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# Improved process control of an industrial sludge centrifuge-dryer installation through binary logistic regression modeling of the fouling issues

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ABSTRACT

Biological wastewater treatment generates huge amounts of waste sludge which need to be dewatered and eventually dried to minimize transportation and incineration costs. A characteristic feature of sludge in this context is that it turns into a sticky substance during its drying process inducing fouling problems in the drying installation. At the wastewater treatment plant of Monsanto in Antwerp, Belgium, one enclosed centrifuge-dryer system is used to dry the sludge. In the past, this installation had to be shut down regularly due to dryer fouling problems. To avoid these operational problems, a binary logistic regression analysis is presented in this research based on a 5-year database, resulting in an empirical model for the evaluation of the dryer fouling risk as a function of the sludge feed characteristics. The model inputs are the sludge volume index (SVI) and the dosing of clay additive and tertiary (flotation) sludge, the latter containing polyaluminumchloride (PACl), to the sludge feed of this particular system.

By exploiting the knowledge captured by this model, the derived control strategy is based on the value of the SVI. Whenever the SVI is high the original high clay dosing to the feed needs to be maintained. At moderate SVI values, implying an intrinsically better sludge dewaterability, the strategy dictates a reduction in the clay dosing to the sludge feed to have a reduced sludge solids dryness after dewatering, thereby avoiding that the sludge exhibits its most sticky phase when passing the most fouling sensitive part of the dryer. When the SVI is lower than 50 mL/g the control strategy states that conditioning of the sludge with PACl is required to mask the stickiness instead of postponing it, avoiding that the stickiness of the sludge already hampers the dewatering stage of the process.



## 1. Introduction

Treatment of industrial and municipal wastewater generates huge amounts of excess activated sludge, mainly as a result of increasingly stringent environmental regulations. According to Sanin et al. [1] the sludge production rate amounts to 60 g dry solids/person/day on average for the European Union Member Countries. Because the cost for the waste sludge handling can amount to 50% of the total operational cost of the wastewater treatment plant (WWTP) [1], sludge minimization techniques are extensively being studied. However, the remaining excess sludge still has to be treated, for which thermal drying, after a first mechanical dewatering step, is an essential processing step to reduce the sludge volume (and related costs) for further downstream processing like storage, transportation and (co-)incineration [2,3].

Carleton and Heywood [4] formulate a general truth in solid–liquid separation processes in that many of the problems in these unit operations do not arise from a failure of the equipment to perform its basic function, but from difficulties in discharging the thickened product and in its subsequent handling. Difficulties arise because conventional designs optimize only the unit operations and do not take into account the (changing) nature of the product or possible handling problems [4].

In industrial sludge drying installations, the stickiness phenomenon of drying sludge is a major issue, which is the case, e.g., in the combined centrifuge-dryer (Centridry®) operation of Monsanto's WWTP in Antwerp, Belgium, where a mechanical dewatering step of the sludge is combined with a flash drying stage of the resulting solids [5]. During the progress of drying, the sludge has a plastic-rubbery, pasty consistency at some intermediate moisture content range, referred to as the *sticky phase* of drying activated sludge [6–8]. The sticky phase of the Monsanto sludge appears in the range from approximately 25% to 40% dry solids (DS) in the case the sludge comprises 51% inorganic material [6]. At that moment, when partially dried, the sludge tends to agglomerate and

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**List of sysmbols**

| | |
|---|---|
| ANOVA | analysis of variance |
| AUROC | area under the ROC |
| $b_0$ | constant value in the binary logistic regression, Eq. (3) |
| $b_i$ ($i$ = 1–3) | coefficient of the explanatory variables $X_i$ in the binary logistic regression, Eq. (3) |
| DAF | dissolved air flotation |
| DF | degrees of freedom |
| DS | dry solids |
| $L$ | likelihood function, Eq. (4) |
| LDA | linear discrimination analysis |
| MLE | maximum likelihood estimation |
| $N$ | number of data |
| $P$ | probability of an event occurring (%) (in this study, the event is fouling occurring on the sludge dryer wall) |
| $p$ ($p$-value) | used in statistical testing. It is the probability of obtaining the results in a given data set, in the case the null hypothesis is true |
| PACl | polyaluminumchloride |
| $R^2$ | square of the correlation coefficient; amount of variation explained by a regression |
| RAS | recycle activated sludge |
| ROC | receiver operating curve |
| SE | standard error |
| SRT | sludge retention time (days) |
| SVI | sludge volume index (mL/g) |
| VIF | variance inflation factor |
| WAS | waste activated sludge |
| WWTP | wastewater treatment plant |
| $X_i$ ($i$ = 1–3) | explanatory variables $i$ in the binary logistic regression, Eq. (3) |
| $Y_i$ ($i$ = 1, 2, . . .) | observed value (0 or 1) of the binary variable for case $i$ |

adhere to the dryer walls, changing its hydrodynamics as a result of lump formation and subsequent growth onto the dryer walls. These lumps result in operational problems, hereby significantly reducing the dryer capacity [5]. Researchers describe this property of drying sludge appropriately as a *phenomenon*, to illustrate the very little that is known about this complex sludge property [7] although, recently, the existence of the sticky phase of drying sludge is proposed by Peeters [9] to be the result of the formation of a dense, strong and stiff rigid network of extracellular polymeric substances as a result of the reduction in the sludge's water content during the course of drying.

To avoid the stickiness related fouling problems in dryer installations, a relationship between this fouling phenomenon and the sludge feed characteristics needs to be derived, which is accomplished in this work through a binary logistic regression based model. To this end, an extended database has been compiled covering almost 5 years of operational experience with the Centridry® technology on site, including a wide variation in the sludge settleability, expressed in terms of the sludge volume index (SVI), and feed stream characteristics. To the best of the authors' knowledge, so far, no other studies can be found that correlate sludge feed characteristics with the fouling issues in a sludge dryer. Moreover, although the binary logistic regression tool is well-established in the field of, e.g., social sciences research, medicine and business-economics, it has rarely been used in the (bio)chemical process industry to model process issues that are binary in nature (like, e.g., plugging of equipment or piping, or the blinding of filters), to improve process control. Hence, this case study could serve as an example of how this powerful statistical tool can be used in the (bio)chemical industry to attain better process control.

## 2. Changing sludge characteristics

The wastewater treatment plant (WWTP) at the Monsanto Europe site in Antwerp, Belgium, is a conventional activated sludge process [10], treating the wastewater of 8 manufacturing plants on site. A flow scheme of the WWTP is depicted in Fig. 1. The excess sludge (waste activated sludge, WAS) is sent to the combined centrifuge-dryer system (Centridry®) to be reduced in volume. The average sludge retention time (SRT) is 30 days. Fine sludge flocs which do not settle in the clarifier are removed in the flotation unit (dissolved air flotation, DAF) with addition of coagulant (polyaluminumchloride, PACl) and an anionic polymer as flocculant. The sludge removed from this flotation unit is also sent to the Centridry®, the latter is discussed in Section 3 and depicted in Fig. 2.

Periodic changes in the $Ca^{2+}$ concentration from 100 to 1300 ppm in the wastewater [11] result in significant variations in the SVI, one of the key sludge characteristics for WWTPs based on the conventional activated sludge process. The SVI is a long established measure of sludge settleability [1,10] and is the volume (in mL) occupied per gram of sludge after 30 min of settling in a lab sedimentation cylinder. A low SVI indicates a good settling sludge and vice versa. The SVI at the WWTP under study varies over time between 20 and 120 mL/g, with the lower SVI values being predominantly induced by $CaCO_3$ precipitates in the flocs which make the flocs heavier [12].

## 3. Centridry® technology

The flow scheme of the Centridry® installation is depicted in Fig. 2. This technology combines conventional centrifugal dewatering (in a decanter centrifuge) with thermal drying (in a flash dryer), both processes taking place in a single (compact and enclosed) apparatus. For details about this installation, the reader is referred to Peeters [5,9]. In short, firstly the sludge is dewatered in the decanter centrifuge. Secondly, the sludge cake leaving the centrifuge is immediately disintegrated by impact on an impact cone surrounding the cake discharge part of the centrifuge. A hot gas stream entrains the resulting fine solids spray, which starts immediately flash drying. The final product of typically 95% DS is separated from the gas stream in a cyclone.

### *3.1. Operational issues within sludge drying units: conventional systems versus Centridry®*

Most of the dewatering–drying technologies used in industry rely on a separate dewatering step in vacuum filters, belt filter presses, centrifuges, or membrane filters. The dewatered solids are then temporarily stored, after which they are conveyed to the next stand-alone drying unit [1,2]. The widely applied operational practice for these systems implies that final dried material is recycled and mixed into the fresh dryer feed of dewatered solids, to avoid the sludge in the dryer to go through its dryness range wherein it exhibits its sticky consistency. This way, the dry solid content of the sludge is brought beyond typically 70% from whereon they do not foul the dryer anymore [1,2].

Because the Centridry® technology is one enclosed system, avoiding the storage of the sludge in between the two unit operations, the practice of back mixing dried solids is, obviously, not feasible. While the continuous transition from centrifugation to drying is what makes the Centridry® a unique technology, it is also its proverbial Achilles' heel. Fouling in the Centridry®