

THICKENING ACTIVATED SLUDGE WITH SUSPENDED AIR® FLOTATION (SAF®)

Summary of three case studies



PREPARED BY:

Harold Leverenz, Ph.D., P.E.

George Tchobanoglous, Ph.D., NAE, P.E.

Department of Civil and Environmental Engineering University of California, Davis,

Christina M. Skalko, P.E.

Short Elliott Hendrickson, Inc.

ABSTRACT

In the practice of wastewater treatment system design, process selection is often constrained by factors such as operational costs, performance, and physical footprint. Processes employing colloidal gaseous aphron (CGA) technology have proven to be highly effective for the clarification and thickening of activated sludge mixed liquor, waste-activated sludge (WAS), and anaerobically digested sludge within a small footprint. Technically, an aphron is defined as a gas or liquid phase encapsulated by a surfactant film. Since their initial identification and formulation, aphrons have been used extensively in a number of chemical processes, including gas and oil drilling and food processing waste-treatment applications. The generation and use of CGAs for thickening of WAS and other wastewater applications has been commercialized with the development of the Suspended Air® flotation (SAF®) process. The purpose of this paper is to (1) provide background on CGAs flotation technology, (2) identify applications of CGA in wastewater treatment, (3) discuss thickening of WAS with CGA, and (4) present findings from three case studies where WAS thickening with a legacy dissolved air flotation (DAF) process was replaced with a CGA process to increase capacity or address operational challenges, typically within the same flotation tank footprint. The case studies demonstrate the versatility of the SAF® CGA process for (a) its ability to process the most challenging feedstock, including stored WAS; (b) enhancement of the digestion process and elimination of digester foaming; and (c) high capacity and ease of operation, reducing operation needs.

Key Words

Colloidal gas aphrons, waste activated sludge, wastewater solids management

1. CGA FLOTATION TECHNOLOGY

Current aphron technology is based primarily on the research of Professor Frank Sebba, who worked on the formation of fine bubble aphrons under atmospheric conditions [1,2]. A detailed review of current research on apron applications as well as

methods for generating aphyrons was prepared by Molaei and Waters [3]. Technically, an aphyron is defined as a gas or liquid phase encapsulated by a surfactant film. Fine bubble aphyrons were first identified as micro foams or micro gas dispersions, but the term colloidal gas aphyron (CGA) has been used more recently. High shear forces are required to generate the CGA suspension from a concentrated surfactant blend. One of the most striking observations was that the micron-sized CGA bubbles do not coalesce immediately if they are immersed completely in water and that when they collide, the momentum is not sufficient to break the encapsulating surfactant film. Based on these properties, CGAs have wide applications in the chemical process field, as well as in gas and oil drilling applications [3]. Additional details on these applications were developed by Sebba [4]. Wastewater applications of the CGA process are considered in the following section. The purpose of this work is to highlight systemic improvements that have been observed in wastewater treatment applications where conventional dissolved air flotation (DAF) has been replaced with SAF®.

2. APPLICATION OF THE SAF® PROCESS IN WASTEWATER TREATMENT

Flotation thickening and clarifying activated sludge mixed liquor using CGA suspension was first demonstrated by Enviro-Bubble Flotation, Inc. (EBF) of Sacramento, CA, USA, in October 1995 at the Red Bluff, CA, WWTP [5]. The current full-scale implementation of CGA clarification for wastewater applications has been commercialized by Heron Innovators Inc. (Roseville, CA, USA), and is known as the Suspended Air® flotation (SAF®) process. To date, the SAF® CGA process has principally been applied for the removal of algae from wastewater treatment pond effluents and for sludge thickening. In the treatment of pond effluent, it has been possible to achieve effluent turbidity values of 0.5 NTU or less. The SAF® process is used in a variety of other municipal wastewater applications, including primary treatment, filtration of filter backwash, and secondary clarification [6]. The principal components of the SAF® CGA process are illustrated in Figure 1. The SAF® process uses an externally generated suspension of micron-sized (about 7 to 25 μm) air bubbles. Each of the bubbles is coated with a thin film of an electrically charged chemically active surfactant such as a soap film, which may be either anionic or cationic, depending on the application. The surfactant film must have sufficient viscosity to remain stable when suspended in the bulk water and thereby minimize the Marangoni effect [3]. In water and wastewater applications, the volumetric air content typically ranges from 30 to 40 percent, compared with the estimated maximum of 5% achieved using DAF [5]. Because the

CGA bubbles are either positively or negatively charged, they are readily attracted to oppositely charged wastewater solids that need to be removed. The wastewater particles are either naturally charged, such as negatively charged waste-activated sludge, or, alternatively, wastewater solids can be coated with charged polymer. Operationally, polymer solution is mixed with wastewater to form flocs and then the CGA suspension is intimately mixed with the flocculated solids before entering the flotation tank (see Figure 1). The flocculated solids buoyed by CGA then move to the flotation portion of the tank, where they float to the surface and are removed by skimming. Clarified underflow passes under a baffle and over a weir into the effluent launder. Once the CGA suspension is formed, the aphanes remain intact for approximately five minutes through the process of pumping, application to the flotation tank, and surface skimming. A few minutes after the solids have been skimmed from the surface, the aphanes collapse and become inactive.

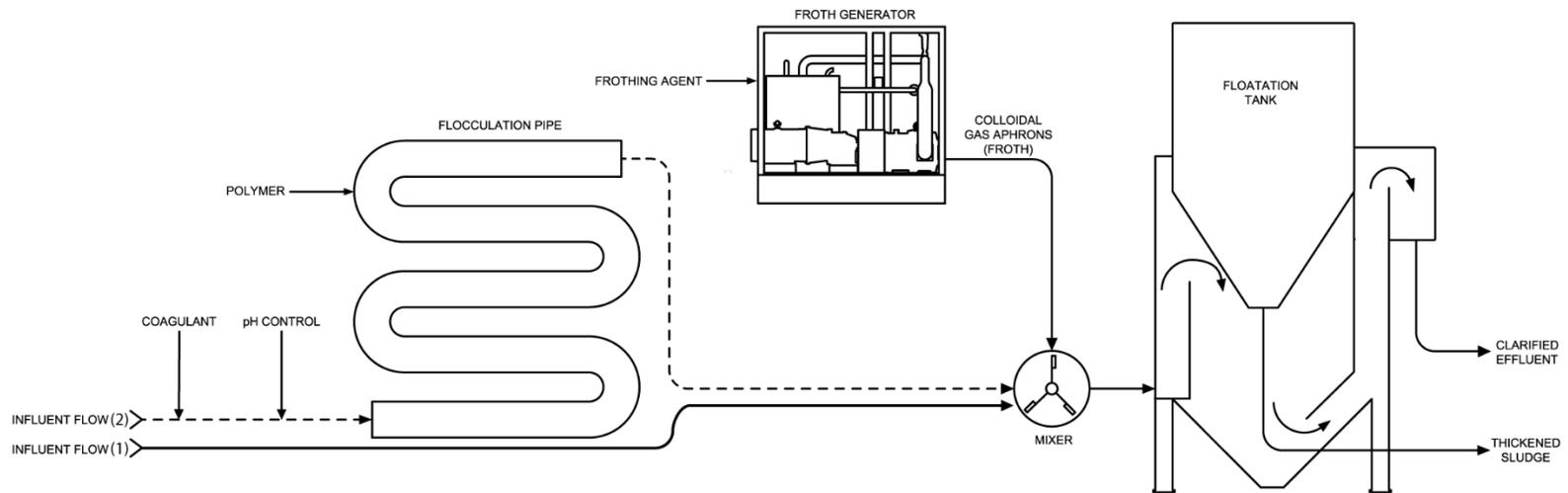


Figure 1

The schematic flow diagram of the Suspended Air® Flotation (SAF®) process. Two modes of operation are possible, depending on the characteristics of the wastewater solids to be thickened: (1) without chemical flocculation, solid line, and (2) with chemical flocculation, dashed line.

3. THICKENING WASTE ACTIVATED SLUDGE WITH CGA

In typical activated sludge treatment process flow diagrams, as shown in Figure 2, WAS thickening can be used for the following purposes: (1) to thicken waste mixed liquor (see Figure 2a) or (2) alternatively, to thicken settled activated sludge (see Figure 2b). In either case, the rationale for thickening is to increase the solids concentration of the WAS by reducing the liquid volume. Where anaerobic digestion is used, thickening of WAS is used (1) to improve process performance, typically gas production, by increasing the solids retention time and (2) to enhance the digestion process stability by reducing the liquid volume of the digester feed. Several alternative thickening processes are used to thicken WAS, including gravity thickening, a belt filter, and DAF.

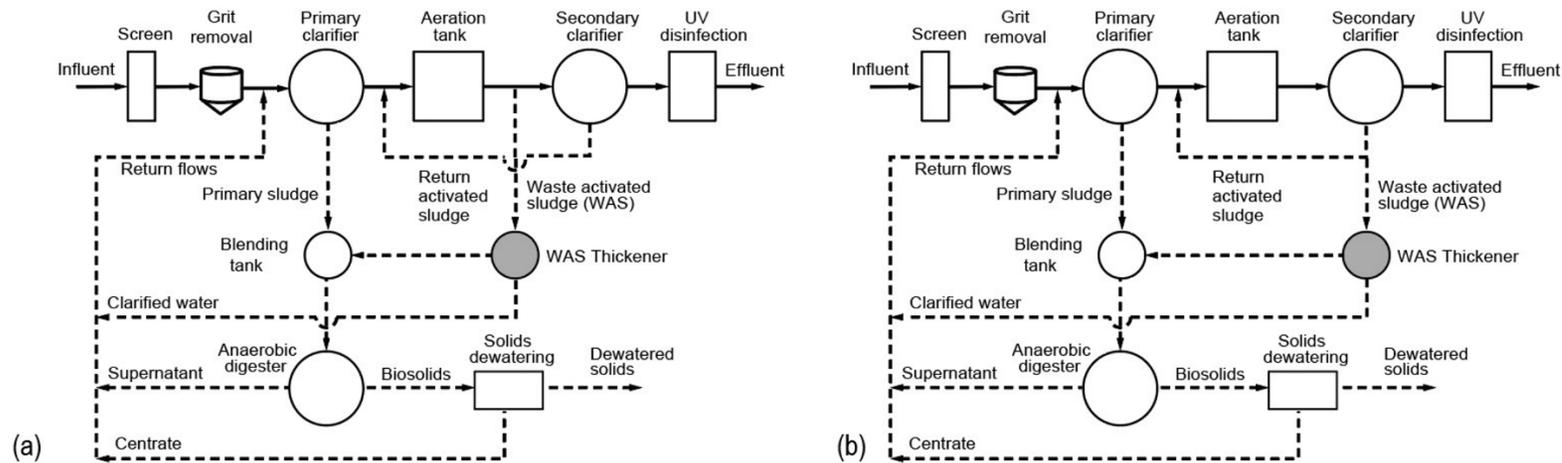


Figure 2

Alternative configurations for secondary sludge wasting: (a) from aeration tank and (b) from secondary clarifier. Note that the primary clarifier may not be present in some cases. Adapted from Tchobanoglous et al., 2014.

While the flow diagram for the SAF® process is similar to that for dissolved air flotation (DAF), there are three fundamental differences between the SAF® technology and the DAF process: (1) aphanes are formed at atmospheric pressure, whereas in the DAF process, air is dissolved into the liquid under pressure; (2) aphanes can be encapsulated in a variety of different films, either anionic, cationic, or non-ionic; and (3) dissolved gas (air) bubbles which form once the pressure is released in the DAF process have a tendency to coalesce when they touch because the surface area of two small bubbles, when combined, is less than the surface area for the two smaller bubbles when separated. By comparison, aphan bubbles do not coalesce; this is an important difference. There are also several important operational differences that have been observed, based on the case studies discussed in the following section, between the aphan technology and the DAF process. Important operational differences include (1) increased solids loadings up to 40 lb/ft²·h, a ten-fold increase over DAF in most applications; (2) the ability to handle high and variable concentrations of total suspended solids (TSSs) of up to about 1.6% TS in one example, (3) easier operation with respect to establishing the operational set point as compared to the DAF process; (4) reduced process operational time in some cases; (5) lower energy consumption, by 90% in one example, due to the lower amount of energy required to generate aphanes compared with compressing air and the reduced operational time needed to process solids; and (6) the potential for a reduced process footprint. These features are highlighted in the following case studies.

4. CASE STUDIES

The SAF® process has been evaluated for thickening of WAS in numerous installations and, in all cases, the SAF® process has been demonstrated to provide consistent high performance and reliable operation. Comparison of the SAF® and DAF process for WAS thickening is best exemplified by three recent case studies [8,9,10] presented in this section, in which the SAF® process was used to replace and upgrade an existing DAF facility. The use of CGA has allowed for significant improvements in TSS removal, capacity, operational time, operational cost, and solids management.

Topeka, KS (Oakland Wastewater Treatment Facility)

A recent case study on WAS thickening at Topeka, KS, was summarized by Tchobanoglous et al. [11]. The total solids content of WAS at the Oakland WWTP varies considerably, depending on the operation of biological reactors and clarifiers. The

SAF® process was evaluated at the Oakland WWTP to replace legacy DAF units for thickening prior to anaerobic digestion to increase the solids content of WAS. For example, WAS pumped from secondary settling tanks containing 0.4 to 0.8% solids was thickened to 4% solid content, resulting in a five-fold decrease in sludge volume and a corresponding increase in digester retention time. In addition to achieving high WAS solids separation efficiency, based on onsite testing, the principal advantages of the SAF® process include a relatively small process footprint, low power requirement, low chemical usage, and the ability to handle both aged/stored sludge and high concentrations of suspended solids (up to 16,000 mg/L in this study).

Performance data for the SAF® pilot test that focused on stored WAS mixed with settled WAS are summarized in Table 1. Performance data were also collected during the July/August and September/October 2021 operational periods [10]. For the entire period of operation, the removal performance was essentially the same; however, the chemical usage was variable due to the age and properties of the stored WAS. It was noted that the SAF® process can operate under a wide range of operational conditions, with influent total suspended solids (TSSs) ranging from about 5000 to 16,000 mg/L and process loading varying from 13 to 46 lb/sq. ft·h for both settled and stored WAS. Typical solids loads for the existing DAF units, when operational, were about 1 to 2 lb/sq. ft·h. Energy consumption for WAS processing was also compared for the two flotation technologies. For the same amount of WAS processed per day, the average energy required for the SAF® was 4.9 kWh/d, while the corresponding energy usage for the DAF equipment was 49.9 kWh/d, which was a 90% reduction. It is anticipated that the energy usage for newer DAF units would be lower. The aphon flowrate used in Table 1 is the volumetric flowrate of the CGA suspension.

Table 1

Summary of representative pilot test performance for SAF® operating on WAS combined with stored WAS (Pilot test, October 2020) at the Oakland WWTP in Topeka Kansas.^a

Influent TSS, mg/L	Effluent TSS, mg/L	Removal, %	Float TS, %	Liquid flowrate, gal/min	Aphron flowrate, gal/min	Loading, lb/ft ² ·h	Polymer, lb/dry ton
8800	57	99.4	5.4	80	3.2	20.1	1.3
8390	33	99.6	7.3	85	3.5	20.4	1.3
6980	461	93.4	7.0	140	7.0	27.9	2.8
4650	ND	100	6.3	95	3.8	12.6	6.0
9250	ND	100	6.6	92	3.8	24.3	3.0
15,700	ND	100	7.5	90	4.3	40.4	1.8
8860	20	99.8	5.9	138	8.2	35.0	5.1

^a Data courtesy Zeller (2023).

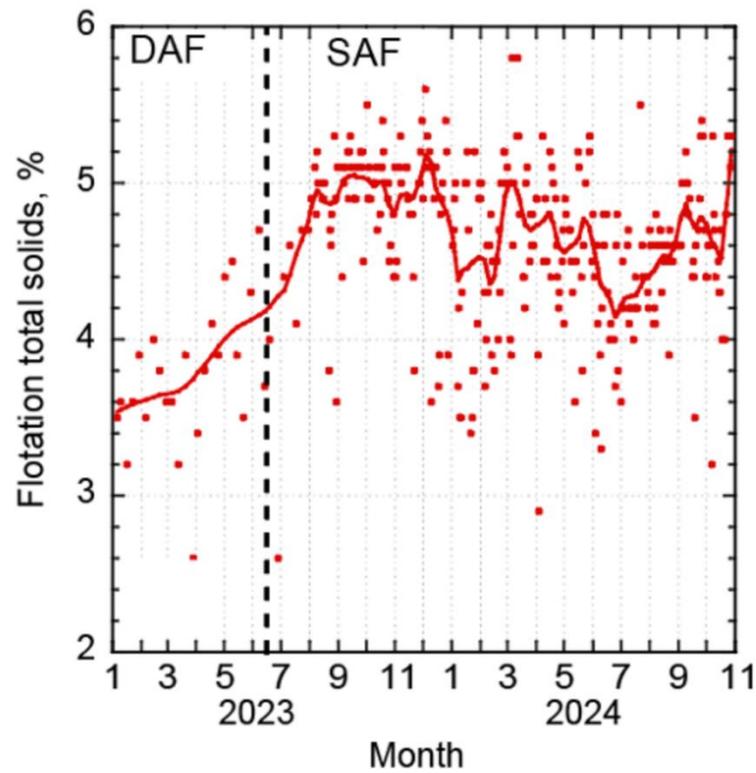
For the pilot test, aphrons were generated using a surfactant solution which was consumed at a rate of approximately 90 gal/month for processing stored WAS with an estimated age greater than 12 months. The consumption of the surfactant was set at a high level due to the challenging nature of processing the stored WAS. Even under the conditions of high CGA usage and aged stored sludge, no residual foaming or digestion issues were observed.

Warminster, PA (Warminster Municipal Authority)

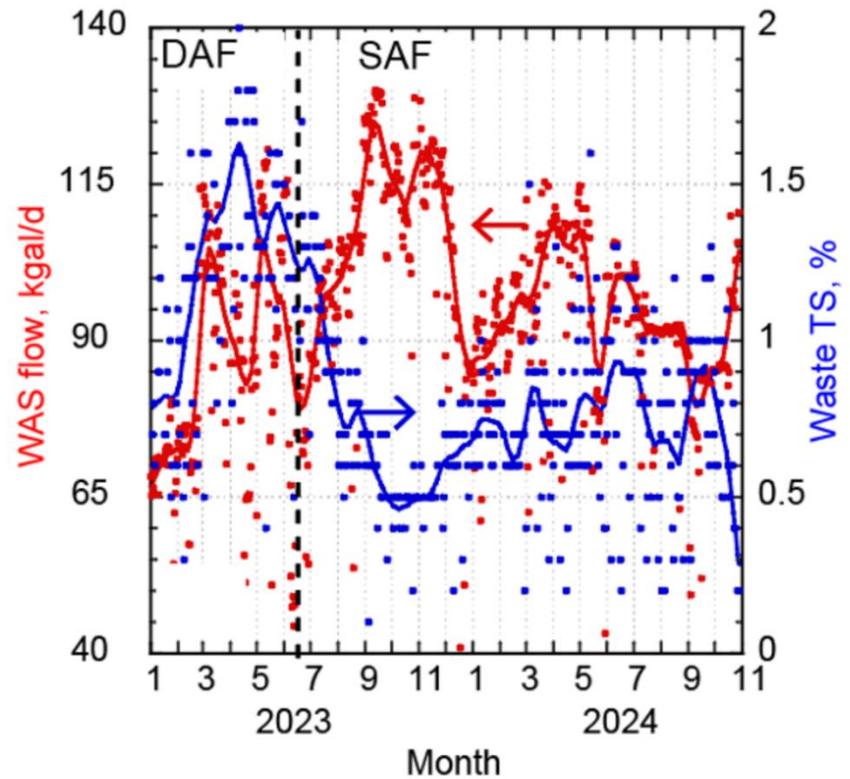
The Warminster case study highlights the potential impacts of improved thickening process performance on downstream solids processing. Prior to installation of the SAF® process at the Warminster facility, a legacy DAF process had been used to thicken WAS prior to anaerobic digestion. The DAF process typically produced thickened solids in the range of 3.5 to 4.5%. The low concentration of solids in the thickened WAS directly impacted the solids retention times (SRTs) in the anaerobic digesters. Also, during operation with DAF, periodic digester foaming events occurred due in part to mixing limitations within the existing digesters and the SRT variations resulting from thickening process control. Digester foaming is commonly associated with anaerobic process overloading and operational imbalances at reduced or fluctuating SRTs.

In mid-June 2023, the DAF process was replaced with a SAF® unit. After the SAF® was placed into service as a direct replacement for the DAF, the thickened TSs increased from 4.5 to 5.5%, resulting in a significant improvement in the stability of the anaerobic digestion process (see Figure 3). The thickened solids concentration achieved by the SAF® process improved the digester SRTs, resulting in an increase in digester alkalinity. It was noted that since the SAF® went into service, foaming has not been observed in the digesters. Foaming is not expected, as the surfactant used is biodegradable and is not present at concentrations that can contribute to any residual foaming in the wake of the flotation process. It should be noted that the process pH, temperature, and HRT were within normal operating ranges during the observation period.

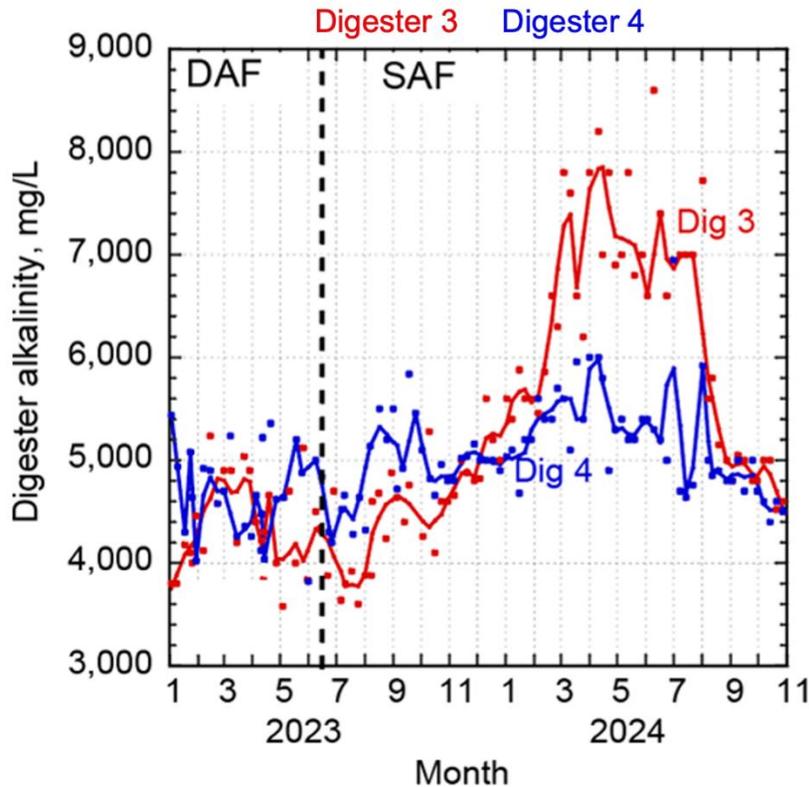
Figure 3 (Data courtesy Krauss, 2024)



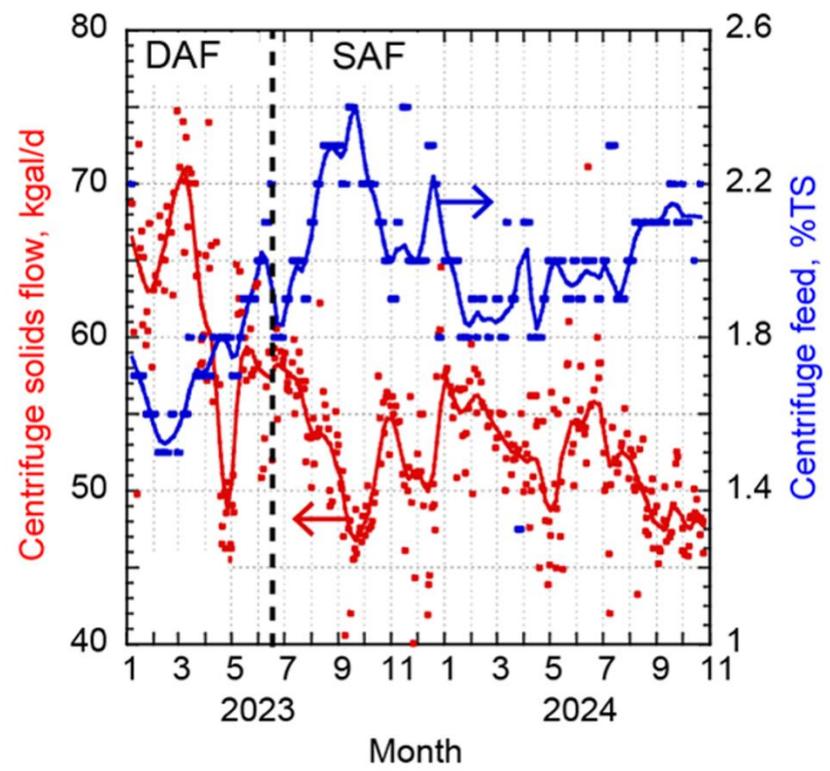
(a) improved thickening before digestion



(b) adaptation to variable WAS flows during drought which resulted in low flow conditions



(c) improved retention time and alkalinity buffer development in digesters, note that uneven transfer of thickened WAS to digesters 3 and 4.



(d) more consistent centrifuge feed resulting in reduced centrifuge run time.

Figure 3. Process data comparing DAF and SAF® at Warminster, PA, revealed the following findings: (a) improved thickening before digestion, (b) adaptation to variable WAS flows during low-flow drought conditions, red data = WAS flow, blue data = waste TS, (c) improved retention time and alkalinity buffer development in digesters (note that uneven transfer of thickened WAS to digesters 3 and 4 resulted in a greater SRT in digester 3), and (d) more consistent centrifuge feed, resulting in a reduced centrifuge runtime, red = solids flow, blue = feed %TS. These data were provided by Krauss [9].

The SAF® process has also allowed the operators to navigate challenging operational conditions imposed by historic drought conditions. Low influent flows resulting from a lack of normal rainfall levels have required the facility to take clarifiers out of service. Operating with a single clarifier requires increased WAS flows and lower WAS solids concentrations. The SAF® process has the flexibility to accommodate a wide range of feed conditions, making it possible to operate reliably through changes in plant influent. The SAF® process has also been effective in managing unstable conditions associated with other elements of the facility. The ability to achieve high performance under a wide range of feed sludge conditions has made the SAF® an indispensable tool for managing the anaerobic digestion process.

Process data comparing DAF and SAF® at Warminster, PA, included the following findings: (a) improved thickening before digestion, (b) adaptation to variable WAS flows during low-flow drought conditions, (c) improved retention time and alkalinity buffer development in digesters (note that uneven transfer of thickened WAS to digesters 3 and 4 resulted in a greater SRT in digester 3), and (d) more consistent centrifuge feed was achieved, resulting in a reduced centrifuge runtime. These data were provided by Krauss [9].

Sauk Centre, MN (Sauk Centre Wastewater Treatment Facility)

The WWTF at Sauk Centre receives primarily domestic wastewater and has a typical flowrate of 0.43 Mgal/d. The WWTF consists of a fine screen (Huber Technology, Denver, NC), grit removal (Pista, Smith & Loveless, Lenexa, KS), an activated sludge process (Short Elliott Hendrickson, Inc., St. Paul, MN, USA), UV disinfection (Trojan Technologies, London, ON, Canada), and WAS thickening (Heron Innovators). Thickened waste solids are stored in a 1.2 Mgal vessel for seasonal land application. The SAF® process was brought in to replace an overloaded DAF process. Considerations for the DAF replacement included the following requirements:

- The replacement should meet or exceed the required capacity, which is equivalent to 96,000 gal/d.
- It should fit within the existing DAF footprint, with an existing tank measuring 60 ft².
- The operational costs (e.g., the cost of the polymer, operator time, and electricity) should be equivalent or lower.

The SAF® process was implemented and began operation in July 2023, and the results to date have been impressive, as summarized in Table 2. Following conversion of the DAF tank to the SAF® process, the thickening process operational time was reduced by 80% from 24 h/d × 7 d/wk to 7 h/d × 4.5 d/wk. In addition, the volume of biosolids produced was reduced by 15% in the first partial year after the SAF® process began operating, increasing the storage capacity and reducing the overall volume for hauling and land application.

Table 2

Comparison of DAF and SAF® processes at Sauk Centre Wastewater Treatment Facility^a

Parameter	Unit	DAF	SAF	SAF® difference
Area	ft ²	60	60	–
Loading rate	gpm	13	75	+ 500%
Operational time	1/wk	24 h/d x 7d	7 h/d x 4.5 d	– 80%
TS	%	4.1	4.7	+ 15%
Polymer use	gal/wk	10.5	4.6	– 60%
Surfactant use	gal/wk	0	2.8	
Biosolids volume	Mgal/y	1.14	0.96	– 15%

^a Data Courtesy Bauer (2024)

The SAF® is noticeably easier to operate than the old DAF, according to the operators in the Sauk Centre. The old DAF startup time was in excess of 30 min each day. The SAF® starts up each morning with the push of a button on the Control Panel, saving the operators time that they can now spend completing other duties at the WWTF. In addition, the room with the SAF® is much quieter than the previous room with the DAF. The loud DAF pump that was used to inject air for the DAF was removed and replaced with the SAF® Froth Metering equipment (SAF® Generator), allowing the operators to work in the space without the burden of excessive noise.

The polymer usage has also greatly reduced as a result of the conversion from the DAF to the SAF® at Sauk Centre. The DAF used 10.5 gallons/week and the SAF® uses 4.6 gallons/week. The operators are working on further reducing the amount of polymer used but are currently limited by their polymer pump; they hope to replace this in the future. A formal analysis of the electrical cost savings has not yet been performed in Sauk Centre. The reduced hours of daily usage alone results in reduced electricity usage. The DAF 5 HP air pump was replaced with a SAF® Froth Generator recycle pump of 3 HP and some other electrical components under 1 HP. The overall solids capture efficiency was 99.7%.

While there are a number of advantages that have been identified, there are also disadvantages that can be noted; for example, the SAF® has a higher equipment price than the DAF, and presents the added complexity of managing two chemicals (polymer and surfactant) rather than just one. While the chemical cost per gallon of wastewater treated actually went down in Sauk Centre, the overall time taken to operate the chemical feed system is now greater because there are two chemicals involved. Also, currently, there is only one supplier for the SAF® Equipment as well as the surfactant, so there is some market risk.

5. DISCUSSION

The thickening of municipal WAS with CGA flotation technology, as discussed in this paper, with a focus on SAF® technology, is gaining acceptance after being initially demonstrated in the late 1990s. The use of the SAF® CGA flotation process for the thickening of WAS was evaluated at several facilities, where the relevant equipment was installed as a replacement for existing DAF units that have exceeded their design life or failed to meet performance expectations. The SAF® units have proven

to be effective for thickening both stored and fresh WAS, adapting to a wide range of WAS concentrations and flowrates, and improving the operation of downstream digesters.

Switching from legacy DAF to SAF® resulted in the stabilization of the digestion process, which previously experienced unstable conditions and foaming due to poor WAS thickening. The fact that the bubbles do not coalesce during the flotation reaction is a key reason that the SAF® process is effective. The bubbles can remain in suspension for an extended period, resulting in a greater number of adsorption sites and creating more opportunities for particle adsorption and flotation.

The advantages for the SAF® process that have been documented by others [7,8,9] include its rapid startup, variable load processing, reduced operating time, and reduced energy requirements compared with the conventional DAF process.

Based on the test results obtained to date, the SAF® process is a viable alternative to replace legacy thickening processes, typically achieving improved performance and capacity within the same or greatly reduced footprint. Because of the documented effectiveness of the SAF® process, as described in this paper and in other studies, it is anticipated that flotation with CGA technology will find broader application in the field of municipal wastewater management and will result in enhanced operations, reduced energy consumption, and reduced personnel requirements.

Author Contributions

Conceptualization, H.L. and G.T.; writing—original draft preparation, H.L. and G.T.; field data collection, C.M.S.; writing—review and editing, H.L., G.T. and C.M.S. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author(s).

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Conflicts of Interest

Author Christina M. Skalko was employed by the company Short Elliott Hendrickson, Inc. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The Short Elliott Hendrickson, Inc. had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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