INSIDE

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MEMBRANE-BASED SOLUTIONS FOR WASTEWATER TREATMENT IN THE DAIRY INDUSTRY

CFR Complete Filtration Resources, Inc.

BERGHOF Membranes Think outside the box

ABSTRACT

With cow's milk consisting of 85-90 percent water, the dairy industry produces much more than the milk, cream, butter, cheese, yogurt, and ice cream products that fill the refrigerated shelves and freezers of supermarkets. It also generates a huge amount of hard-to-treat wastewater.

As a result, milk processing facilities must meet stringent environmental standards for disposing of this effluent, an extremely complex task given its constituents. Doing so requires treatment technologies that are historically capital-intensive and can be a challenge and costly to operate. What's more, water recovery and reuse are gaining acceptance and even becoming a necessity as traditional sources of clean fresh water are increasingly limited and costly in certain areas.

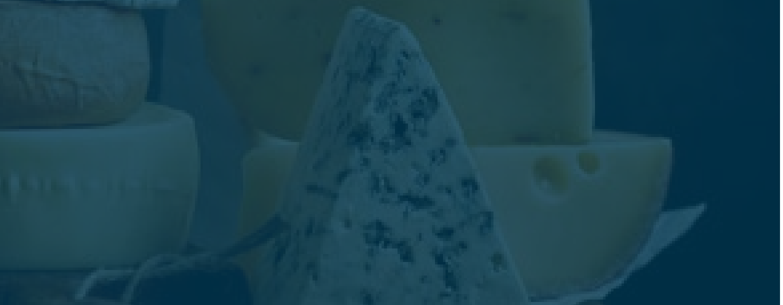
Aerobic and anaerobic MBR systems are the top choice for food and beverage production plants, given that they can provide high-quality effluent in the face of widely varying wastewater flow and loads. In the case of high-strength dairy wastewaters, the anaerobic MBR solution can also generate biogas to fuel boilers or generators and save on energy costs.

INTRO

The dairy industry covers the transformation of raw milk into several products such as pasteurized milk, yogurt, cheese, butter, ice-cream, whey powders and many others. The global consumption of these products is huge, as is the volume of wastewater generated as a result.

The dairy industry is considered to be the largest producer of wastewater within the Food & Beverage Industry. With cow's milk consisting of 85-90% water, and with the high volumes of water consumed during CIP practices, large volumes of wastewater are produced. What's more, according to the FAO[1] (Food and Agriculture Organization of the United Nations) global milk production reached nearly 2 trillion pounds (906 million tonnes) in 2020, up 2% from 2019, driven by output increases in almost all geographical regions. Milk volume increases were highest in Asia, followed by Europe and the Americas.

And this tendency is not expected to change: the consumption of dairy products will continue to rise due to increasing milk consumption in developing countries and the shifting of consumer preferences for innovative dairy products, such as high nutritional value milk-protein based products.



Dairy operators are currently facing several challenges for managing large volumes of high-strength wastewater because the environmental standards for disposing of this effluent are becoming more stringent. Additionally, water recovery and reuse are gaining acceptance and they are even becoming a necessity as traditional sources of freshwater are increasingly limited in some regions.

Due to the limited amounts of organics and nutrients that can be discharged, conventional biological treatment approaches are falling behind and more advanced technologies are necessary for addressing a more efficient and cost-effective on-site wastewater treatment process. In fact, dairy wastewater should be viewed as a resource instead of a waste due to the high amounts of energy that can be generated from it.

Complete Filtration Resources (CFR) and Berghof Membranes partnership has been providing solutions based on the combination of aerobic and anaerobic biological processes and external tubular membrane separation – membrane bioreactor (MBR) and anaerobic MBR (AnMBR), respectively– for numerous dairy facilities for more than 15 years. This process has been optimized over the years to allow dairy plants to treat their wastewater in the most efficient and economical way possible.

DAIRY WASTEWATER

Characteristics

The dairy industry involves the processing of raw milk through different processes such as pasteurization, sterilization, centrifugation, filtration, etc. Through the use of many different manufacturing techniques, the dairy industry manufactures products such as market milk, cheese, yogurt, butter, ice cream, milk powder, and many others.

The main sources of dairy wastewater are:

- Raw material: It is predominantly milk and product losses from unloading tank trucks, equipment and pipelines, or spills caused by overflows, malfunctioning, or poor handling procedures.
- Cleaning and sanitizing: A significant volume of wastewater is generated during the cleaning and disinfection of equipment and pipelines that is required daily. The use of acid and alkaline products results in a highly variable pH.
- Whey processing: The equipment used to further process whey into value add products generates large volumes of wastewater, which at times, can have high organic loads.
- Process water: This is mainly clear water with low concentrations of pollutants. This water is typically managed separately as long as it can be reused or discharged with minimal pre-treatment.

The volume and loading of dairy wastewater is highly dependent on the size of the facility, the type of dairy products being manufactured, the applied processing technologies, the cleaning procedures, or the use of good manufacturing practices. As a reference value, it can be considered that between 0.12 and 0.24 gallons of wastewater are generated per 1,000-pound of raw milk processed (1-2 m3 of wastewater per tonne of raw milk). However, as detailed in Table 1, wastewater flows can be highly variable, depending on the product and region.

TABLE 1. GENERATION OF WASTEWATER IN DIFFERENT DAIRY ACTIVITIES. SPECIFIC VOLUME OF WASTEWATER PER MASS OF RAW MILK PROCESSED. [IN BRACKETS SI UNITS].

Product	Wastewater discharge range gal ww/1000 pounds raw milk [m3 ww/tonne raw milk]		
	USA[2]	CANADA[1]	EUROPE[3]
Milk	0.012 - 0.65 [0.1 - 5.4]		0.024 - 0.94 [0.2 - 7.8]
Cheese	0.19 – 0.68 [1.6 - 5.7]	0.095 – 0.71 [0.79 - 5.9]	0.09 – 0.39 [0.75 - 3.25]
Ice cream	0.096 – 0.67 [0.8 - 5.6]	0.039 -0.51 [0.33 - 4.2]	
Condensed milk	0.12 – 0.39 [1 - 3.3]	0.044 – 0.31 [0.37 - 2.6]	
Butter	0.096 (ave.) [0.8 (ave.)]	0.098 – 0.38 [0.82 - 3.2]	
Powder	0.18 – 0.71 [1.5 - 5.9]		0.12 – 0.39 [1 - 3.25]
Cottage cheese	0.096 – 1.49 [0.8 - 12.4]		0.24 – 1.32 [2 – 11]
Mixed products	0.096 – 0.55 [0.8 - 4.6]		

DAIRY WASTEWATER

Characteristics

Dairy wastewater is mainly characterized by the features below:

- High organic load: up to 90% of the organic matter comes from the milk components. The ratio BOD5/COD presents values up to 0.8, meaning that the biodegradability of dairy wastewater is high.
- Fats, oils and grease (FOG): low-moderate concentrations (average 100-200 mg/L), in the form of emulsions. When manufacturing certain products such as butter, FOG can be higher (>1,000 mg/L).
- Total Suspended solids (TSS): they are small particles generated during the processing of milk into solid products (small pieces of cheese, coagulated milk, milk film, curd...).
- Conductivity: it can vary significantly depending on the final dairy product. Brining of cheese and cleaning chemicals are major contributors.
- Nitrogen: it comes from milk proteins and also from ionic species such as NH4, NO2 and NO3. It is becoming increasingly common that a dedicated treatment process for nitrogen removal is required for fulfilling the discharge requirements.
- Phosphorus: it comes from raw milk and also from certain cleaning products containing phosphates. As with nitrogen, the need for removing phosphorus is becoming more common.

TABLE 2: COMPOSITION OF DAIRY WASTEWATERS, ACCORDING TO THE DAIRY PRODUCT MANUFACTURED. LITERATURE REVIEW [4].

Dairy process	pH	BOD5 g/L	COD g/L	FOG g/L	TSS g/L	TN g/L	TP g/L
Mixed dairy	4 - 11	0.24 - 5.9	0.24 - 5.9	0.02 - 1.92	0.06 - 5.80	0.06 - 5.80	0.01 - 0.6
Milk reception	7.2	0.8	0.8	1.06	0.65	0.65	-
Butter	12.1	0.22 - 2.65	0.22 - 2.65	2.88	0.7 - 5.07	0.7 - 5.07	-
Icecream	5.1 - 7.0	2.45	2.45	-	3.1	3.1	0.014
Cheese	3.4 - 9.5	0.59 - 5	0.59 - 5	0.33 - 2.6	0.19 - 2.5	0.19 - 2.5	0.01 - 0.28
Cottage Cheese	7.8	2.6	2.6	0.95	3.38	3.38	-
Cheese whey	3.9 - 6.5	27 - 60	27 - 60	0.9 - 14	1.27 - 22.1	1.27 - 22.1	0.12 - 0.53
Hard cheese whey	5 - 8	9.48	9.48	0.99	7.15	7.15	-
Soft cheese whey	5.3	26.77	26.77	0.49	8.31	8.31	-
Cottage cheese whey	4.5	-	-	-	-	-	-
Whey processing effluent	5 - 9	0.59 - 1.21	0.59 - 1.21	-	0.08 - 0.44	0.08 - 0.44	-
Washing water	10	3.47	3.47	3.11	3.82	3.82	-
General dairy (EPA[5])	4 - 11	0.45 - 4.79	0.45 - 4.79	-	0.02 - 5.7	0.02 - 5.7	0.011-0.16

DAIRY WASTEWATER

Main challenges for producers

The dairy industry produces some of the largest quantities of wastewater and is one of the highest producers of organic pollutants. As a result, proper treatment is essential for several reasons including regulatory compliance, environmental stewardship and/or brand reputation.

Economic drivers are also important: if a dairy only applies a simple pre-treatment step and discharges to the local municipality's treatment facilities, it can pay high surcharges which can add up to millions of dollars per year in large dairy plants. The alternative is that the dairy invests in an on-site wastewater treatment facility, for which an efficient and cost-effective solution is needed.

As the effluent requirements for discharge to surface water bodies continue to get tighter, the discharge fees continue to increase and the cost of fresh water continues to rise, the topic of water is becoming a mandatory discussion point in every industry.

When implementing an on-site wastewater treatment facility, the high variability in volumes and loading is known to be the main challenge. This variability arises for different reasons:

- Because of the highly seasonal nature of milk production, the volume of milk received (and the volume of wastewater generated) is typically higher in summer and lower in winter months.
- Additionally, the waste streams generated from the different individual operations within the dairy processing plant are discharged independently. Furthermore, the batch nature of most of the processes and the intermittent operations for cleaning and sanitizing lead to a wide daily variation in wastewater flows and quality.
- Finally, notable differences are found between the different dairy plants. Dairy wastewater characteristics depend on the products being created, the production technology and automation, the type of equipment used, the degree of water reuse, the loss of raw materials, the waste management strategies, etc.

KEY MESSAGE

Managing variability, while maintaining the effluent quality required for discharge or reuse, demands the implementation of advanced and robust technologies. The core technology of the treatment facility is the biological process, whose performance may be affected by the presence of cleaning and sanitizing products (potential toxicity and inhibitory effect), poor sludge settleability (hampering the conventional activated sludge processes), and the presence of FOG and dissolved salts. Tubular UF MBR technology has been proven to be one of the best available technologies for dealing with the most challenging dairy wastewaters.

DAIRY WASTEWATER

Membrane-based technologies for dairy wastewater treatment

Dairy operators have a few different options for managing the wastewater: it can be hauled away for offsite land application, it can be minimally pre-treated and discharged to the municipal sewer system, or it can be treated to a high quality and discharged to a local surface body of water. Each option has its pros and cons. Hauling wastewater offsite for land application is becoming less common. Regulations are becoming increasingly difficult to meet and the cost to haul large volumes of wastewater erodes profitability. Discharging to a municipal sewer system can be practical in some applications, however, the high organic loading usually results in significant surcharges. As a result of the drivers described previously, on-site treatment is now the most common, as it is economically more viable over the life of the production facility.

The treatment of dairy wastewater typically follows this process:

1. Primary treatment: it includes screening for the removal of large particles and debris, equalization for organic load, pH, temperature and volume fluctuations, and neutralization when pH shifts are detected. Sedimentation and flotation are also applied in some cases.

2. Secondary treatment: it is performed by using biological processes for removing the carbon, nitrogen, and phosphorus compounds. Organic matter removal can be achieved by aerobic and anaerobic processes.

3. Tertiary treatment: it aims to polish the treated effluent to a very high quality and is dependent on final effluent goals. It can involve advanced nutrient removal, disinfection, softening, salt removal, temperature reduction, etc.

DAIRY WASTEWATER

Membrane-based technologies for dairy wastewater treatment

Aerobic vs. anaerobic processes

Both the aerobic and anaerobic processes use microorganisms, such as bacteria, archaea and protozoa, to feed on and digest the organic matter. However, the microorganisms involved in each process utilize distinct metabolic pathways. The main difference is that the aerobic process uses oxygen, while anaerobic processes occur in an oxygen-free environment.

To explain further, aerobic microorganisms need oxygen to convert wastewater organics into CO_2, water, and new biomass. This is why air must be supplied continuously with blowers or other aeration systems, which require energy input. Since the biomass grows when assimilating the organic matter, the excess sludge must be removed from the system and further treated, which adds operational expenses.

In contrast, anaerobic digestion occurs in the absence of oxygen and can be a net energy positive process. The main byproduct of the anaerobic process is biogas, which consists of 55-65% methane. The biogas can be used as fuel for a biogas engine to generate renewable thermal and electrical energy. At times, enough electricity can be generated to power the entire wastewater treatment facility. Additionally, anaerobic processes produce approximately 75% less sludge than aerobic processes, and this helps significantly reduce solids handling costs.

TABLE 3. COMPARISON BETWEEN AEROBIC AND ANAEROBIC TECHNOLOGIES

Feature	Aerobic	Anaerobic
energy	Higher, due to oxygen requirements (directly related to the organic load to be removed)	Minimum energy consumption and positive net energy generation (biogas)
organic load	Low – medium (COD < 10 - 15 g/L)	Medium - high (COD > 10 - 15 g/L)
effluent quality	Very good (Effluent COD < 100 mg/L achievable)	Higher than aerobic due to higher soluble COD (up to 5x higher)
nutrient removal	N and P removed with the appropriate reactor configuration	Limited N removal and considerable P removal depending on technology
sludge production	High (30-40% of the inlet COD)	Low (8% of the inlet COD)
biokinetics	Simple, generally stable (some control required in nitrification)	Slightly more complex and operate best within tighter process control windows
others	Most readily known technology	Alkalinity addition can be required

DAIRY WASTEWATER

The membrane bioreactor technology

The membrane bioreactor (MBR) is basically a highly efficient evolution of the conventional activated sludge system, where the clarifiers are replaced by ultrafiltration (UF) membranes. With membranes, significant improvements are achieved: superior effluent quality, higher biodegradation rates, smaller footprint, less sludge production, and the ability to further reuse the water. All of these features are essential as dairy plants are being forced to meet increasingly stringent discharge requirements and are looking to save on fresh water costs.

As a result, membrane filtration is no longer an option for wastewater treatment but it is in fact becoming a standard in dairy facilities.

Among the different membrane configurations commercially available, the external tubular UF has been shown to be the most robust option for dealing with the variabilities and challenges typically found in dairy wastewater.

Aerobic and anaerobic MBR technologies are known to be some of the best available technologies for dairy wastewater treatment. Depending on the organic load and discharge requirements, the most adequate process or a combination between both of them will be implemented. Figure 1 summarizes the tubular MBR-based approaches for dairy wastewater treatment.

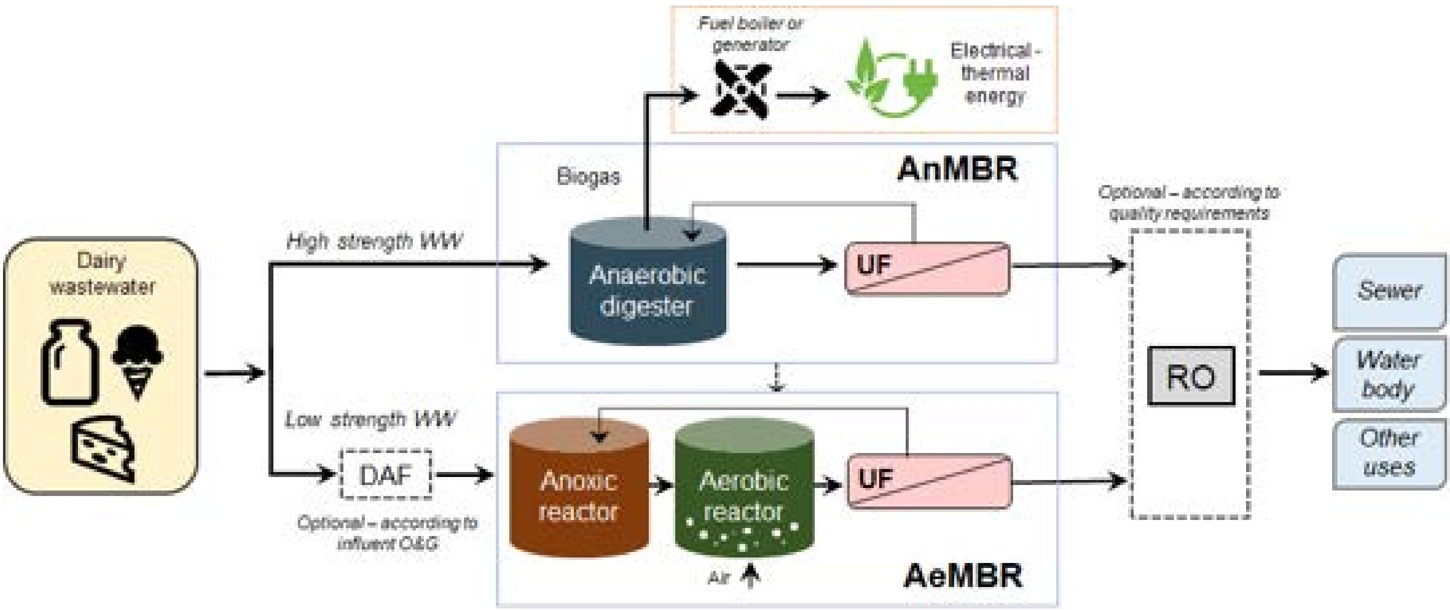


FIGURE 1. GENERAL APPROACH FOR DAIRY WASTEWATER TREATMENT WITH AEROBIC AND ANAEROBIC MBR TECHNOLOGY.

DAIRY WASTEWATER

Aerobic membrane bioreactor

Aerobic membrane bioreactor (AeMBR)

Dairy wastewater is challenging due to variability in day-to-day operations, high organic loadings, presence of FOG and calcium, and toxic or inhibitory components coming from CIP operations. Its treatment demands a robust, adaptable and reliable technology which can be achieved using an MBR with tubular UF membranes. Tubular MBR allows for numerous advantages over the conventional biological treatment as well as the submerged MBRs:

- Robustness against fluctuations: The organic load peaks are known to strain the conventional activated sludge systems and can also promote the fouling of submerged membranes. The filtration conditions in tubular membranes are easily adapted, providing the most stable operation under any circumstance.
- Superior effluent quality: conventional activated sludge technology is known to present reduced sludge settleability which can hamper the fulfillment of tight discharge limits. The tubular MBR achieves COD removals higher than 99%, excellent nitrification (and de-nitrification, if required). It produces a clear effluent, free of solids, turbidity and FOG and COD < 50 mg/L.
- Increased bioprocess efficiency: membranes allow for a higher concentration of biomass and longer sludge ages in the bioreactor. This leads to highly specialized biomass which is less affected by influent variabilities and has very good nitrification capacity.
- Ability to cope with higher concentrations of FOG: Tubular PVDF membranes operated in cross-flow conditions are not significantly affected by the presence of FOG. In most of cases, the DAF pretreatment can be avoided with the consequent savings in chemical consumption and sludge management.
- Hardness can be high in dairy wastewater (300 – 1,000 mgCaCO3/L). Because of this, precipitation of carbonates is prone to occur, leading to scaling in submerged MBRs. The negligible cake layer formed on tubular membranes reduces the risk of carbonate biomineralization and membrane scaling. Therefore, the chemical treatment commonly required in submerged MBRs for hardness removal is minimized.

TABLE 4. TYPICAL RESULTS FROM AN MBR OPERATION AT A LOW-MEDIUM STRENGTH DAIRY WASTEWATER.

PARAMETER	COD	BOD5	TSS	FOG	TN	N-NH4
Influent (mg/L)	4,000	3,000	300	150	150	60
Effluent (mg(L)	< 50	< 5	non detect	< 1	< 10	< 1
Removal efficiency	> 98%	>99%	~100%	> 99%	> 93%	> 98%

DAIRY WASTEWATER

AnMBR vs. Conventional anaerobic technologies

Anaerobic membrane bioreactor (AnMBR)

For high-strength dairy effluents (COD > 10 - 15 g/L) the AnMBR is often the best choice. Anaerobic digestion is best suited for high-strength wastewater, and if properly designed, it can remove 95-98% of the COD in a single step. The tubular UF is coupled to a simple High Rate Complete Mix digester, allowing the operation with high organic loading rates (OLR up to 5-8kg COD/m3·day) while producing a high-quality effluent. The UF membranes ensure complete retention of the biomass within the anaerobic digester and brings a significant improvement in the digestion process, making it more robust, reducing the footprint and increasing the biogas production. As summarized in Table 5, the AnMBR provides significant benefits for treating industrial wastewater when compared with conventional anaerobic technologies, such as the anaerobic filters or the granular sludge-based technologies (UASB, EGSB, IC, etc.).

TABLE 5. ADVANTAGES OF ANMBR FOR OVERCOMING THE LIMITATIONS OF CONVENTIONAL ANAEROBIC TECHNOLOGIES FOR INDUSTRIAL WASTEWATER (ADAPTED FROM[6])

CONDITIONS	CONVENTIONAL ANAEROBIC TREATMENTs	ADVANTAGES of AnMBR
High TSS)	• Less efficient granulation • Deterioration of effluent quality due to TSS • Accumulation of slowly degradable compounds and lower biogas production • Problems at influent distribution systems • Clogging in anaerobic filters • Precipitation of inorganics (Ca and P) leading to granulation interference	• Biomass retention is not dependent on granulation, effluent free of TSS. • Pretreatment for TSS removal is avoided and biogas production increases • There is no need for complex influent distribution systems due to using a continuously mixed tank
High FOG	• Impairment of granulation • Biomass flotation and wash out	• Suspended biomass is retained by the membranes, regardless of its settling/granulation properties • No biomass wash out nor effluent deterioration
Toxic or inhibitory compounds	• Problems in granulation and biomass loss • High acclimation time for specific microbes, slow start-up. • Inhibition of methanogenesis, especially in stratified systems	• No biomass wash out • Provides a better dilution under a toxic shock in the CSRT compared to stratified systems • Bioaugmentation of specialized microbes, for specific compounds is easier
High T	• Difficulty in granulation of anaerobic biomass	• Biomass retention is not dependent on granulation

DAIRY WASTEWATER

Anaerobic membrane bioreactor

The high-strength dairy wastewater or by-products like whey can be treated in the AnMBR, which offers major advantages over other anaerobic technologies:

- **Better effluent quality: AnMBR's can remove 95-98% of the incoming COD which allows it to be a great option as a pre-treatment system for discharge to a municipal sewer system.**

- **Ability to handle high TSS and FOG concentrations that are typically present in dairy wastewater that can constrain the operation of granular type anaerobic systems.**

- **Eliminating the need for primary FOG separation with a DAF system, which generally consumes large amounts of chemicals and generates a sludge that is difficult and costly to dewater. The AnMBR design allows for the fat to be converted to biogas instead of being hauled away as a sludge.**

The robust tubular UF system is a physical barrier that ensures that all of the solids are retained within the system regardless of the settleability of the biomass. Tubular UF membranes are simple to operate and are easy to clean, which promotes long-term operations and long membrane life, which can go beyond 10 years.

CASE STUDY

Grasslands dairy products

INTRO

Family-owned since 1904 with roots in the Swiss Alps going back generations, Wisconsin-based Grassland Dairy Products, Inc. is a leading sustainable producer of high-quality butter products and dairy ingredients. It is the world's largest family-owned buttery.

Their butter plant in Wisconsin processes up to 6 million pounds of milk per day, sending 500,000 gallons of wastewater a day (approximately 1900 m3/d) to a custom-engineered retrofit of its existing wastewater treatment plant with a membrane bioreactor (MBR) system. Low and high-strength streams are segregated to optimize aerobic and anaerobic digestion performance.

The upgrade to the aerobic and anaerobic MBR systems has enabled Grassland to re-use up to 80,000 gallons of water per day for steam generation and cooling tower purposes. The anaerobically produced biogas fuels a generator that produces 9,000 kW per day of electricity, saving nearly $230,000 per year in energy costs.

Overall, the new wastewater treatment process is saving Grassland up to $150,000 per month when compared with the operational costs of their old system

Grassland®

BENEFITS

The benefits reported by Grassland include water reuse, substantial energy cost savings, plus other sources of savings, and the responsible, environmentally sound treatment of 500,000 gallons of wastewater per day. The latter fact enhances one key brand attribute that Grassland is particularly proud of: an environmentally sustainable business model. In fact, the company produces three times more butter than it did 15 years ago, using less energy, water and land.

ABOUT CFR

Complete Filtration Resources Inc, (CFR) was founded in 1993 and is a well-established designer of skidded membrane filtration systems for the food & beverage Industry. In more recent years, CFR has expanded their services to include wastewater treatment engineering and design. CFR's Wastewater Solutions team has significant experience in managing difficult to treat waste that is common in the dairy and food and beverage industries.

As the world's preeminent supplier of some of the largest "state of the art" food production systems, CFR can now integrate decades of membrane separation expertise with the rapidly transforming world of wastewater membrane bioreactor systems. Aerobic and anaerobic membrane bioreactor systems are becoming the go to process of choice for food and beverage production facilities due to their inherent assurance of high-quality effluent in the face of widely varying wastewater flow and loads. These variations are well known to be the 'Achilles heel' of traditional wastewater treatment systems. The CFR team has an integrated staff capable of providing cutting edge analysis and application of appropriate technical solutions to all of your water and wastewater management challenges.

ABOUT BERGHOF MEMBRANES

Berghof Membranes is the leading manufacturer of tubular UF membranes. For more than 50 years, we have been working closely with leading OEMs for addressing the most challenging industrial water projects with efficient, reliable and cost-effective solutions.

To provide the best support and track experience to end-users we put our deep knowledge and extensive know-how at the disposal of our partner OEM's,

Berghof tubular UF is recognized for the robust and reliable operation, resulting in a consistent output and low cost of ownership. It is why more than 2.000 industrial end-users put their trust in our products day-by-day.

ABOUT THIS WHITEPAPER

Dairy operators have to deal with huge volumes of heavily polluted wastewater, with stringent environmental standards and a focus on sustainable business that fosters their environmental pledge.

Traditional treatment is often insufficient: poor effluent quality and unreliable performance due to wastewater variability are common in conventional activated sludge plants. The large footprint and chemical consumption are additional pain points identified in dairy plants.

CFR and Berghof Membranes partnership has been providing solutions for dairies for more 15 years. In this white paper we aim to share our know-how and perspective for the sustainable and cost-effective treatment of dairy wastewater.

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