ACCELERATED MATERIALS

K[1]

Reaction Systems

Product Brochure

Overview

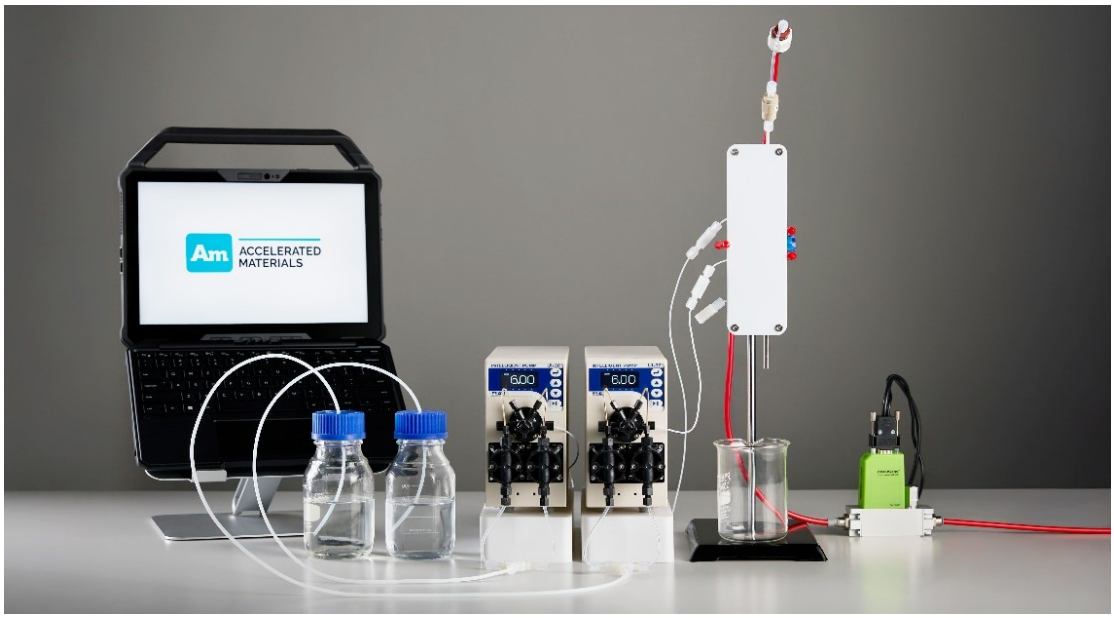
Description

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 millilitres of samples in minutes, 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 the K1 Start, incorporating annular flow reactor technology with AI-driven optimization and automation

K1 System Models and Features

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 Automated Product Collection with Spray Reduction
Use Cases	Single Batch Synthesis	Multi Sample Synthesis	High Throughput Synthesis
Sensors	None	Pressure	Pressure

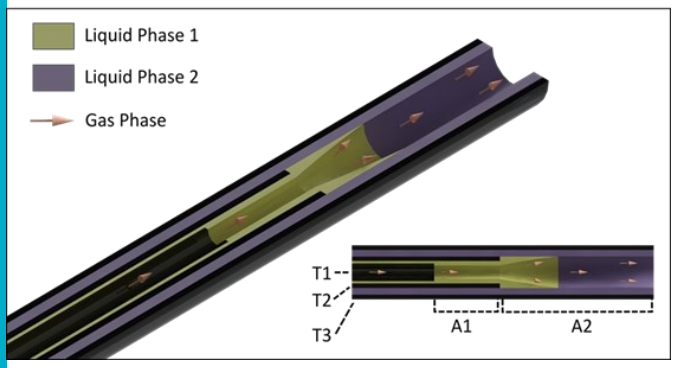
Annular Microreactor Module

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 mixing and nanoparticle formation dynamics 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 µm), 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.

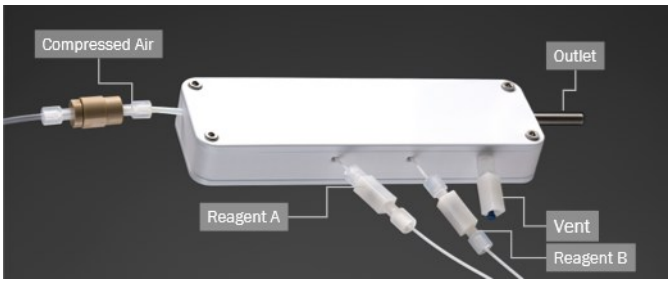
Label	Description
A1	Annular Region 1
A2	Annular Region 2
T1	Tube 1 (Gas)
T2	Tube 2 (Liquid 1)
T3	Tube 3 (Liquid 1+ Liquid 2 Mixing Zone)

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 quenching, tip cleaning, or as a vent port .



K1-2T Reactor Schematic

K1-2T Technical specifications	
Dimensions	21.5 x 5.8 x 2.6 cm
Weight	200 g
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

Reactor 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

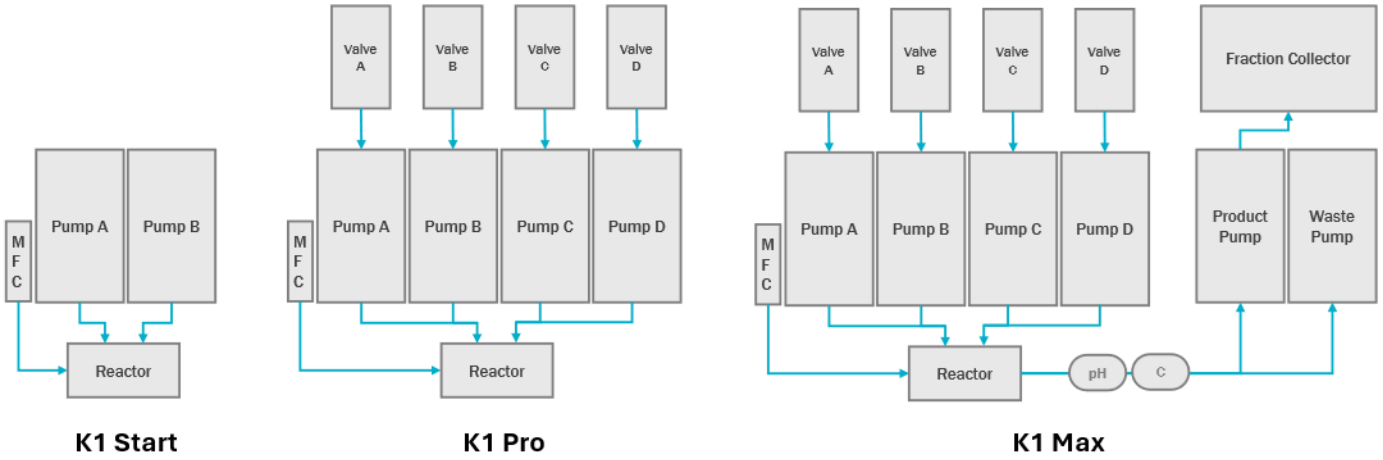
K1 Dosing Modules consist of continuous, medium-pressure low pulsation pumps for liquid reagents, mass flow controllers for compressed air, peristaltic pumps and fraction collectors for product collection, and sensors for monitoring reaction pressure and product pH and conductivity. Additional options are available upon request, such as temperature regulation and additional analytical equipment. Max systems are made to customer specifications.

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. Pump pressure sensors provide basic monitoring capabilities. Changing between reagents and cleaning solvents is done manually. The K1 Start is ideal for laboratories that are starting out in nanoparticle synthesis, with low sample generation frequency (<10/day).

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 pressure sensors provide in-depth process data and facilitate semiautonomous process optimization. This makes the K1 Pro ideal for generating multiple samples (>10/day) and optimizing workflows swiftly.

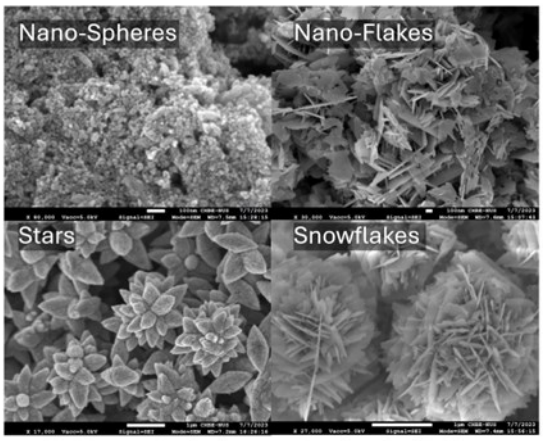


K1 Configuration Schematics. Reagent and compressed gas not shown.

Capabilities	Start	Pro	Max
Air dosing	1 x Mass Flow Controller 5 SLPM Max	1 x Mass Flow Controller 5 SLPM Max	2 x Mass Flow Controller 5 SLPM Max
Liquid Dosing	2x Low Pulsation Pumps 20 bar max 0.1 - 50 mL/min max	4 x Low Pulsation Pumps 20 bar max 0.1 - 50 mL/min max 4 x Selector Valves (4 Port)	4 x Low Pulsation Pumps 20 bar max 0.1 – 50 mL/min 4 x Selector Valves (4 Port)
Dosing Sensors	2 x Pressure Sensors (Liquid) 1 bar accuracy	5 x Pressure Sensors (1 x Gas, 4 x Liquid Sensors) 0.01 bar accuracy	5 x Pressure Sensors (1 x Gas, 4 x Liquid Sensors) 0.01 bar accuracy
Analytical Sensors	None	None	1 x pH Sensor 1 x Conductivity Sensor
Product Collection	None	None	Collection Vessel Waste & Product Peristaltic Pumps Fraction collector
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

To see relevant publications, please visit https://acceleratedmaterials.co/amacademy

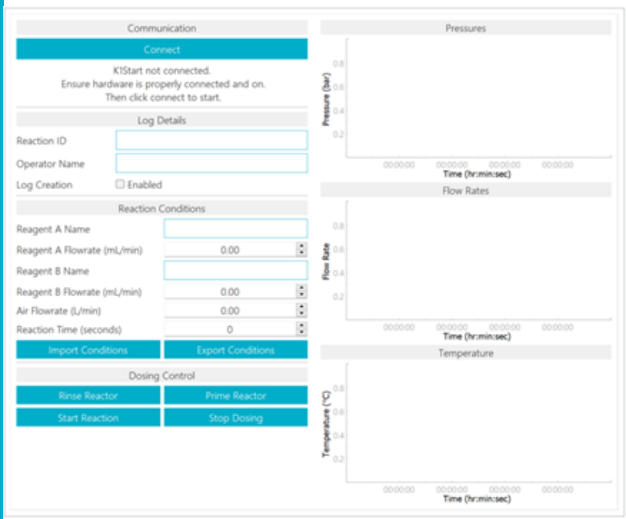
Software

AM Learn

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.

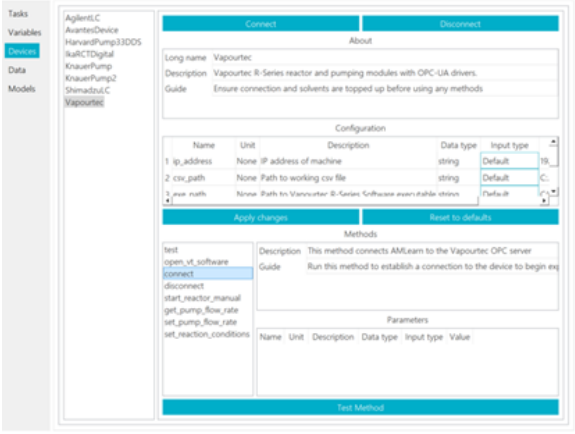
K1 reaction systems are bundled with Dash, Optima and K1 applications (K1 Start, K1 Pro and K1 Max). Combining the two, users can rapidly create reliable and scalable synthetic protocols in as little as

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		



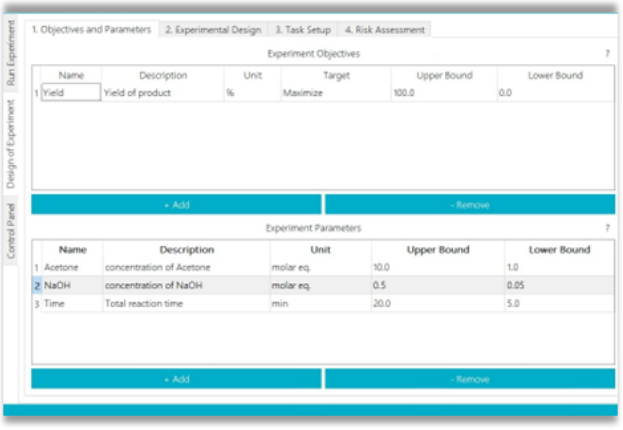
K1

- **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.



Dash

- **Monitor:** Visualize the status of all system components, from variables, to task and data
- **Control:** Easily execute both high and low level commands to initiate protocols or directly control equipment



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.

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.

Technoeconomic Analysis Results

Parameters	g-kg		kilo		kilo - tonne	
	K1	50L reactor	K10	1,000L reactor	K100	10,000L reactor
Capacity kg/day	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

Total Cost Reduction			
Capacity (kg/day)	1	10	100
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** (at $50/kg) **~6 months (a reduction of 8.47 Years)**

Get Your K1

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, rent-to-own schemes, and R&D services to enhance your K1 purchase.

Contact

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