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technical paper

feed-forward automation for cost effective chemical treatment of food manufacturing wastewater

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abstract

A food manufacturing plant in the western United States pre-treated its wastewater with pH neutralization followed by dissolved air flotation (DAF), prior to discharge to a municipal water reclamation plant. Due to manpower limitations, chemical treatment of the DAF was automated based on flow-paced feed with manual dosage set points. It was discovered that the wastewater varied in both quantity and quality, independently, which led to significant overdosing to ensure adequate final effluent quality. Chemical coagulant demand was found to be proportional to wastewater turbidity (suspended matter). A relationship was developed and converted into a control algorithm for automation of coagulant and flocculant dosages. This feed-forward control loop was implemented on top of the flow-paced control. Chemical costs were reduced by more than 40% following implementation, with little change in effluent quality. The plant continued to meet its discharge limits.

keywords

Wastewater, Industrial, Chemical Feed, Automation, Turbidity, Feed-forward, Coagulation, Flocculation, Flotation, Chemical Cost.

introduction

A food manufacturing plant in the United States discharges its wastewater to a publicly owned treatment works (POTW) or water resource recovery facility (WRRF). The plant's permitted discharge limit is 2700 lb/day of BOD (5-day biological oxygen demand, an indicator of organic contamination). With limited operator time available, the company had commissioned a new wastewater treatment plant. The plant was designed to remove suspended matter, which being a food plant, comprised the majority of its BOD loading. An initial storage tank was followed by screening, pH adjustment, and then the DAF, prior to discharge to the WRRF. See Figure 1 for schematic.

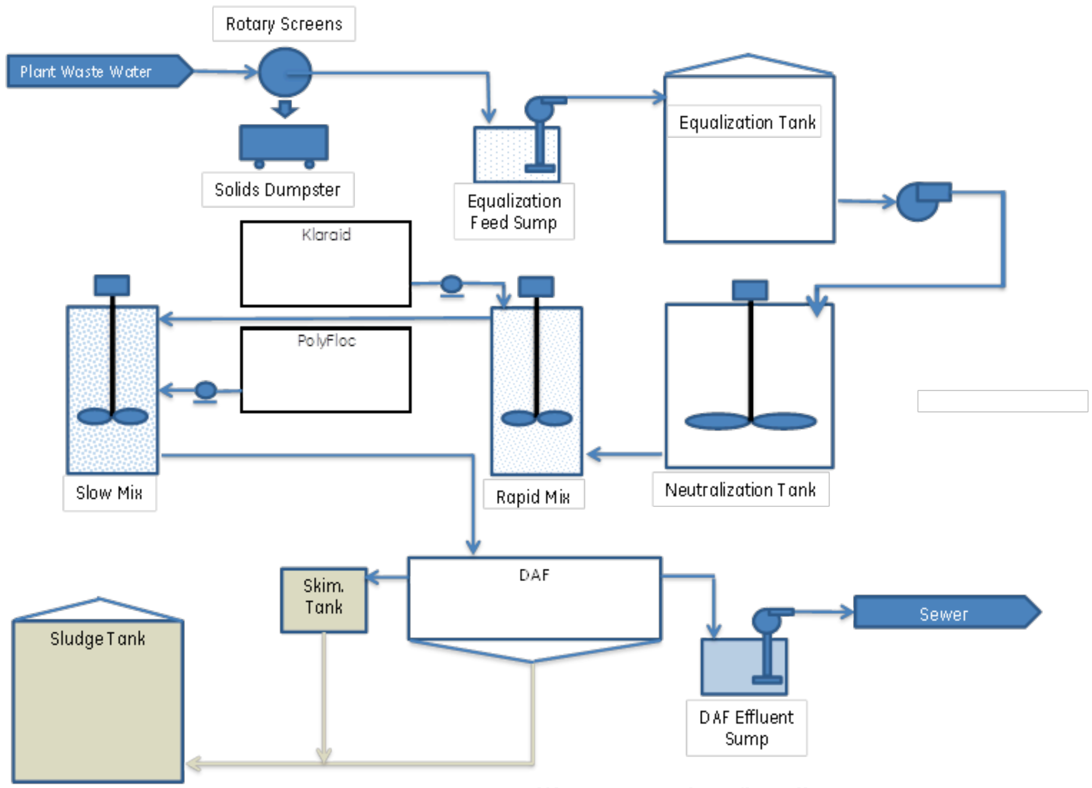

Figure 1: **Wastewater plant flow diagram**

The DAF unit is a key part of the wastewater treatment plant. It works by attaching micro air bubbles to particulate contaminants, reducing their specific gravity. These particulates, or floc, float to the surface where they are gathered together by a circulating surface skimmer. The floc is removed in a weir box and piped to sludge storage. For effective operation, the particulate contaminants must be flocculated into a large enough size for bubble attachment and flotation. Very large particles are removed by prior screening; it is the residual small particles and colloidal material that are targeted by the DAF.

Chemical coagulants and flocculants are often used to destabilize colloidal material and to produce suitably sized floc. The coagulant, in this case a SUEZ KlarAid* product, works by a combination of charge neutralization and sweep-floc adsorption reactions. It is a crucial part of the treatment because it allows for greater removal of very small particulate matter (which in this plant is virtually all BOD). The coagulant is added to a “fast mix” tank that provides high-energy mixing. Following this process, a high molecular weight polymer, known as a flocculant, is added to further increase floc size. This SUEZ PolyFloc* product is added in a “slow mix” tank, which provides gentle mixing for flocculation.

Wastewater pH can affect colloid charge and thus often plays a role in coagulation. Therefore, pH stabilization is often desirable for the most cost effective coagulation and flocculation reactions. pH stabilization is carried out in a tank prior to coagulant addition (see Figure 1). This process is automated with a separate pH feedback loop to control sulfuric acid and caustic addition.

KlarAid and PolyFloc clarification aids were fed under flow-paced automatic control. This was done knowing that the wastewater was highly variable in flow. However, it gradually became apparent that the total suspended solids (TSS), and thus BOD loading, were independently variable as well, and so chemical demand varied independent of flow. Figure 2 shows turbidity and flow variation during a one year time period.

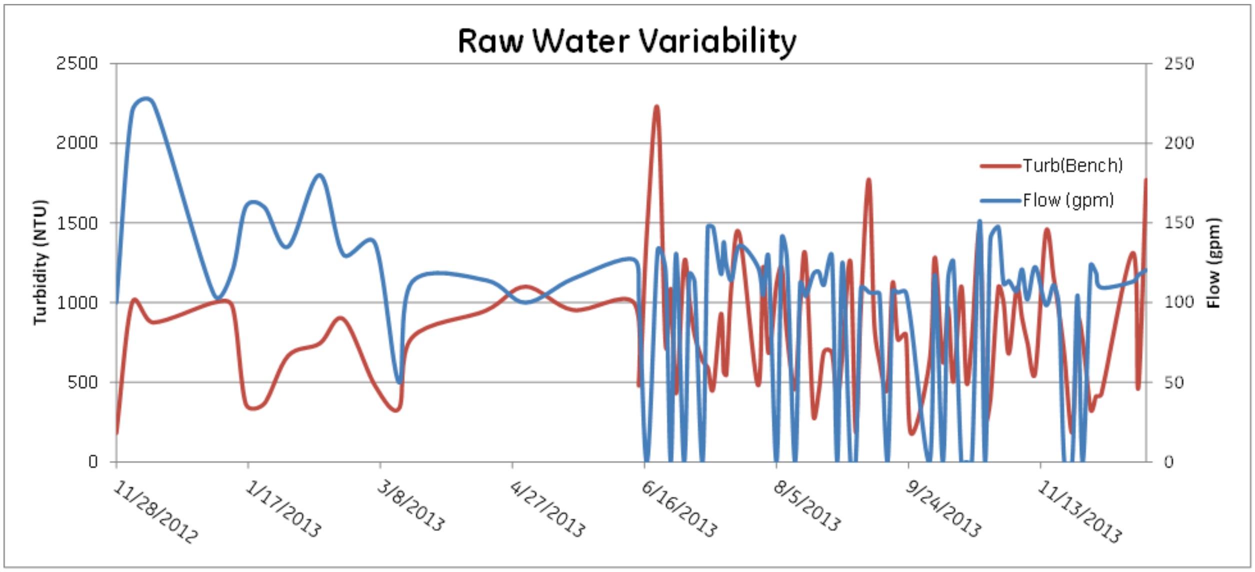

Figure 2: Variation of wastewater flow and turbidity

The variation made chemical control difficult and although effluent quality generally remained within the permitted discharge limit, chemical costs had risen significantly. This mainly occurred because the operator, who was only assigned to the plant part time, found it more effective to set the dosage for the higher influent turbidities, and leave it there for extended periods of time. Thus, overdosing was common. Not only does overdosing lead to higher costs, but it can often negatively impact coagulation. Being a charge neutralization phenomenon, excessive dosage of coagulant can ultimately over charge the colloidal particles, leading to dispersion (re-stabilization), and therefore a worsening of solids separation efforts.

SUEZ was asked to suggest improvements to reduce chemical treatment costs, while keeping BOD within the limit. This was the objective of the project described herein.

Various automated chemical feed systems have been proposed and/or implemented over the last 30 years. Fergie and Kerk (1987) and Yavich et al (2008), discussed mathematical modelling using historical data. Not having much historical data, this approach was not considered. Others, such as Mels et al (2004) have researched the use of turbidity control in a similar feed-forward mode. Mels and his colleagues carried out laboratory-scale work on municipal wastewater and confirmed that there was a linear relationship between turbidity and particulate chemical oxygen demand (COD). He demonstrated that on a small scale polymer control was feasible, based on influent turbidity. It was decided that this approach would be pursued.

methodology

Chemical treatment of wastewater for solids removal is typically optimized using onsite bench testing, also called "Jar Testing." Fresh wastewater taken from the influent of the equipment to be treated is mixed with varying dosages of suitable chemical clarification aids. After solids separation, the treated water is evaluated for clarity (e.g. turbidity). In the case of this food plant's wastewater, the turbidity generally correlated with BOD, as most of the organics present were in particulate form. In this way cost effective clarification aids can be chosen. In the case of the DAF being treated, both a coagulant and flocculant were evaluated initially when the treatment program was started. Later testing showed that the product choices were appropriate, but dosages, especially of the coagulant, varied significantly over time.

With pH adjustment taking place automatically, the variability appeared to be due to changes in the raw wastewater's TSS. The TSS was mostly organic, which meant that the BOD (and COD) also varied significantly. This information was not initially available, and SUEZ carried out a program of sampling, and testing of the raw wastewater to determine variability. Ultimately, it was shown that the wastewater, even after some equalization, averaged 776 NTU turbidity, but varied from 177 to

3628, with a standard deviation of 436 NTU, or 56% of the average. Jar testing showed a concomitant large range in coagulant demand from 50 to >250 mg/l. It would be impracticable for any operator, much less a part time one, to complete jar testing frequently enough to allow optimum dosage adjustments (to the ppm set point in the control system).

SUEZ and plant engineering personnel decided to evaluate the use of real-time TSS/turbidity monitoring and use that information for coagulant dosage control. This has been used before in feedback mode (i.e. measuring the effluent quality) for trimming dosages, but suffers from the disadvantage of always been slightly behind the demand due to the equipment retention time lag. This older approach was usually implemented because traditional turbidity meters worked best and were more reliable at the lower turbidities seen in the effluent of treatment equipment. Recently, however, SUEZ had become aware of a new TSS/turbidity meter on the market, supplied by the HACH Co. This unit offers enhanced capabilities and specifications that appear to make it more reliable and sensitive for the higher turbidities seen in this wastewater. Thus, it was decided to evaluate this turbidity meter installed in the neutralization tank, in feed-forward control mode.

The instrument was installed in late 2012, with the probe placed in the neutralization tank. It was operated in monitor mode only for several months, while manual bench checks on turbidity were carried out.

In addition, SUEZ field engineers began a series of wastewater jar tests to develop the turbidity versus coagulant dosage curve needed for the control algorithm. The overall controller selected was SUEZ's PaceSetter* Platinum controller. This controller takes up to eight analog and sixteen digital inputs and exports data for remote monitoring and control.

In order to obtain real-time data trending and analysis for all stakeholders, SUEZ also implemented its InSight* monitoring platform that routinely uploads data to SUEZ's Trevose, PA computer network and Customer Reliability Center. Automatic trending and data analysis was made available to plant personnel, corporate engineers, and SUEZ via the internet. Automatic alarms were set up to notify SUEZ field support personnel when internal limits were exceeded, or when problems occurred with the new control system. Complete, real-time data visibility allowed operating personnel to determine quickly if the system was not operating as planned.

InSight was an important benefit for both SUEZ service engineers and plant personnel, providing online availability of real-time chemical usage, and various critical operational parameters, such as wastewater turbidity, and pH. Without full-time operator attention, this online data availability provided improved system monitoring and an early warning of chemical usage variability.

A conclusion on the success of the chemical control system cannot be made without reference to the treated water quality. It could be counterproductive to just turn down the chemical dosage if the effluent quality suffers and becomes unacceptable. Therefore, data was also collected on effluent quality before and after automation and will be discussed in the next section.

results

raw water variability

Table 1: Raw water variability

	Average	Standard Deviation	Std. Dev as % of Average	Maximum
(a) Before Chem. Automation (11/28/12 to 6/12/13)				
Flow (gpm)	129	45	35	225
Turbidity (NTU)	745	291	39	1100
(b) After Chem. Automation (6/14/13 to 12/31/13)				
Flow (gpm)	88	53	60	151
Turbidity (NTU)	831	407	49	2216

As can be seen in Table 1 and Figure 2, both flow and turbidity varied significantly. This was most likely related to the factory's production schedule. The original automation system varied chemical feed rates to obtain the set point dosages paced to flow. This reduced some of the variation due to flow, however the set point had to be set manually, and could not be changed often enough to track influent turbidity changes. An equalization tank was supposed to eliminate these quality variations, but its operation was less than ideal.

Another observation from Table 1 is that the turbidity, and thus BOD loading, increased 12% and began to vary even more in the months following the project implementation (due to unrelated reasons). The coefficient of variability increased from 39% to 49%

on-line turbidity meter performance

Spot-checks on wastewater turbidity were carried out by SUEZ personnel using a calibrated bench-top turbidity meter. The results were compared to the online turbidity instrument. During the period before

automation, but after the instrument was deployed, the difference in turbidity between the two measurements averaged 7.7%, with very similar standard deviations. After some further fine-tuning of calibration and probe placement, (6/14/13 to 12/31/13), the difference in measurements averaged 0.5%.

chemical usage

Table 2: Chemical usage (gpd)

	Average	Standard Deviation	Coeff. of Variation (%)
(a) Before Chem. Automation (11/28/12 to 6/12/13)			
KlarAid Coagulant	38.0	12.4	33
PolyFloc Flocculant	1.3	1.0	
(b) After Chem. Automation (6/14/13 to 12/31/13)			
KlarAid Coagulant	19.9	8.3	42
PolyFloc Flocculant	1.5	1.2	

Table 2 shows that coagulant chemical usage fell 48%, with a slight increase in the small flocculant dosage. This occurred even though wastewater solids increased by almost 12%, with a significant increase in variability (as measured by turbidity, Table 1). The daily dosage varied more after automation, showing that the controller made much more frequent adjustments to match demand.

Figure 3 is a trend graph that shows how the various efforts to control chemical usage impacted chemical usage, with the commissioning of full automatic control in June of 2013 indicated with the arrow.

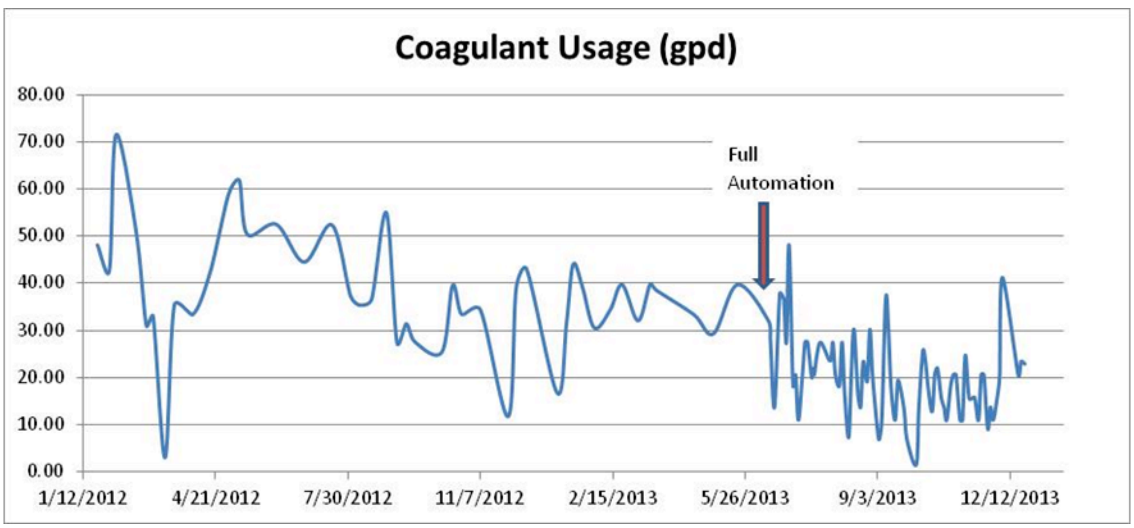

Figure 3: Chemical usage before and after full automation with influent turbidity and flow

Treated Wastewater Quality

Table 3: DAF effluent quality

	Average	Maximum (No. >Limit)	Limit
(a) Before Chem. Automation (11/28/12 to 6/12/13)			
BOD_5 (lb/day)	1356	2302 (0)	2700
Turbidity (NTU)	138		None
(b) After Chem. Automation (6/14/13 to 12/31/13)			
BOD_5 (lb/day)	1511	2968 (2)	2700
Turbidity (NTU)	187		None

Notes: These measurements were not online, but grab samples taken 1 to 2 times/week.

Effluent quality deteriorated slightly, with average BOD rising 11% and turbidity rising about the same (see Figure 4). Two instances of excessive BOD were measured, one soon after implementation of full control. Operational problems with the DAF, not the chemical feed system, contributed to both of these high results. Overall, the primary goal of meeting the BOD discharge limit was maintained.

Further optimization is taking place to adjust the control algorithm and to further reduce the total cost of operations. Two approaches being considered are more frequent calibration jar testing and building in a slight extra chemical dosage above what the jar tests demonstrate. Other control optimization steps could include online effluent turbidity feedback to the controller for fine-tuning chemical feed.

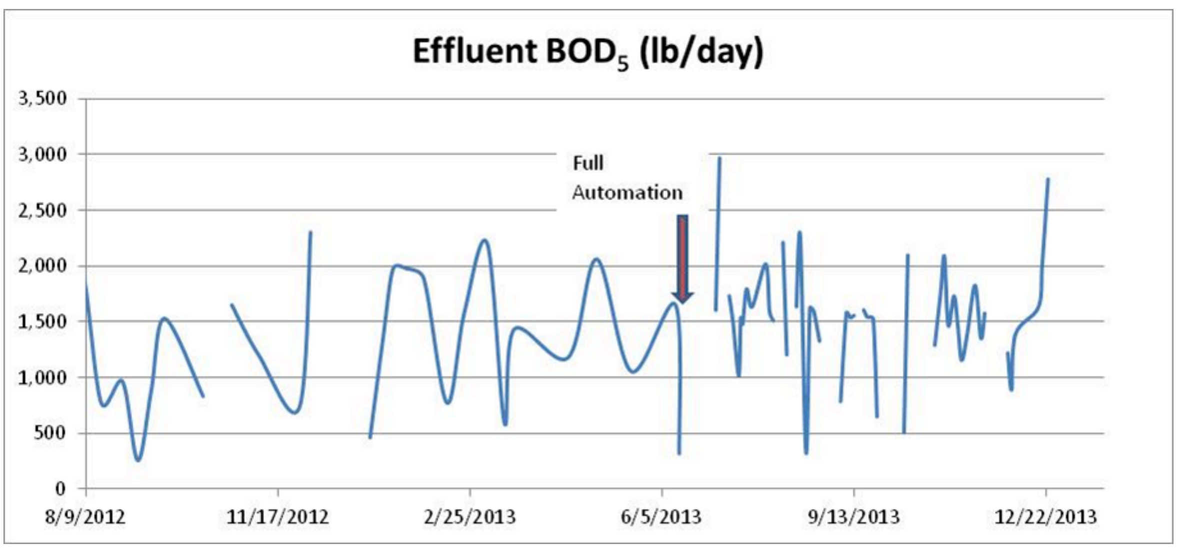

Figure 4: Effluent BOD_5

conclusions

It was demonstrated that feed-forward control involving online influent solids monitoring, together with flow measurement, could reduce total operating costs on a chemically treated DAF unit. With extremely variable contaminant loading - especially when contaminant and flow variability are not well correlated - manual control of chemical feed often does not meet both objectives of effluent quality and chemical cost minimization. The full automation project successfully reduced chemical costs by more than 40%, with only a small deterioration in effluent quality; all this, despite a large increase in raw wastewater contaminant loading and variability.

Further work is being carried out to optimize the control algorithms used in the SUEZ PaceSetter controller.

references

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