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# DRYNESS LIMIT: A USEFUL PARAMETER TO ASSESS SLUDGE DEWATERING

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## Abstract

It is usually recognized that sludge management is a major problem in water and wastewater treatment, as it can account for up to 50% of total operating costs. The effectiveness and cost of sludge treatment and disposal operations are strongly affected by its volume. Hence, the water content (or solids concentration) of the sludge is a key parameter which can impact the different steps of the whole treatment. Consequently, thickening and dewatering are key steps in the total sludge processing train. Sludge is classically dewatered by centrifuge, filter-press, belt filter or screw filters. In every case, the process efficiency is strongly affected by sludge properties. That is why users and suppliers need a parameter to assess sludge dewaterability and a standard method to measure it. Suppliers might use this standard data to guarantee dewatering performances of their equipment.

The dryness limit is a well-known parameter used by French actors of sludge treatment. It is classically measured by a filtration-compression test until filtrate flowing stops. However, for highly compressible sludges, this condition is difficult to reach. That is why a simple mathematical model fitting compression data was used to extrapolate data for dryness limit assessment.

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. The influence of test time, pressure, cake thickness, filter cloth, flocculation conditions, pre-thickening and storage time on the dryness limit was strongly discussed for different kinds of sludge. The results enable to establish a proper procedure to measure the dryness limit. This limit is always higher than the dryness reached with industrial devices. The deviation depends mainly on the sludge nature and the type of dewatering equipment used.

## Keywords:

Dryness limit, Sludge dewatering, Flocculation, Filtration-compression cell

## INTRODUCTION

The effectiveness and cost of sludge treatment and disposal operations are strongly affected by its volume and, thus, by water content or solids concentration. Consequently, thickening and dewatering are important steps in the total sludge processing train. They both have a serious 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 by 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].

Users and suppliers need a parameter and simple methods to assess sludge dewaterability in industrial devices. Correlations were 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, is another important parameter that can be useful to describe and forecast the efficiency of the filtration process or a single mechanical action.

This parameter is all the more interesting as it gives a limit to sludge dewatering performances linked to intrinsic sludge properties. Suppliers and users of dewatering equipments agree on the fact that it is a fundamental datum of sludge to give guarantees on the performances of their machines. Nevertheless, a standard method is still required. The concept of the dryness limit was defined in the old French Standard XP-T97001 Part 3 [4] developed in the early eighties. It represents the theoretical maximal dryness reached by filtration-compression test after an infinite operating time. Although, it does not represent the dryness reached with industrial equipment but this parameter enables to compare the dewaterability of sludges in reference conditions. Each supplier had its own correlation between the dryness limit and the dryness obtained on their equipment [5]. The problem of the XP-T97001 Standard lies on the lack of information concerning solids load, expression pressure and time which strongly affect the dryness limit. A task group was recently created in Afnor organization, in the frame of the French mirror group of CEN TC 308 “Sludges 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 present work aims to impose the operating conditions for the development of a future standard.

Previous communication [7] highlighted the role of 3 main parameters: solids load, pressure and compression time on the dryness limit of a mineral and activated sludge. This paper highlights the influence of pressure and cake thickness aiming at the reduction of the duration of limit dryness experiments. It also studies the role of other parameters: flocculation conditions, filter cloth nature, storage time, gradual increase of pressure. It compares laboratory results with sludge dryness reached with industrial devices.

## MATERIALS AND METHODS

### Sludge

Experiments were carried out with different kinds of sludges:.

- Activated sludge was sludge in four different French municipal wastewater treatment plants (WWTP): Moulins (3% DS, 72% VM), Varennes sur Allier (1% DS, 53% VM), Rouquet-Agen (3% DS, 61% VM) and Noyal sur Vilaine (3% DS, 61% VM)
- Drinking water treatment sludge (2.5% DS, 25% VM) sampled at Apremont
- Digested sludge (3.6% DS, 66% VM) sampled at Albi WWTP
- Food industry sludge (2.6% DS, 75% VM)
- Synthetic mineral sludge (11.6% DS, 0% VM) composed with a mixture of kaolin (10% DS) and calcium chloride (0.165% DS)

### Polyelectrolytes

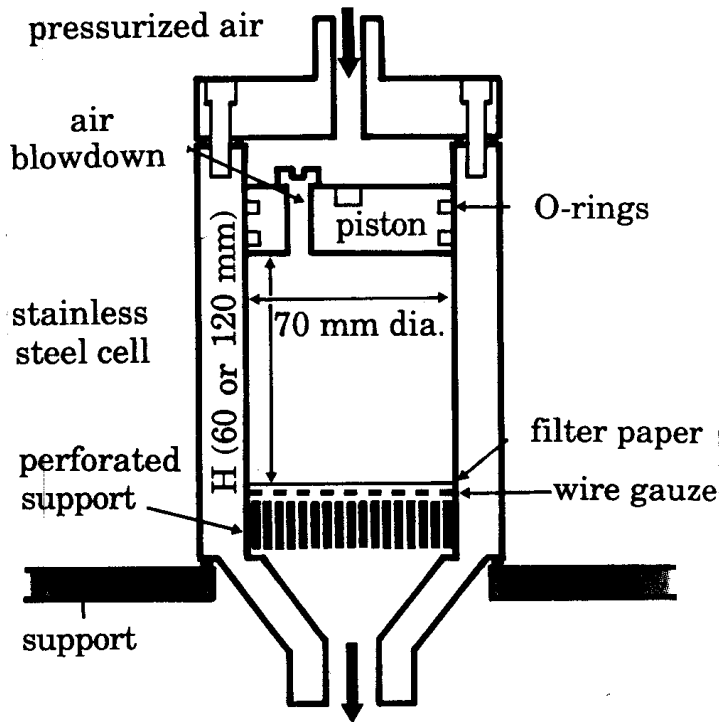
Cationic polymer with different charge densities, molecular weights, physico-chemical form (powder, emulsion) and structure (linear chain, cross-linked backbone, structured) were supplied by two manufacturers: SNF FLOERGER and BASF. The amount of polymer solution used was fixed against the quantity of dry sludge (kg/T DS), according to the optimal dosage of polyelectrolyte (actives matters).

### Flocculation and thickening

Sludges were flocculated before dewatering 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 [8]. The 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. Three different filter clothes, supplied by Sefar Fyltis (France) and referenced as: 05-1001-SK 025, 05-1010-SK 008 and 04-1010-K-006, were used in this study. The pressure was applied by a piston moved pneumatically.



**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 over the experiments. It reached an asymptote where no filtrate was released from the cake by mechanical compression. The cake dry solids content corresponding to this asymptote was called dryness limit. It corresponds to the cake dryness obtained after an infinite operating time (as defined in FD-T 97001-1 [4]). For compressible sludge, it is generally difficult to reach the asymptote in a reasonable test time. It is the reason why we proposed to use a simple mathematic model to extrapolate cumulative curves of filtrate mass versus 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 ( $S_{\infty}$ )

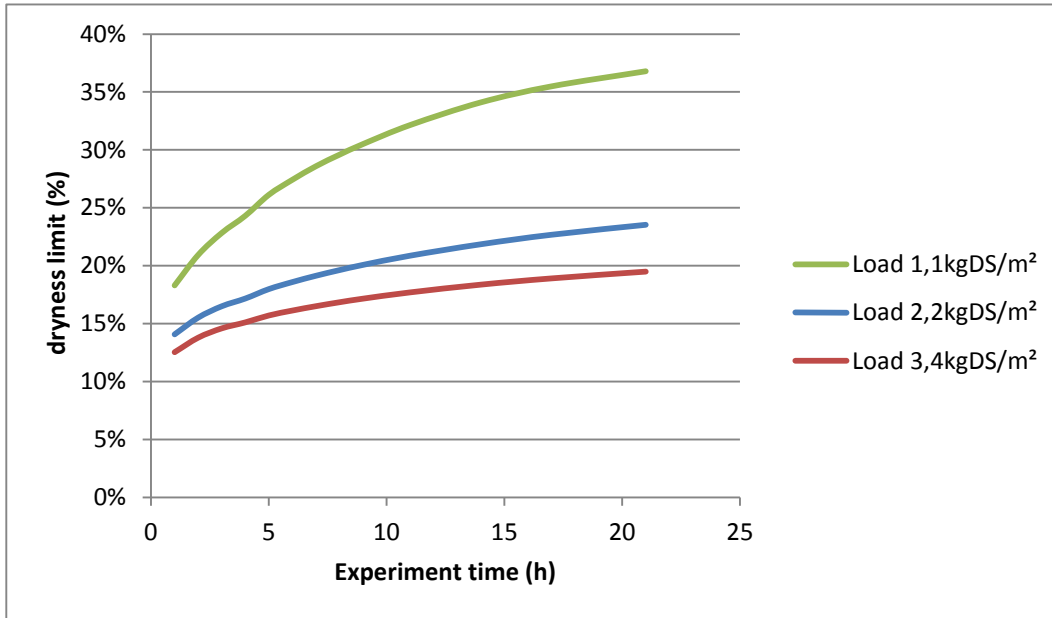
$$\frac{t}{S} = \frac{b}{a} + \frac{ct}{a} \qquad S_{\infty} = \frac{a}{c}$$

Previous work [7] showed that the model fits well compression of flocculated sludges thickened by gravity drainage.

## RESULTS AND DISCUSSION

### Choice of operating conditions for dryness limit determination

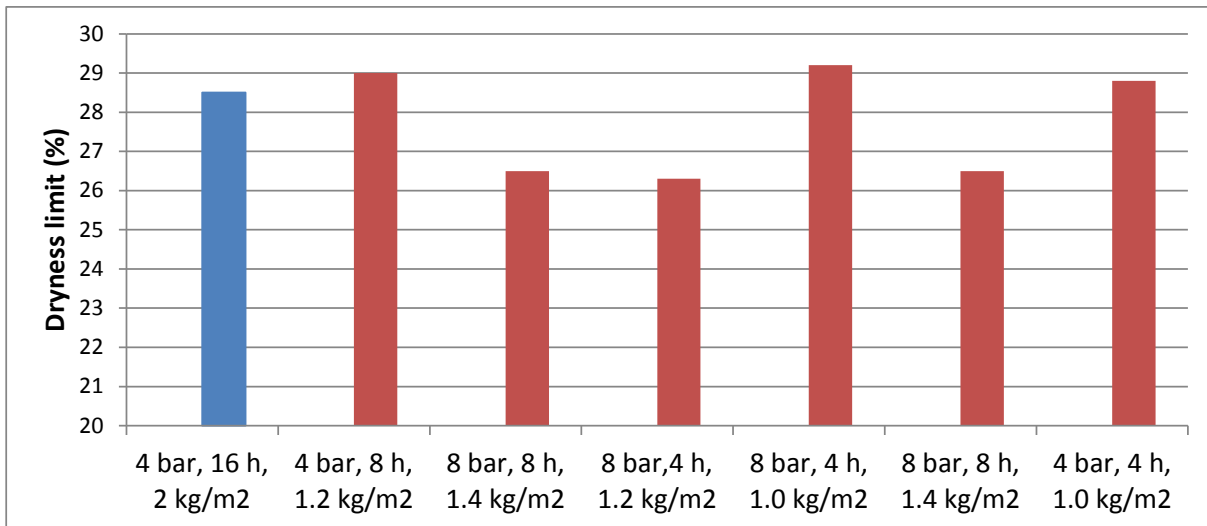
The dryness of biological flocculated sludge usually increases slowly with compression time, consequently, the dryness limit of the filter-cake is often reached after 24 hours of running test. Sludge dryness limit depends also strongly on solids load and consequently on the final cake thickness as illustrated in figure 2.



**Figure 2:** Evolution of dryness limit at 4 bar with activated sludge (Vareennes WWTP) flocculated with a reticulated polymer (EM 640 BD from SNF Floerger) at 7 kg /t MS

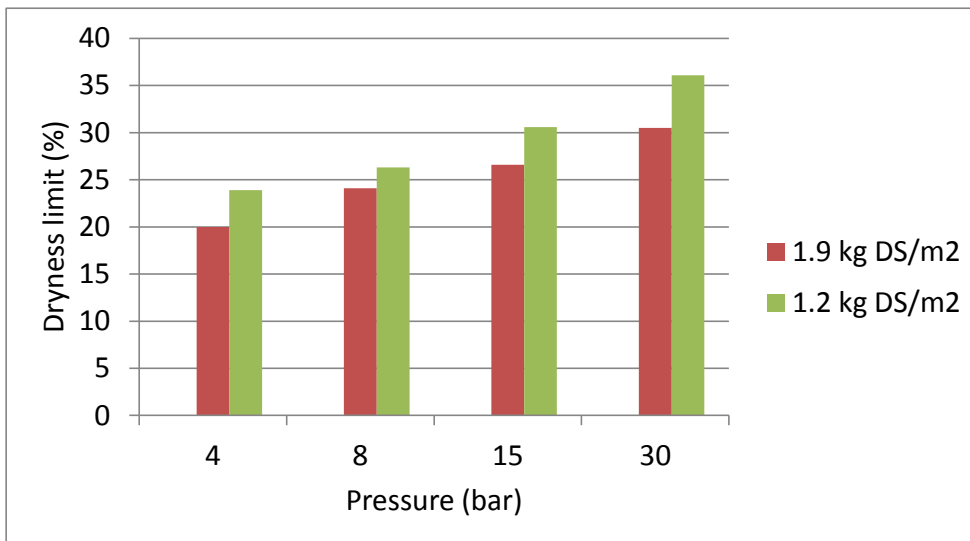
With regards to the results reported on Figure 2, the compression time is too long to offer useful test. A part of the present work aimed to find reference conditions to achieve equivalent results with test no longer than 4 hours. Moreover, an excessively long compression time (16 h) or an excessively high pressure (30 bar) can lead to the breakage of weak flocs. A decrease of dryness limit from 72% to 50 (30 bar) or 55% (16 h) was observed for kaolin sludge flocculated with anionic polymer AN 926 SH at 2 kg/T MS.

Figure 3 compares dryness limit of activated sludge (Rouquet WWTP) for various dewatering conditions. The results show that experiment time could be decreased from 16 h to 4 h, when the sludge load was reduced from 2 to 1 kg DS/m<sup>2</sup> (that corresponded in our case to a final cake thickness of 5±0.5 mm).



**Figure 3:** Evolution of dryness limit with activated sludge (Rouquet WWTP) flocculated with a reticulated polymer (EM 540 BD from SNF Floerger) at 15 kg /t MS

Nevertheless, less thick cakes are more sensitive to pressure. we observed on figure 4 that the sensitivity to pressure increased when cake thickness decreased. For a pressure ranging between 4 and 30 bar the deviation may achieve 12% for a 5 mm-thick cake (1.2 kg DS/m<sup>2</sup>). The reference pressure will be 4 bar as it is generally well adapted to run tests in classical filtration-compression cells.



**Figure 4:** Evolution of dryness limit with activated sludge (Rouquet WWTP) flocculated with a reticulated polymer (EM 540 BD from SNF Floerger) at 15 kg MA/t MS

Table 1 summarizes the dryness limit reached with different sludge origins. The results are presented for two laboratory protocols (P1. compression time: 16 h, final cake thickness: 10±1 mm and P2. compression time: 4 h, final cake thickness: 5±0.5 mm), in comparison to dryness achieved with industrial devices. They show a quite good agreement between the two laboratory protocols except for one activated sludge (to be checked in further work) and for mineral sludge. For the latest, the protocol might be

adapted as this type of sludge behaves quite differently from biological sludges (as showed in previous work [7]).

**Table 1: Sludge characteristics after dewatering**

Sludge	Flocculation conditions		Dryness limit (%)		Dryness machine*	
	Polymer	Dose (kg/ MS)	P1	P2	Value (%)	Ratio
1.Activated sludge (Rouquet)	EM 540 BD	15	28.5	28.8	21	0.73
2.Activated sludge (Noyal)	EM 840 HIB	6	29.9	24.9	17	0.68/0.57
3.Activated sludge (Varennnes)	EM 640 BD	7	32.7	32.8	-	-
4.Digested sludges (Albi)	Zetag 9018	20	25.5	24.4	22	0.86 / 0.90
5.Water supply (Apremont)	Zetag 8140	7	36	35.7	23	0.64
6.Food (Royan)	EM 640 TBD	21	21.8	21.8	19	0.87
7.Kaolin sludges	AN 926 SH	2	68	71.9	-	-

\*1 : centrifuge – 2 : belt press – 3 : no dewatering device- 4 : centrifuge – 5 : centrifuge – 6 : centrifuge – 7 : no data (synthetic sludge)

The dryness reached with centrifuge corresponds to 0.8-0.9 of the dryness limit when the operating conditions are optimized for a dewatering purpose (that was probably not the case for Rouquet WWTP).

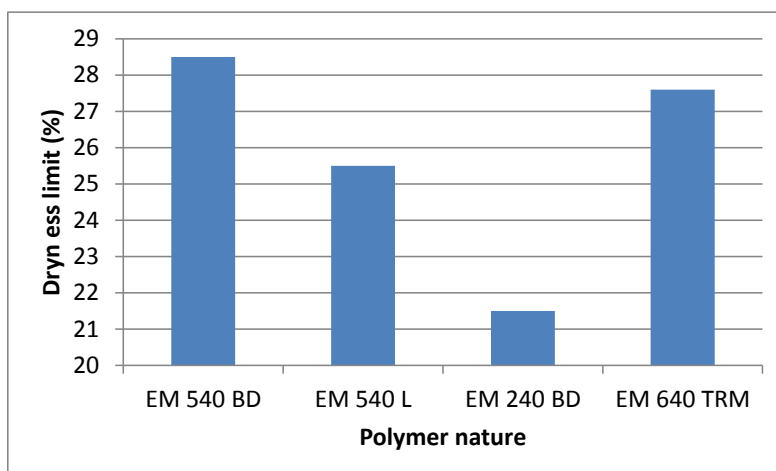
The ratio between laboratory and industrial data is lower-for belt press (between 0.6-0.7).

**Influence of other parameters**

In order to consolidate the laboratory protocol, the impact of other parameters, less relevant than pressure, compression time and cake thickness was studied.

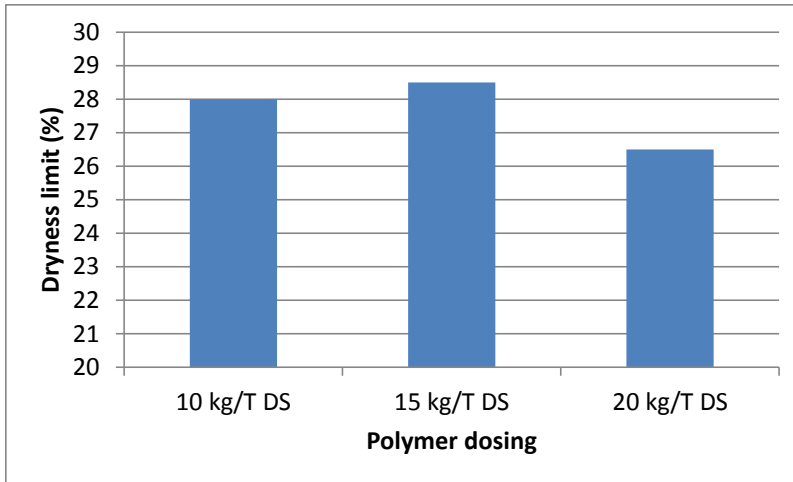
*Influence of conditioning conditions*

The influence of 4 main parameters was studied: nature of polymer, dose of polymer, mixing time and sludge temperature before flocculation. Results are illustrated on figures 5, 6, 7 and 8.

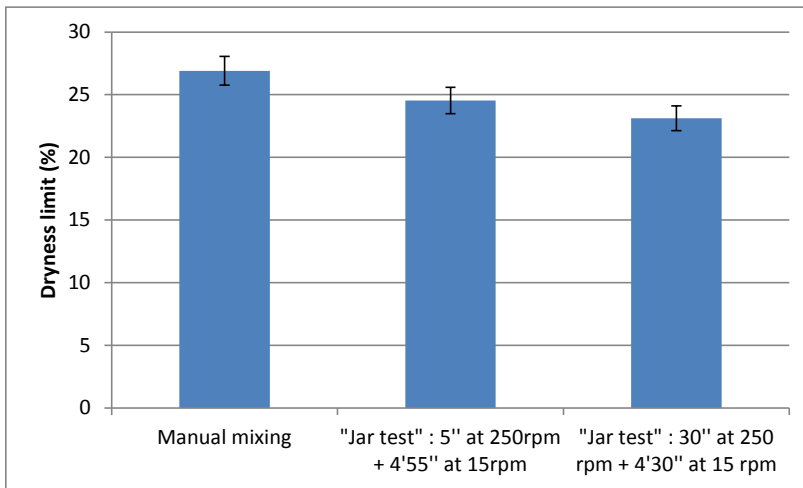


**Figure 5:** Influence of the polymer nature on dryness limit (protocol P1) with activated sludge (Rouquet WWTP) at dosage of 6 kg/T DS (only for EM 640 TRM) and 15 kg/T DS (other polymers)

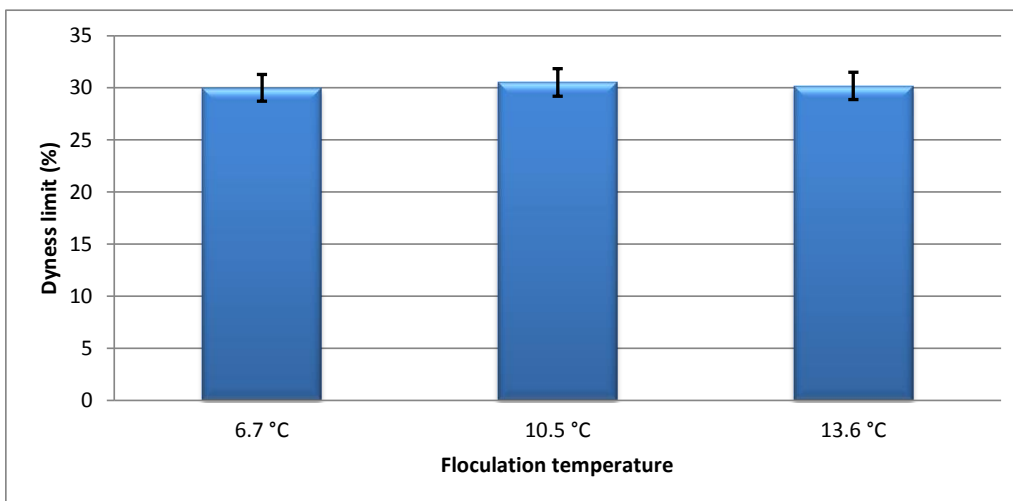




**Figure 6:** Influence of polymer dose on dryness limit (protocol P1) with activated sludge (Rouquet WWTP) flocculated with EM 540 BD polymer (Bootest)



**Figure 7:** Influence of polymer mixing with sludge on dryness limit (protocol P2) with activated sludge (Varennnes WWTP) flocculated with EM 640 BD at 7 kg/T MS

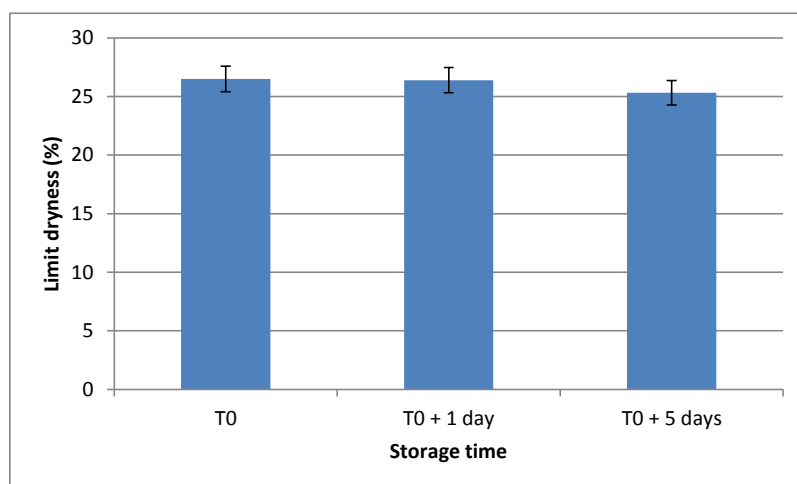


**Figure 8:** Influence of sludge temperature before flocculation on dryness limit (protocol P2) with activated sludge (Varennnes WWTP) flocculated with EM 640 BD at 7 kg/t MS

These figures show that the most sensitive parameter is the nature of the polymer whose the cationicity and the structure influence the state of water within the cake and thus the ability to liberate water by compression. The polymer dose has a lower influence provided that sludge is properly flocculated. Overdosing increases viscosity of filtrate and can delay the release of water and cake structuration. The influence of mixing of sludge with polymer on sludge limit dryness determination is rather significant as sheared flocs are generally more difficult to dewater. It is important to control hydrodynamic parameters according to European standard prEN 14742 to obtain a repeatable flocculation. Temperature of sludge has no significant effect on the dryness limit.

#### *Influence of storage time*

Time storage of sludge before flocculation and compression was evaluated and its influence on dryness limit is illustrated figure 9. For these experiments, sludge was stored at 4°C.



**Figure 9** : Influence of sludge storage time before flocculation on dryness limit (protocol P2) with activated sludge (Moulins WWTP) flocculated with EM 640 BD at 7 kg/t MS

Results show that tests can be carried out over the full first working week after reception.

#### *Influence of filter cloth*

Tests carried out with flocculated the activated sludge from Rouquet plant (protocol P1) show a difference of 2% on the dryness limit which decreased from 28 to 26% when the permeability of the filter cloth increased. Differences of the same order of magnitude were observed with the activated sludge from Moulins plant. Results have to be completed to check if this effect is significant.

#### *Influence of pre-thickening*

Comparative tests carried out on flocculated sludge and thickened flocculated sludge by gravity drainage did not point out significant differences on the final sludge dryness. Nevertheless, the application of the mathematical model is valuable only for pre-thickened sludge.

## CONCLUSIONS

The concept of “dryness limit” is a useful index to assess sludge dewaterability, nevertheless, it significantly depends on solids load, expression pressure and compression time. A consensus will have to be found to select these parameters for the development of a future standard and a new simple protocol has been developed to achieve tests in a reasonable time (4 hours) 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 exchanges between end-users and suppliers of dewatering machines who should give guarantees of their machine performances on the basis of this value according to their own experience.

Further work should be done to consolidate the experimental protocol and to carry out common tests with organisms 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

DS : dry solids or dry matters

$S_{\infty}$  : dryness limit

t : compression time (s)

VM : volatile matters

a, b, c : constant parameters

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