ACCELERATED MATERIALS

Reaction Systems

Technical Data Sheet

Overview

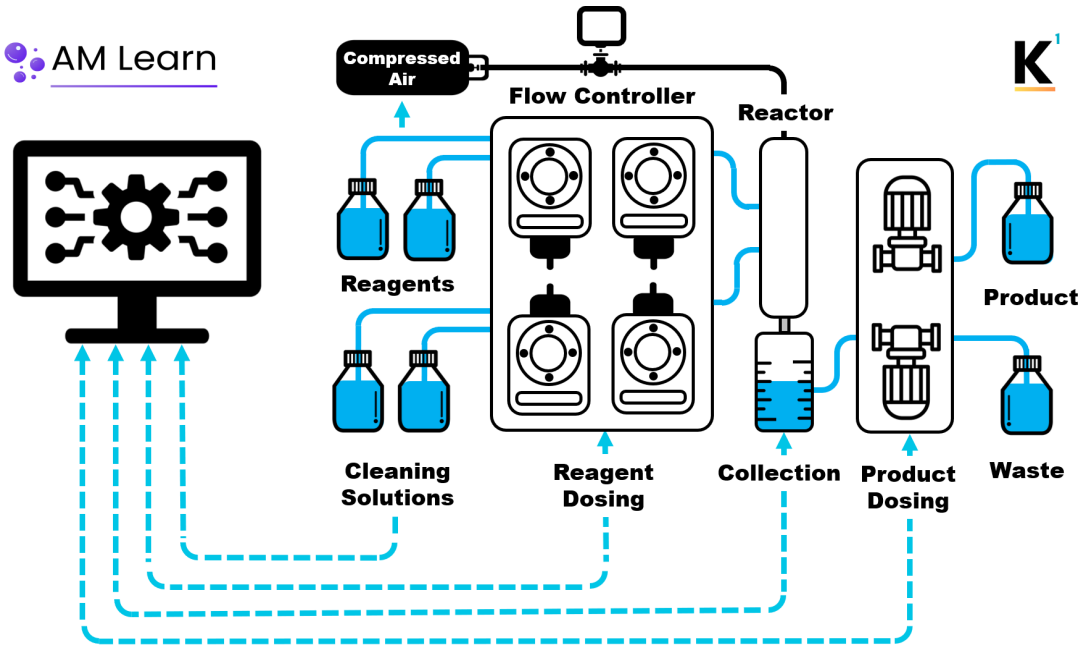
Description

The **K1** reactor system revolutionizes nanomaterial production through its unique combination of speed, safety, precision, and intelligent automation. This innovative system harnesses continuous flow chemistry and modular components to generate high-value nanomaterials in mere seconds. Within a single benchtop, the K1 is capable of generating either 50 mL samples in seconds, or over a kilogram of nanomaterial in a day.

The K1 is built with patented high shear annular flow technology, which eliminates the need for extreme temperatures and pressures in nanoparticle synthesis, creating a safer working environment and minimizing potential hazards. Precise control over the shear rate ensures consistent particle size, morphology, and ultimately, the performance of the nanomaterials across all batches.

Furthermore, the K1 system integrates powerful machine learning algorithms that analyze reaction data and optimize process parameters to achieve your desired nanomaterial specifications. When combined with our fully automated workflows, this intelligent optimization streamlines development by reducing time spent on experimentation and accelerating the path from concept to production

Ultimately, the K1 is easy-to-scale system that allows scale-up without significant reconfiguration and additional optimization, to AM's 10 and 100 kg/day systems (the **K10** and **K100**).



Schematic of K1 Max equipped with AI-driven optimization and automation through AM Learn

Features	Start	Pro	Max
Dosing	• Continuous Low Pulsation Pumping	• Continuous Low Pulsation Pumping • Automated valves	• Continuous Low Pulsation Pumping • Automated valves
Product Collection	None	None	Stirrer Waste and Product Pumps
Max Number of Reagents	2	4	4
Automation Level	• Single Batch Dispensing • Manual Cleaning & Loading	• Continuous Dispensing • Autonomous Reaction and Cleaning	• Continuous Dispensing • Autonomous Reaction and Cleaning • Autonomous Product Collection with Spray Reduction
Use Cases	Single Batch Synthesis	Multi Sample Synthesis	High Throughput Synthesis
Sensors	None	Pressure	Pressure

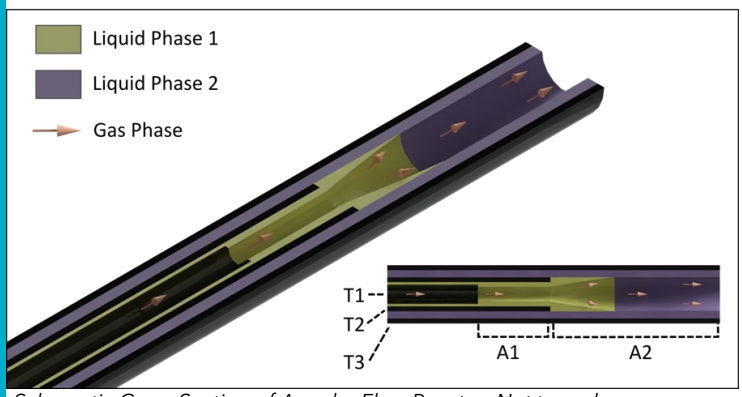
Reactor Modules

Reactor Principles

The K1 reactor operates on the principle of high, precision shear rate control. By precisely controlling shear rates at magnitudes as high as 10^6 s^{-1}, the annular flow reactor enables precise manipulation of nanoparticle formation dynamics and mixing. This results in precision synthesis of targeted particle size, crystallinity, morphology and other critical characteristics of nanomaterials.

High yet precise shear rate is achieved by accessing a fluid dynamic regime known as "multiphase annular flow". In this regime, liquids and gases flow through a pipe with high differences in relative velocity. A high velocity gas forces liquids to the very edges of the pipe, leaving a gaseous annulus core. In the thin film that the liquids occupy (10 – 200 um), there is a very high yet uniform distribution of shear rates. Chaotic mixing also occurs at the gas and liquid interface due to a phenomenon known as "Kelvin-Helmholtz instabilities".

An example schematic of a two reagent flow is given below, where three tubes (T1, T2, T3) create two annular flow zones (A1, A2). In section A1, air flow through T1 forced Liquid Phase 1 into a thin film at the inner walls of T2. In A2, the thin film of Liquid 1 from A1 is then contacted with a thin film of Liquid Phase 2. In T3, mixing and reaction occur.



Schematic Cross Section of Annular Flow Reactor. Not to scale.

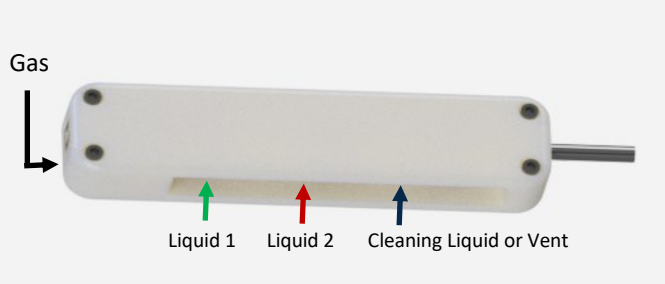
Label	Legend
A1	Annular Region 1
A2	Annular Region 2
T1	Tube 1 (Gas)
T2	Tube 2 (Liquid 1)
T3	Tube 3 (Liquid 1+ Liquid 2 Mixing Zone)

Reactor Specifications

The K1's patented design and proprietary assembly process enables precision alignment of microcapillaries in a coaxial manner.

The K1 can be purchased in three different configurations to enable different chemistries. For a single step reaction of two reagents, the 2T is a simple yet versatile solution. For multi-step reactions involving 3 or 4 reagents, the 3T or 4T may be used. This capability opens doors to multistep processes or the incorporation of quenching agents, expanding the versatility and applicability of the reactor system. Please note that only two reagents lines can be mixed simultaneously with the current K1.

Each K1 also comes equipped with a vent line which can be used for tip cleaning or as a vent port.



K1-2T Reactor Schematic

Property	Quantity
Footprint	0.1 m x 0.1 m
Weight	< 1 kg
Wetted materials	ETFE, PEEK, PP, Quartz
Minimum micromixing time	0.5 ms
Maximum shear rate	10^6 s^{-1}
Maximum liquid flowrate (total)	20 mL/min
Maximum air flowrate	5 L/min
Maximum pressure	7 bar
Reaction length	50 mm

Models

Capabilities	-2T	-3T	-4T
Number of Reagents	Up to 2	Up to 3	Up to 4
Use Case	• Single step processes • Manual Quenching • Manual Tip Cleaning	• Multistep processes • Automated Quenching • Automated Tip Cleaning	• Multistep processes • Automated, Simultaneous Quenching and Cleaning

Dosing Modules

Start

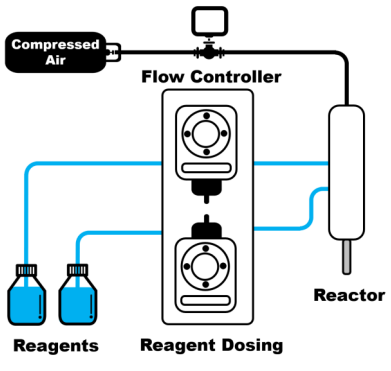
The Entry level model of the K1 reactors equipped with a continuous low-pulsation pumping system, enabling high-volume production with precision and speed. Low precision sensors provide basic monitoring capabilities and manual valves are included to assist with cleaning between reactions. All K1 models come bundled with AMLearn, our bespoke control and machine learning software that facilitates automation, system control and machine-learning driven process optimization.

Pro

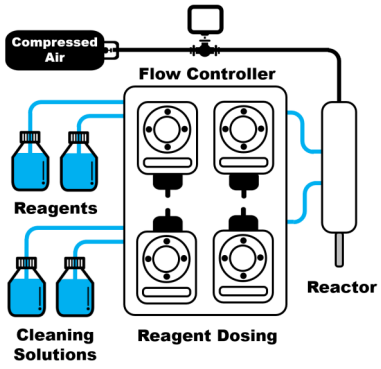
The K1 Pro expands on the K1 Start, enabling more complex nanomaterial syntheses. It features four continuous low pulsation pumps allowing for more intricate reagent combinations. The autonomous valves provide automated cleaning between reactions, enhancing workflow efficiency. High-precision sensors provide in-depth process data and facilitate semi-autonomous process optimization. This makes the K1 Pro ideal for generating multiple samples and optimizing workflows swiftly.

Max

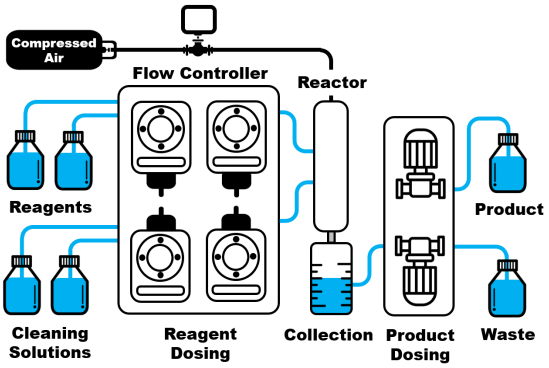
The K1 Max is the pinnacle of automation and efficiency in nanomaterial production. Equipped with high-precision sensors, including pH and conductivity sensors, the K1 Max supports comprehensive analytical capabilities. It also features an advanced automated sample collection module, enabling fully autonomous workflows and continuous synthesis without manual intervention. The K1 Max sets a new standard for streamlined synthesis processes and optimized production, with seamless scalability to AM's larger systems.



Schematic of K1 Start



Schematic of K1 Pro

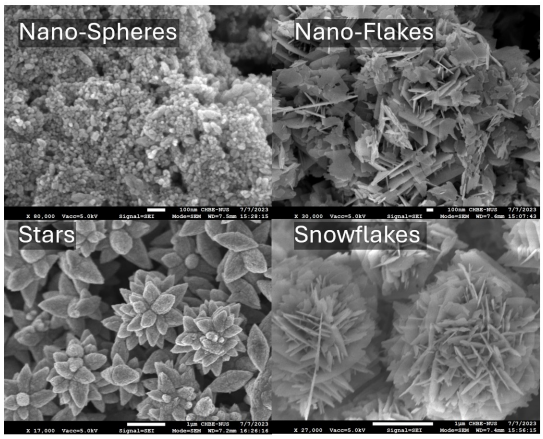


Schematic of K1 Max

Capabilities	Start	Pro	Max
Air dosing	1 x Mass Flow Controller	1 x Mass Flow Controller	2 x Mass Flow Controller
Liquid Dosing	2 x Continuous Low Pulsation Pumps	4 x Continuous Low Pulsation Pumps 8 x Automated Selector Valves	4 x Continuous Low Pulsation Pumps 8 x Automated Selector Valves
Dosing Sensors	2 x Pressure Sensors (Liquid)	5 x High Precision Pressure Sensors (1 x Gas, 4 x Liquid Sensors)	5 x High-Precision Pressure Sensors (1 x Gas, 4 x Liquid Sensors)
Analytical Sensors	None	None	1 x pH Sensor 1 x Conductivity Sensor
Product Collection	None	None	• Spray Reducing Connector • Collection Vessel • Waste & Product Pumps
Max number of reagents	2	4	4

Material Capabilities

Families	2D Materials Metals Metal Oxides Metal Organic Frameworks Quantum Dots Organic Nanoparticles
Size Range	<5 nm to 5 um
Morphologies	Spheres, Flakes, Rods, Stars and more
Throughput (dry basis)	1 kg/day



ZnO morphologies synthesized with K1

Type	Two Dimensional Materials	Metals	Metal Oxides	Metal Organic Frameworks	Quantum dots	Organic Nanoparticles
Bonding type	Multiple	Metallic	Ionic	Covalent/ Coordination/Ionic	Ionic/Covalent	Covalent
Reaction Mechanism	Multiple	Reduction	Co-precipitation	Co-precipitation	Co-precipitation Solvothermal	Anti-solvent precipitation
Examples	Hydrotalcite Graphene	Silver Gold	Zinc Oxide Iron Oxide	Copper BDC ZIF-8	ZnO Graphene Quantum dots	Curcumin
Applications	Sensors Optics Battery electrodes Construction additives	Conductives Sensors Antimicrobials Catalysts	Coatings Catalysts Antimicrobials	Carbon capture Industrial-Adsorbents	Optoelectronics Biosensors Security inks	Drug delivery Pharma

Relevant Publications*	
Constant shear continuous reactor device	Patent
Hydrodynamic assembly of two-dimensional layered double hydroxide nanostructures	Journal publication Material: Layered Double Hydroxides
(1)Scalable and precise synthesis of two-dimensional metal organic framework nanosheets in a high shear annular microreactor (2)Assembly of Two-Dimensional Metal Organic Framework Superstructures via Solvent-Mediated Oriented Attachment	Journal publication Material: Metal Organic Frameworks
Nanonization of Curcumin in Continuous Annular Flow	Poster Presentation Material: Organic Nanoparticles
Pushing nanomaterials up to the kilogram scale–an accelerated approach for synthesizing antimicrobial ZnO with high shear reactors, machine learning and high-throughput analysis	Journal Publication Material: Metal oxide
Influence of hydrodynamics on wet syntheses of nanomaterials	Book Chapter

*see attached zip document

AM Learn

ACCELERATED MATERIALS

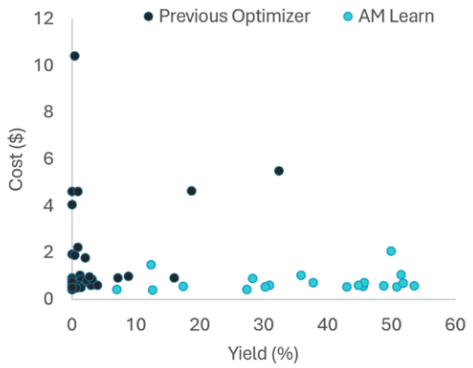
Software

K1 reaction systems are easily operated with **AMLearn**, an operating system for advanced equipment control, automation and machine learning integration. AM Learn contains apps for AM's equipment as well as our proprietary machine learning methods for data analysis and optimisation. These capabilities significantly reduce the time, expense and error of manual experimentation.

K1 reaction systems are bundled with Optimize and K1 Control applications (K1 Start, K1 Pro and K1 Max). Combining the two, users can rapidly create reliable and scalable synthetic protocols in as little as 20 experiments, varying up to 25 variables and 4 objectives simultaneously.

Control Features	K1 START	K1 PRO	K1 MAX
Dosing Rate and Times	◆	◆	◆
Pressure Monitoring		◆	◆
Autonomous Cleaning		◆	◆
Experiment Scheduling		◆	◆
Data Report Generation		◆	◆
Optimize Features	**OPTIMIZE**		
Intelligent Model Selection	◆	◆	◆
No. of Variables	25	25	25
No. of Objectives	4	4	4
Variable Types	Continuous, discrete & integer variables		

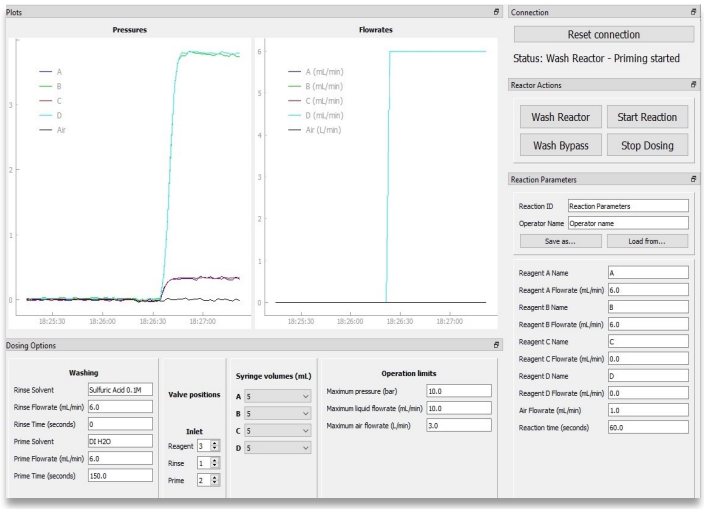
K1 Control and Optimize Capabilities by system type



Example case study results with Optimize

K1

- **Precision Dosing:** Control flow rates and reaction times with exceptional accuracy for consistent, reproducible results.
- **Automated Workflows:** Schedule experiments, automate repetitive tasks, and free up your time for characterisation and development.
- **Real-time process monitoring:** Monitor reaction conditions to ensure safety and optimize process parameters.
- **Data Management:** Import/export reaction recipes seamlessly, and generate detailed data reports for comprehensive analysis.



K1 Control Pro User Interface

Optima

- **Advanced Optimization for Chemical Processes:** Employ sophisticated algorithms to intelligently predict optimal reaction pathways, solvent choices, and balance multiple objectives in complex chemical processes.
- **Code-Free Workflow Integration:** Utilize a user-friendly, graphical interface to design and execute AI-driven optimization protocols without the need for coding expertise.
- **Streamlined Automation:** Design and execute AI-driven optimization workflows with ease using a code-free, intuitive graphical interface.

Optimize User Interface

Industrial Case Study – Synthesis of Nano Zinc Oxide

Nano zinc oxide is highly versatile industrial material, with applications ranging from sunscreen to electron transport layers.

Unfortunately, it is a particularly challenging material to efficiently scale-up, due to the wide diversities of morphologies, sizes and crystalline structures it can form.

To demonstrate the industrial viability of our K-series pipeline, we have successfully scaled up the manufacture of morphology-controlled nano zinc oxide with the K1, K10, K100 systems *in a matter of months*.

Compared to conventional batch synthesis methods, the approach exhibited the following benefits:

- Reduced labour in both experimental time and manufacturing personnel , especially useful for constrained R&D timelines
- Reduced space usage – a K1 replaces a 50L reactor, while a K100 replaces a 10,000 L reactor - saving valuable factory and laboratory space.
- Preservation of product uniformity across 1, 10 and 100 kg/day scales, without the need for additional optimization.

Combining these benefits, the return on investment is dramatically accelerated – as much as 90%!

To learn more about our nano zinc oxide products, which are available for license under the *ZArmour* brand, you can visit acceleratedmaterials.co/products

	Comparison Scale					
Parameters	**g-kg**		**kilo**		**kilo - tonne**	
	K1	**50L reactor**	**K10**	**1,000L reactor**	**K100**	**10,000L reactor**
Capacity kg/day (Control)	1	1	10	10	100	100
# of experiments per day	10	1	1	0.5	1	0.2
Space requirement, (sqm)	1.5	5	3	25	25	100
Production cost, $/kg	$ 254.00	$ 509.00	$ 20.00	$ 50.00	$ 15.00	$ 33.00
Total Investment	$ 43,185.00	$ 126,833.00	$ 203,750.00	$ 692,387.34	$ 576,100.00	$ 4,155,871.71
Capex Reduction ($)	$ 83,648.00	**66%**	$ 488,637.34	**71%**	$3,579,771.71	**86%**
Opex Reduction ($/kg)	$ 255.00	**50%**	$ 30.00	**60%**	$18.00	**55%**
Years to **breakeven** ($50/kg)					**0.51 Years**	**8.47 Years**

Get Your K1

Package

AM's standard K1 package consists of:

- The K1 Start, Pro or Max, along with the desired reactor (-2T, -3T or -4T)
- 1 year of customer service, including remote installation guidance, training and troubleshooting
- 1 year warranty on dosing and reaction equipment
- 1 year subscription to AMLearn

Proof of Concepts and Services:

Unsure if the K1 is right for your application? Need additional services or customization? AM offers proof-of-concept projects and services to enhance your K1 purchase.

Contact

To request a quotation, a proof-of-concept, or get more information, contact AM's team at sales@acceleratedmaterials.co.