit (flocculated sludge C)
P1: 2bar-1h/3bar-1h/4bar-2h, P2: 2bar-0.5h/3bar-1.5h/4bar-2h, P3: 4bar, 4h

In the procedure, the applied pressure was 4 bar for an easy application in any filtration-compression cell.

Flocculation conditions may have a strong influence on dryness limit. The impact of 5 flocculation parameters (polymer cationicity, structure, dosing, mixing conditions and temperature) has been studied in previous work [8]. Polymer cationicity and structure influence the moisture distribution in the cake and the ability to liberate water by compression. Polymer dosing and mixing conditions mainly affect floc size distribution. Temperature affects mainly filtrate viscosity which has an impact on dewatering kinetics but not on the final cake dryness.

Sludge flocculation has to be controlled very carefully. For this reason, a specific device (Bootest) and an operating procedure (prEN 14742) have been developed to form flocs in a repeatable way.

Other parameters (filter cloth, storage during 5 days, pre-thickening by gravity drainage or not) have been tested in previous work [8]. The results showed only a little influence of these parameters on sludge dryness.

The developed procedure consists in filtration-compression of flocculated and thickened sludge during 4 hours at 4 bar to form cakes of 5 ± 0.25 mm thickness. The extrapolation of data obtained during the last 2 hours of compression with the mathematical model enables to calculate the so-called “dryness limit”.

Comparison of dryness limit measured at lab scale and industrial data

The dryness limit aims at giving maximal sludge dryness that can be obtained by mechanical dewatering equipment. The value obtained at lab scale (31.5%) for an activated sludge (sludge D) was compared to the free water content measured by thermo-gravimetric tests which was assessed to $26.9\pm 1.5\%$. This value is closed to the dryness obtained with the filter press (between 23 and 30% with a mean value of 25.8%). These results confirm that the dryness limit determined at lab scale is always higher than the dryness reached at industrial scale (table 2). This comparison was carried out with different devices like centrifuge (operating under conditions set to obtain the maximal dryness) and belt press. The ratio between the dryness obtained at industrial scale and the dryness limit depends on both the sludge nature and on the dewatering equipment. For activated sludge, the ratio varies from 0.8 (obtained with filter-press) to 0.5 (obtained with belt press). This ratio achieves 0.9 for digested sludges with centrifuge but falls to 0.6 with water supply sludges. This later is mainly composed of mineral matters and behaves differently from organic matters, A specific procedure could be imagined for this type of sludge.

Table 2: Sludge characteristics after dewatering

Boue	Type	dewatering device	Lab dryness (S _i)	dryness limit (S _∞)	Industrial dryness (S _i)	S _i /S _∞ (%)	S _i /S _∞ (%)
C	activated	centrifuge	25.5	28.1	20	91	71
D	activated	filter press 25 bar	28.9	31.5	24.9	92	79
E	activated	belt press	22.8	32.4	17	88	52
G	digested	centrifuge	22.8	27.6	23	83	83
H	digested	centrifuge	23.4	31.9	27	73	85
I	digested	centrifuge	21	24.4	22	86	90
J	water supply	centrifuge	47.8	49.3	30	97	61
K	water supply	centrifuge	33.4	39.4	23	85	58
L	food	centrifuge	20.8	21.8	19	95	87
M	MBR	centrifuge	25.5	29.3	20	87	68

CONCLUSIONS

The concept of “dryness limit” is a useful index to assess sludge dewaterability. It is measured at lab scale from a filtration-compression test. As the definition refers to the dryness obtained after an infinite time, the use of a mathematical model is necessary to extrapolate data obtained in a reasonable experiment time. The dryness limit significantly depends on final cake thickness, expression pressure and compression time. A consensus will have to be found to select these parameters for the development of a future standard. A new simple procedure has been developed to achieve tests in a reasonable time (4 hours) with a moderate pressure (4 bar) and a measurable cake thickness (5 mm) to have a reference value. Obviously, sludge flocculation has also an impact on the sludge dryness and should be carried out in a repeatable way, as recommended by the standard prEN 14742.

The reference value of dryness limit should facilitate the discussion between end-users and suppliers of dewatering machines. Suppliers should give guarantees on their equipment performances on the basis of dryness limit according to their own experience. The ratio between dryness obtained at industrial scale and the dryness obtained at lab scale depends on dewatering equipment and sludge type. It varies from 0.5 to 0.9 which shows that the dryness obtained at lab scale (in the proposed reference conditions) represents a “limit” to sludge mechanical dewatering.

Further work should be done to consolidate the experimental procedure and to carry out common tests with organisations involved in the project.

The authors acknowledge all the participants of the French mirror group for their contribution in this work and suppliers and end-users who provide all the sludges.

SYMBOLS

a, b, c: constant parameters
 DS: dry solids or dry matters
 S: sludge dryness
 S_∞: dryness limit
 t: compression time (s)
 VM: volatile matters

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