Clarifex:

An Automated Membrane Filtration System Engineered to Precisely Separate Fine Particles from Liquids with Intelligent Process Control



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In an era when industrial efficiency and environmental sustainability are paramount, demand for high-precision, cost-effective technologies has never been higher. For decades, industries have relied on conventional manual membrane filtration—specifically microfiltration and ultrafiltration—to separate suspended or colloidal particles from liquids. While foundational to many sectors, these traditional methods face several operational inefficiencies, including heavy reliance on human intervention, inconsistent data collection, and disruptive maintenance cycles. To address these critical bottlenecks, a research team from the Center for Sustainable Development (CSD) at Qatar University has developed an automated solution that integrates Artificial Intelligence (AI), the Internet of Things (IoT), and membrane technology. A U.S provisional patent, "Membrane-assisted automated colloidal or suspended particles separation from liquid" (No. US 63/733,369), was granted to the research team consisting of Dr. Probir Das, Shoyeb Khan, and Maryam Mohammed H A Al-Emadi.

The Innovation: Bridging the Market Gap

The core innovation of this patent lies in its transition from passive, manually operated hardware to an intelligent, self-regulating ecosystem. In conventional setups, managing multiple membrane units to process large volumes of liquid is cumbersome and error-prone. Operators must physically monitor the system, manually extract samples at infrequent intervals, and subjectively decide when to clean the membranes. This traditional approach creates several operational gaps: heavy reliance on manual labor, inconsistent data, an inability to perform continuous sampling, and a complete lack of remote monitoring capabilities. The Qatar University team's invention introduces a paradigm shift by creating a fully autonomous system that directly closes these gaps. Instead of relying on human operators, the system utilizes a sophisticated Python-based software architecture to control a network of IoT devices, including microcontrollers (Arduinos devices), precision flow sensors, pumps, and valves.

"This innovation transforms a conventional mechanical process into an intelligent and adaptive operation." The system can independently monitor the liquid's physical and chemical properties—such as turbidity, pH, and temperature—or even use computer vision to assess cellular characteristics in real time. By continuously analyzing this data, the system decides exactly when to initiate filtration, when to pause for maintenance, and when the process is complete. This entirely removes the guesswork and inconsistency of human intervention, providing high precision and highly repeatable results. Furthermore, upon completion of the process, an automated email containing process data is sent to the desired recipients.

Key Features of the Automated System

A pilot-scale prototype consisting of two large ultrafiltration membrane units (each 50 sq. m) was developed. Currently operating at a high Technology Readiness Level (TRL) of 6 –7, the pilot-scale unit can process 2000 L of microalgal culture per hour (Figure 1). The prototype has the following (Table 1):



Figure 1: Pilot-scale prototype unit operation at Qatar University Algal Demonstration Facility (QUADF).

Table 1: Prototype features.

Key Feature	Technical Description	Operational Advantage
Intelligent Auto-Backwashing	Continuously monitors permeate flow rates. If the flow drops below a set threshold due to membrane fouling, the system automatically halts, backwashes the specific membrane, and resumes operation.	Prevents irreversible membrane damage, significantly extends membrane lifespan, and eliminates the need for disruptive manual cleaning.
Remote & Continuous Sampling	Utilizes an array of integrated sensors to constantly evaluate the liquid's dynamic properties without physical sample extraction.	Allows for deployment in hazardous or remote environments while ensuring decisions are made on real-time, high-frequency data.
Fault Tolerance & Isolation	Programmed to detect individual membrane unit failures. If a unit malfunctions, the software automatically isolates it and re-routes the workload to functional units.	Guarantees uninterrupted processing and prevents total system shutdowns, ensuring process reliability.
Automated Data Logging & GUI	Captures all operational events, pressures, and flow rates and exports them directly to organized Microsoft Excel files. A Graphical User Interface (GUI) displays real-time metrics.	Completely solves the issue of inconsistent data, providing stakeholders with transparent, actionable insights for optimization.
Automated Reporting & CIP	Upon completing a batch, the system initiates a Clean-In-Place (CIP) protocol to prepare for the next run and automatically emails a comprehensive summary report to designated personnel.	Drastically reduces turnaround time between batches and keeps management effortlessly informed.

Potential Applications across Industries

This AI-driven filtration system stands as a testament to Qatar University's commitment to solving real-world challenges, promising a future in which industrial processes are fundamentally smarter, more profitable, and more sustainably integrated into the modern world. By introducing remote monitoring, high-precision control, and continuous sampling, the system's commercial potential extends far beyond standard water filtration across multiple high-value sectors (Table 2):

Table 2: Industrial Sectors.

Industrial Sector	Specific Application	Value Add for the Industry
Biotechnology & Aquaculture	Harvesting and concentrating microalgae, bacteria, and sensitive enzymes.	Reduces the exorbitant costs of microalgal biomass harvesting, accelerating the development of sustainable feed and other bulk products.
Pharmaceuticals	Liquid-phase particle isolation and separation of delicate cellular components.	Ensures the strict purity and consistency that are non-negotiable in drug development, while reducing contamination risks through hands-free automation.
Industrial Processing	Recovery of valuable suspended materials, such as colloidal catalysts, from chemical mixtures.	Directly improves chemical yields, reduces industrial waste, and enhances the circularity of manufacturing processes.
Water Quality Monitoring	Automated, remote water quality sampling and the efficient removal of suspended impurities in natural bodies of water.	Enables continuous environmental protection efforts without requiring personnel to be stationed in remote or harsh locations.
Wastewater Treatment	Treating industrial and municipal wastewater for safe discharge or resource recovery.	Significantly reduces the energy footprint and operational costs of large-scale water purification.

Expected Impact on Economy and Sustainability

The expected impact of this provisional patent is both economically significant and closely aligned with global sustainability goals, particularly Qatar's National Vision 2030. The innovation has the potential to transform wastewater treatment and advance the rapidly growing microalgae industry by integrating biomass production with wastewater bioremediation and nutrient recovery, thereby contributing to a sustainable circular economy. In addition, microalgae cultivation offers an effective pathway for carbon capture, as the production of every kilogram of algal biomass can utilize approximately 1.8 kilograms of CO_2. This breakthrough technology will enable automated, efficient, and cost-effective biomass harvesting, accelerating the wider application of microalgal biomass, as traditional harvesting is often a major bottleneck and can account for up to 40% of biomass production costs.