EXPERT SYSTEM FOR CONTROL OF INDUSTRIAL-SCALE ANAEROBIC DIGESTORS

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ABSTRACT

An expert system (ES) named MSAD (Mixed Sludge Anaerobic Digestion) has been developed to control a conventional sludge stabilization process consisting of two digesters working in parallel. The two digesters treating a mixture of primary and secondary sludge were operated with an Hydraulic Retention Time (HRT) of 24 days. Adequate mixing of the digestion liquor was provided by injecting part of the produced biogas into the digesters. Part of the heating from biogas combustion was used as heating source for operating the digestion process in the mesophilic range. The MSAD was built on both simple and fuzzy rules, written with wxCLIPS 1.61 for Windows (an specific E.S. builder). During operation parameters such as organic load (B_v), temperature (T), hydraulic load, FVA, and alkalinity, were determined daily and registered in an external ".xls" database. This information was used by the MSAD as input providing as output not only some conventional information but also specific solutions to commonly encountered operation problems that are detected by the MSAD. The ES outputs include diagnostics, forecasts, and recommendations for operating the digesters. Also the MSAD provides with the graphic representation of some parameters evolution and stores valuable legal information.

KEYWORDS

Anaerobic digestion; expert systems; fuzzy; industrial operation; sludge.

INTRODUCTION

The anaerobic digestion of the excess sludge generated by wastewater treatment plants aims its stabilization, i.e. the reduction of volume, pathogens content, offensive odors and its putrefaction potential. The anaerobic digestion process involves the complex metabolism of microorganisms undergoing decaying processes, with poorly known dynamics influenced by a lot of external variables. The experimental difficulties together with the intrinsic uncertainty when determining some crucial parameters such as the concentration of active microorganisms and some intermediate metabolites, do not recommend the usage of detailed mechanistic models. In consequence the modeling of sludge digestion processes is often limited to the macroscopic level and in practice, the control of anaerobic digestion processes is commonly based on empirical and subjective decisions. The usage of Expert Systems seems to be an acceptable alternative to these practices, since ES are based on imitating the human reasoning. MSAD is a simple, easy to use tool to control an industrial anaerobic stabilization process. It follows a previous ES developed at the University of Valladolid by Fdez Polanco et al. (1992). Release 1.0 was installed a few months ago; and nowadays release 1.1 is being developed, including new operating data and user's comments. A simple plant layout of the digestion process appears in Figure 1. According to the process the main features of the ES is that:

1. the two digesters are modeled separately, instead of one reactor of double volume.
2. the primary and secondary sludge entering into the digesters were differentiated and considered separately in the modeling. It is known that secondary sludge has a higher VS content that is more difficult to stabilize.

MSAD has been built for PC with Windows 95/98/NT. The programming tool used, WxCLIPS 1.61 (an Expert Systems builder), was selected for keeping the hardware and software requirements to a minimum. The only additional software used was a database under ODBC (dbf, .xls, .dbt ...). According to this, MSAD was built to provide a specific rule-when writing syntax and Fuzzy Logic.

SOFTWARE DESCRIPTION

Inputs and Outputs

The following parameters were daily registered in the xls database and further used as quantitative inputs of the ES: influent flow rate (m^3/d) of primary and secondary sludge, B_v (kg VS/m^3 d), temperature (°C), pH, concentrations of TS and VS (g/L) entering and leaving the digesters, CH_4 and CO_2 molar fractions in the biogas, FVA concentration (mmol/L), and alkalinity (mmol/L). Optionally, the following information can be directly introduced by the user in the ES through the window displayed by MSAD: concentration of TSS at four digester levels, size of the torch flame (high, small or none), color of the digested sludge (black...), presence of foam (yes or not), and the operation state (transient or not).

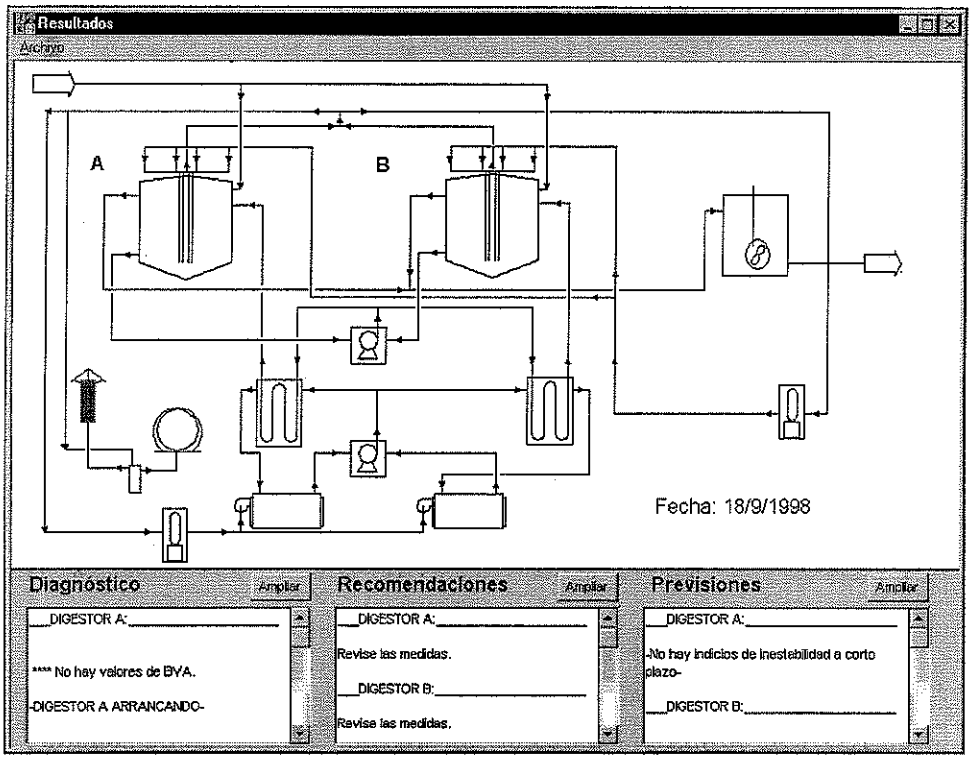


Fig. 1. *Results* window

The main MSAD output is the *Results* window (Fig. 1), in which warning information is displayed in three colors (yellow, green, and red) representing situations of warning, low risk and high risk, respectively. Also three brief reports, with three associated buttons for extended explanation, are displayed informing on the actual situation of each digester and recommending actions to solve any encountered operation problem:

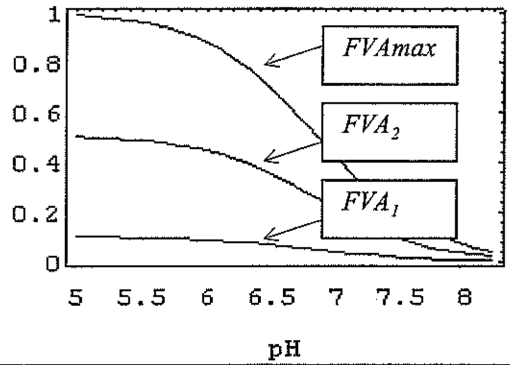
- ✓ Diagnostic report. Based on the operating assumptions and inputs the MSAD informs of the present state of the system warning of any existing problem. E.g.: “HRT too low”, “Warning: strong FVA raise”
- ✓ Recommendation report. MSAD suggests actions to be taken to solve any detected problem. E.g.: “Reduce input flow”, “Pay special attention to FVA in the following days”
- ✓ Forecast report. MSAD informs on the probable evolution of the process if recommendations are followed. E.g.: “It is possible the system recovers before pH drops”

Other MSAD outputs includes: plotting of data series (monthly) and storage of Legal Regulations (for instance those related to land application of digested sludge).

Architecture

Base of facts and data analysis

It is necessary to evaluate the certainty of the facts/data to be used by the MSAD. This is done by filtering the input data. Data filtering consists on detecting measurement errors or even type writing errors by evaluating the significance (absolute and relative) of each numeric input by comparing the input values with a reference value. The reference value is established by evaluating the trend of the numeric variable over a reasonable period of time. Due the to inertia of the process the reasonable time period was established in 27 days, in between the HRT (24 d) and one month. Also, in absence of useful registered data, the ES needs to estimate the input which is done by evaluating the trend of the numerical variable in a previous period of 5 days (the estimated data are used for calculation purposes but not registered). The results of this data analysis are the final base of facts used as input to the expert system.



$$Index = \frac{FVA_i}{FVAmax} \cdot \frac{10^{pH-2.2}}{55555.6 + 10^{pH-2.2}} \quad (1$$

FVA_i = Fatty Volatile Acids, mmol/L
$FVAmax$ = max. FVA registered, mmol/L

Fig. 2. Acidification index

Base of knowledge (rules and mathematical model):

- Empirical rules: In general, each rule adds a "conclusion note " to Diagnostic, Recommendations and Forecast reports. Both mathematical modeling and Fuzzy Logic were used to obtain empirical conclusions in numerical, final specific recommendations. Two basic principles were followed according to the real operation:

  B_V: The overloading is one of the more frequent causes of failure. MSAD gives instructions about:

  - Bv max (T) allowed. (See below)
  - % of input flow reduction, after overloading detection.

  Ca(OH)2: External alkalinity addition

  - Adequate $Ca(OH)_2$ dose in case of acidification.
  - Use of a defined "acidification index" parameter (Equation 1 in Fig. 2.), containing FVA and pH (FVA equilibria) information (See Fig. 2.). This aids both to predict acidification and to calculate the alc. dosage.

- Mathematical model: The following model (Equation 2) was used for calculating $B_v$max (T):

$$X - Xo = t \cdot Y \cdot k \cdot VS / (Kx / X + 1) \cdot \quad VSo - VS = (X - Xo) / t \qquad (2)$$

Xo, X = Anaerobic bacteria entering and leaving the digester, mg/L
VSo, VS = Volatile Solids entering and leaving the digester, mg/L
Y = yield coefficient, kg_X/kg_{VS}
t = HRT, d

k = kinetic constant, mg_{VS}/d
Kx = kinetic constant, mg_X^{-1} L

Inference Engine

It connects the base of facts (translation of inputs) with the base of knowledge. The rules are fired accordingly to a pre-fixed priority order. Fuzzy ones are fired at the end (giving some conclusions).

RESULTS AND CONCLUSION

At the present moment, the MSAD system continues to be developed, including more registered data from the plant and user's comments. Some Visual Basic modules are being tested too. Some of the final results obtained were:

- Some errors in the experimental determination of some alkalinity data were detected. The alkalinity balance could not often be closed. New considerations are being included, regarding to this.

- MSAD detected organic overloading and predicted imminent acidification episodes, which finally occurred. These episodes could have been avoided if MSAD had been installed at the startup stage, since overload had been clearly detected.

- MSAD recommended the convenience of repeating analyses, when weir trends were detected, for instance when pH and FVA simultaneously increased.

As a general conclusion, MSAD unable us to detect and predict operation and performance problems in a rapid way, and provide us also with an stored list of all known and available solutions.

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