Advances in Energetic Materials Processing Enabled By ResonantAcoustic® Mixing

Testimonials • Published Articles • Patents & Patent Applications

April 2024

This document is a portfolio of testimonials, articles, and patents/patents pending that reference Resodyn's ResonantAcoustic® Mixing (RAM) technology in a variety of energetics materials industry applications. This collection of abstracts and links to published articles is intended to provide insight into the value of RAM technology as a means of solving challenges, improving quality, and raising productivity in development and processing of materials used for pyrotechnics, explosives, propellants and related energetics.

Resodyn Acoustic Mixers, Inc. 130 N. Main Street, Suite 630, Butte, MT 59701
+1-406-497-5333 | info@resodynmixers.com | https://resodynmixers.com

Resodyn Acoustic Mixer Processing of Energetic Materials

The world needs constantly improving energetic materials and better ways to manufacture these critical products. These important efforts include establishing quantifiable gains in the performance of energetic materials based upon accepted standards of measure. Improving manufacturing methods increases safety, reduces costs, and mitigates environmental impacts of energetic materials manufacturing.

Resodyn's innovative **ResonantAcoustic® Mixing "RAM" technology** uses the physics of resonance to thoroughly, but gently mix explosive formulations safely. RAM technology has eliminated purging and post-cure machining by enabling near-net-shape methods. Government and contractor ammunition and propellant manufacturing sites that switched to RAM have gained 6X-10X capacity increases and 3X-7X cost reductions. Resodyn has already helped the McAlester Army Ammunition Plant (MCAAP), the U.S. Department of Defense's premier bomb and warhead loading facility save taxpayers over $20 million.

Energetic materials and munitions are employed in mission-critical applications such as rockets, missiles, ammunition, and pyrotechnic devices. These materials are complex mixes of many different chemicals that are formed into products including powders, viscous pastes, highly viscous pastes, and liquids, each of which must be manufactured to demanding standards. British rocket companies, hobbyists and others worldwide also benefit from these improvements. RAM can also mill, sieve, and coat 10X-100X faster than conventional methods, yet gently enough for processing 3D printing energetic and explosive inks.

Achievement of these essential military requirements is enabled by Resodyn Acoustic Mixer (RAM) Technology, which is the advanced product development tool and improved processing method of choice for the energetics industry globally.

RAM technology is used to mix energetic materials all over the world.

= Customers of ResonantAcoustic® Mixers

What energetics industry professionals are saying about RAM

"Our engineers have achieved a 20 percent increase in munition explosive mixing power by current polymer bonded explosives using the Resodyn Acoustic Mixer. "

- BAE Systems Inc.
Richard Brown
Head of Technology Communications

"...[RAM] allows us to obtain a better quality of the final mixtures in a reduced amount of time. Some exciting work is also being performed on propellant while using this vanguard technology, and very promising results obtained."

- Roxel Group, a propulsion systems company

"Acoustic energy delivers efficient energy transfer...[and] reduces mixing time: hours to minutes, minutes to seconds. [We] mix in sealed vessels—waste reduction! No impellers, blades, or shafts. RAM vessels are easy to clean out and transfer materials."

- Munitions Engineer at U.S. Dept. of Defense

RAM: 21st Century Mixing Technology for Additive Manufacturing Materials

More than a thousand RAM systems are in use in more than 40 countries around the world. RAM is the world's preferred choice for innovation in materials processing.

PUBLISHED ARTICLES

Resodyn™ ACOUSTIC MIXERS
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Icon Legend

- RAM testing, evaluation
- Material/chemical properties
- Powder/powder
- Armament material
- Propellant material
- Liquid/powder
- Materials processing
- Materials/product quality
- Pyrotechnics material
- Explosives material

Icons	Publication Title (Live Links)*	RAM Application Summary	Year
	Effect of resonant acoustic powder mixing on delay time of W–KClO4–BaCrO4 mixtures	By comparing the thermal conductivity of WKB mixtures mixed manually and using an **acoustic powder mixer**, we found that **acoustic powder mixing** resulted in minimal deviations in thermal conductivity, proving more uniform mixing.	2024
	Study on the control of flow field by resonance acoustic mixing technology for purification of high performance spherical HATO crystals	The spheroidization of HATO has been achieved in an environmentally friendly manner by **resonance acoustic mixing** assisted solvent erosion technology, effectively improving its thermal properties, mechanical sensitivity, and the mechanical properties of HATO explosive columns.	2024
	Novel Solid Propellants Enabled Through In Situ Martian Perchlorates	Three propellants made from Martian perchlorates were manufactured and compared to a control propellant with AP as the oxidizer... Mixing was carried out using a **LabRAM I** benchtop mixer (**Resodyn™**...	2024
	A review on the preparation and characterization methods of spherical explosive crystals	Then, the RDX crystal particles with a sphericity greater than 90 % were prepared by **resonance acoustic mixing** assisted solvent erosion technology. Compared with the raw RDX, the thermal performance and safety performance of spherical RDX crystals were improved.	**2023**
	Microstructural investigation of PBX 9501: Comparing wet slurry and resonant acoustic mixing techniques	These initial results suggest that differences in the microstructure do exist between PBX 9501 prepared via wet slurry and **LabRAM mixing**. Greater homogeneity in the binder prepared with **LabRAM** was confirmed by µCT and resulted in consistently higher densities when pressed under the same conditions.	**2023**

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	Mixing Characteristics and Parameter Effects on the Mixing Efficiency of High-Viscosity Solid–Liquid Mixtures under High-Intensity Acoustic Vibration	High-intensity **acoustic vibration** is a new technology for solving the problem of uniform dispersion of highly viscous materials. In this study, we investigate the mixing characteristics of high-viscosity solid–liquid phases under high-intensity acoustic vibration and explore the effect of vibration parameters on the mixing efficiency.	2024
	Preparation of NCh-B and NCh-B-Ti nanocomposites and their ignition and combustion performances	To overcome the agglomeration and insufficient combustion of nano-boron (n-B) powders, this study successfully prepared two novel types of boron-based nanocomposites using the **acoustic resonance technology**, namely high-substitute nitrochitosan/nano-boron (NCh-B) with ratios of 1:3, 1:5, 1:7 and 1:9, and nitrochitosan/nano-boron powder/nano-titanium (NCh-B-Ti) with Ti contents of 5 wt%, 10 wt%, 15 wt% and 20 wt%.	2023
	Difurazanopyrazine (DFP): A promising candidate for insensitive high explosive (IHE) applications	DFP was formulated with a variety of binders via **resonant acoustic mixing** and spray drying and pressed into pellets up to 98 % theoretical maximum density (TMD).	2023
	Parametric Effects on the Mixing Efficiency of Resonant Acoustic Mixing Technology for High-Viscosity Mixture: A Numerical Study	Numerical investigations were conducted on the mixing efficiency of **resonant acoustic mixing (RAM)** technology using a high-viscosity mixture under vertically forced vibrations.	**2023**
	Manufacturing superfine AP by milling in a lab-scale resonant acoustic mixer (LabRAM)	Small AP particles (≤15 µm) are difficult to obtain from commercial vendors due to restrictions derived from increased explosion hazards for superfine AP (SFAP). An in-house SFAP manufacturing process was devised herein using **resonant acoustic mixing (RAM)**.	**2023**
	Centrifugal And Acoustic Mixing Technologies For The Homogenization Of Propellant Powder Formulations	This study investigates the impact of **resonant acoustic powder** mixing on the delay time of the W-KClO4-BaCrO4 (WKB) mixture and its potential implications for powder and material synthesis.	2023
	A new ternary high-energy composite based on nano titanium powder with low sensitivity and stable combustion	For solving the low combustion efficiency caused by aggregation and further promoting the application of nano titanium powder (n-Ti), a new ternary composite high-substitute nitrochitosan/nano titanium/graphene oxide (NCh/n-Ti/GO) was prepared by a **resonant acoustic mixing** method.	2023
	Mechanical Characterisation and Cohesive Law Calibration for a Nitrocellulose Based–Cyclotetramethylene Tetranitramine (HMX) Polymer Bonded Explosive	The binder and the HMX crystals were mixed in the presence of a solvent using **Resonant Acoustic Mixing (RAM)** at a high temperature until the solvent evaporated.	2023
	The impact of resonance acoustic mixing on the production of solid propellants and explosives	The second part provides a method for the equivalence of impact force in **resonance acoustic mixing (RAM)** and impact sensitivity data, which can convert the height data of the impact sensitivity into the corresponding impact stimulus force.	2022

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Icons	Publication Title (Live Links)*	RAM Application Summary	Year
	Preparation and Thermal Decomposition of CL-20-based Cocrystals Using Resonant Acoustic Mixing.	Three CL-20-based cocrystals including CL-20/2-mercap-to-1-methylimidazole, CL-20/4-methyl-5-nirroimidazole, and CL-20/caprolactam have been prepared by using **Resonant Acoustic Mixing (RAM)** technique, and their structures, mor-phology, thermal decomposition and ignition were studied by using PXRD, SEM, TG-DSC, TG-MS, and laser ignition appara-tus.	2022
	Apparent viscosity evolution law of trace RDX-based explosive ink in Resonance Acoustic-Mixing process	To solve the problems of poor mixing consistency, low prepa-ration efficiency and serious material waste of trace and high solid content explosive inks, this paper proposes a new preparation process by combining **Resonant Acoustic-Mixing** technology with rheological apparent viscosity.	2022
	The Production and Development of Acoustically Milled Reactive Ni-Al Com-posite Powders Consolidated via Cold Spray Deposition	The objective of this research was to evaluate **acoustic mill-ing** as a reactive powder processing method by establishing relationships between milling parameters and the resulting reactive powder. The **acoustically processed** nickel-aluminum (Ni-Al) reactive powder was subsequently consolidated to form a structural energetic material via hydraulic pressing and cold spray deposition.	2022
	The impact of resonance acoustic mixing on the production of solid propellants and explosives	...provides a method for the equivalence of impact force in **resonance acoustic mixing (RAM)** and impact sensitivity data, which can convert the height data of the impact sen-sitivity into the corresponding impact stimulus force. In the third part, the impact forces obtained in **RAM** and impact forces obtained from an impact sensitivity testing course are compared to evaluate the safety of the process.	2022
	3D Printing Energetics for Gun Propulsion Technology	Innovative 3DP formulations, incorporating legacy energetic materials, and novel energetic 3DP molecules are candidates for improving the overall system performance and optimizing for lethality and accuracy... To date, formulations consisting of an energetic photosensitive resin, nitrate ester plasticizer, and nitramine have been successfully mixed utilizing **Resodyn Acoustic Mixing** (**RAM**)...	2022
	Continuous flow resonance acoustic mixing technology: a novel and efficient strategy for preparation of nano energetic materials	In this report, a novel strategy to enhance the mixing perfor-mance of fluid is developed by combining continuous flow microfluidic and r**esonant acoustic mixing (RAM)** technol-ogies. The results of the fluid visualization and 3D-Comput-ational fluid dynamics (CFD) simulation showed that the new continuous flow **resonance acoustic mixing** (CFRAM) technology has better mixing efficiency than the traditional microfluidic approach.	2022

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	The surface activation of boron to improve ignition and combustion characteristic	B coated with nano-Al or GF were prepared by **acoustic resonance** and solvent evaporation methods.	2021
	Styrene-Ethylene/Butylene-Styrene (SEBS) Block Copolymer Binder for Solid Propellants	This paper reports on the production of two composite propellants made from a commercially-available-off-the-self polymer as binder by means of a **resonant acoustic mixer (RAM)** slurry process.	2021
	Evolution of HTPB/RDX/Al/DOA mixed explosives with 90% solid loading in resonance acoustic mixing process	**Resonance acoustic mixing (RAM)** technology is an attractive and safe mixing method for material mass and energy exchange... The density test of the cured sample further proved that the PBX was very uniform.	2021
	Rational design of gradient structured fluorocarbon/Al composites towards tunable combustion performance	PTFE/Al ink is prepared by acoustic **resonance mixing** to control rheological properties (viscosity and modulus) for 3D printing technology.	2021
	Rocket Propellant Comparison: Conventional Planetary Mixing and Resonant Acoustic Mixing	A standard HTPB/AP/Al composite rocket propellant formulation was prepared with a conventional vertical planetary action mixer and **resonant acoustic mixer (RAM)**... This result, therefore, indicates more thorough mixing in the case of the **RAM** process, but this requires confirmation...	2021
	Primary Explosive Processing in the Resonant Acoustic Mixer	"[**RAM'**s} ability to rapidly mix even highly viscous substances through application of acoustic energy while avoiding the use of traditional blades has provided substantial leaps forward in both safety and efficiency."	2021
	Resonant acoustic mixing of polymer bonded explosives	The findings are then reconciled with wider literature observations and recommendations are made as how to best implement **RAM** for 'PBneXt' manufacture, ultimately allowing for explosive compositions with improved performance, mechanical, safety, and ageing properties.	2021
	Is ResonantAcoustic Mixing® (RAM) a Game Changer for Manufacturing Solid Composite Rocket Propellants?	This study is a structured literature review of published **ResonantAcoustic® Mixing (RAM)** literature, considering the benefits and constraints of using **RAM**... Overall **RAM** offers numerous benefits to mixing existing and new materials with large savings in time, cost, improved safety and is more environmentally friendly.	2021

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	Combustion of Gelled HAN/Methanol/ Water Propellants	In the present work, an aqueous HAN/methanol solution (70.1 wt% HAN and 14.9 wt% methanol) was gelled with 1 wt% polyacrylamide in an **acoustic mixer**.	2021
	Safer Resonant Acoustic Mixing Methods for High-Volume Production of Pyrotechnics	"... , projected benefits of a production-scale **RAM** process may result in significant increases to overall throughput, labor cost reduction of 61-96%, and a reduction in acetone used for cleanup operations by over 99%."	2020
	Comparison of Propellant Processing by Cast-Cure and Resonant Acoustic Mixing	"For the propellant studied in this research, **resonant acoustic mixing** is a very promising, advanced processing technique that can be applied as an alternative to the conventional mechanical mixing of this high solid load propellant composition."	2020
	Resonant Acoustic® Mixing: Processing and Safety	"...technologies include additive manufacturing and **Resonant Acoustic® Mixing** (**RAM**), which are being demonstrated to reduce processing times, environmental impact and of course cost."	2020
	Burning Rate Characterization of Ammonium Perchlorate Pellets Containing Nano-Catalytic Additives	"Intimate contact between the AP (composite Ammonium Perchlorate) and nano-catalysts was ensured using a R**esonant Acoustic Mixer** (**RAM**)."	2020
	Formulation via Resonant Acoustic Mixing at LANL	The possibility of an alternate method needed to be looked at to advance the process by expanding solvent choices, substrates, and reducing costs. **Acoustic mixing** had been shown to mix powders, slurries, pastes or even liquids.	2020
	Simulation of dispersion characteristics of resonant acoustic mixing with low solid content of powder	The investigation on the flow field and dispersion characteristics of **resonant sound mixing** is of great significance for the dispersion mixing of heat sensitive superfine materials. In order to simulate the flow field and dispersion characteristics of **resonant sound mixing**, a gas-liquid-solid three-phase flow model based on CLSVOF-DPM was established...	2019
	Research on Changing Law of Resonance Acoustic Mixing Process of Plastic Bonded Explosive Simulant	In order to obtain the r**esonance acoustic mixing** process rule and achieve the efficient mixing of plastic bonded explosive (PBX) under the conditions of safety and low energy consumption, the effects of mixing acceleration and time on mixing process are studied for PBX simulant with 88% solid content.	2019

PUBLISHED ARTICLES

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	Processing Studies of Energetic Materials using Resonant Acoustic Mixing Technology	"...manufacturing methods within the energetics field can involve large amounts of solvents, long processing times, high waste output, high shear moving parts, and have single large batch limitations...manufacturing of energetic materials, propellants and pyrotechnics via **RAM** technology have highlighted many potential advantages."	2019
	Resonant Acoustic Mixing Performance and Optimization for Energetic Materials	**Resonant Acoustic Mixing (RAM)** is a recent technique that uses low frequencies acoustic vibrations to generate a large displacement in order to mix compounds. Many tests (verification of Relative Standard Deviation, Chemical Imaging, Ultrasonic testing) and experiments are conducted in order to compare the performance of **RAM** with other traditional mixers.	2019
	Milling of Energetic Crystals with the LabRAM	"...[confirms] feasibility of safely dry milling micron size energetic crystals on a **LabRAM** acoustic mixer while optimizing mill parameters to effectively reduce size."	2019
	The Effects of Resonant Acoustic Mixing on the Microstructure of UHPC	"We study the effects of **RAM** on the microstructure of a designated UHPC mix...our results show that RAM mixing produces a dense UHPC matrix with low porosity."	2019
	Meta-structure Enhancement of Resonant Acoustic Mixing via Embedded Additive Manufacturing	"The performance of energetic materials is founded on a wide range of material and mixing parameters. **Resonant acoustic mixing** (**RAM**) is advantageous as a scalable, contactless energetics mixing method..."	2019
	Evaluation of novel propellants manufactured from commercially available Thermoplastic Elastomers (TPE) using resonant acoustic mixing	"The objective was to advance the current scientific understanding of the PSP relationships underlying **RAM**... it may be possible to tailor pre-mix meta-structure designs for targeted applications, providing promising new means [for **RAM**] to support industries that rely on energetics."	2019
	Determination and optimisation of Resonant Acoustic Mixing (RAM) efficiency in Polymer Bonded eXplosive (PBX) processing	An investigation into how the efficiency (time and energy required for homogeneity) of **Resonant Acoustic Mixing (RAM)** can be determined and optimised was undertaken. An idealised Polymer Bonded eXplosive (PBX) simulant based on glass microbeads (28.3 m D50, 62% v/v in binder and plasticiser) was used for mixing.	2019
	New mixing technology achieves more explosive power	Our engineers have achieved a 20 percent increase in munition explosive power by mixing current polymer bonded explosives using **Resonant Acoustic Mixing (RAM)** technology.	2019

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	Vibro-Engineering in Armaments	For instance... **resonant acoustic mixing** of propellants and pyrotechnics, oscillations of test bed in static evaluation of rockets, acoustic and non-acoustic combustion of propellants inside rocket motors, recoiling of gun during the firing of guns, generation of pressure waves in gun chamber during combustion / projectile motion etc., vibration remains an omni-present factor, influencing the product quality, performance, life and reliability.	2019
	Environmentally Sustainable Manufacturing for Energetic Formulations	In this research, we utilize **Resonant Acoustic® Mixing (RAM)** technology to generate secondary explosive pressing powder and cast-cure formulations that minimize the use of processing and cleaning solvents and reduce the amount of energetic scrap and waste.	2018
	Future Sustainable Propellants	"... we used **Resonant Acoustic Mixing** (**RAM**) as an effective and efficient manufacture method."	2018
	Green Processing of Energetic Materials Using Resonant Acoustic Mixing Technology	This project will demonstrate the ability of the new R**esonant Acoustic® Mixing (RAM)** technology to produce energetic weapons systems components in a single processing step and quantify the reduction in processing waste generated as compared to legacy manufacturing techniques.	2018
	Chapter 6: Co-crystallization of Energetic Materials	Novel techniques such as **resonant acoustic mixing** are introduced as a means for the large-scale production of energetic co-crystals.	2018
	Interactions of Polymers and Energetic Materials	For calorimetry, foams were ground in a coffee grinder and sieved to particle sizes of 150-300 µm. They were mixed in a Resodyn Acoustic Mixer with pyrotechnic.	2017
	Development of Energetic Formulations for Additive Manufacturing (2017 TechnicalInterchange presentation)	EPEx1 (Extrudable Paste, Explosive 1) developed using **LabRAM II**... Use of **RAM** technology allowed high quality mixing at the small scales required.	2017
	Time for pairing: cocrystals as advanced energetic materials	In addition, **resonant acoustic mixing (RAM)** technique, bead milling and spray flash evaporation technique are also introduced as means for large-scale production of nanosized energetic cocrystals.	2016
	Formation of Additive-Containing Nanothermites and Modifications to their Friction Sensitivity	In the present work, MoS2, graphene, and hexadecane additives were dispersed in MoO3 prior to nanothermite formation with the aim of reducing friction sensitivity. Nanothermites were subsequently prepared using a palmitic acid–passivated nano-aluminum (L-Al) and additive-containing nano-MoO3 by the **resonant acoustic mixing** of dry powders.	2016

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	Promising CL-20-Based Energetic Material by Cocrystallization	A novel cocrystal (NEX-1) of CL-20 and MDNT is presented herein. The CL-20:MDNT cocrystal, obtained in high yield by **resonant acoustic mixing**, shows new properties versus the discrete components.	2016
	RAM Mixer Technology Controls Introduction and Control at Resonance (2016 TechnicalInterchange presentation)	Swing example: Well-timed inputs of small energy will cause a swing to maintain or increase height. The energy is supplied by the person on the ground pushing on the swing as it moves away from them. Only small synchronized energy inputs are required to keep the swing going.	2016
	Putting the squeeze on energetic co-crystals: High-pressure studies of 2(CL-20):HMX and NQ:DNP	Two energetic co-crystal systems have been investigated under pressure using neutron powder diffraction – 2(CL-20):HMX, and nitroguanidine:2-hydroxy-3,5-dinitropyridine (NQ:DNP). The 2(CL-20):HMX co-crystal was prepared with a **ResoDyn LabRAM Resonant Acoustic Mixer** using a published method.	2016
	The Advantages of ResonantAcoustic Mixing (RAM) For Making Novel High-Energy Composite Materials (2016 Technical Interchange Presentation)	At NAWCWD we are using our **LabRAM II** nearly everyday.	2016
	Dry Powder Coating of Energetic Materials: Feasible or Futile? (2015 Technical Interchange Presentation)	Capece and Davé used the acoustic energy produced by the **RAM** to deform a micronized polymer over the surface of ascorbic acid crystals, forming a continuous layer. Applying the same process to energetic materials is not a simple matter, and many factors must be considered to determine whether dry powder coating can be carried out without the risk of initiating the energetic material.	2015
	Resonant acoustic mixing: Its applications to energetic materials	"[**RAM**] has several demonstrable applications to the field of energetic materials..."	2015
	Macro and micro characterization of powder mixing processes	**Resonant acoustic mixing** significantly affected the final properties of lubricated blends, increasing their density with increases in acceleration and blending time. These changes in blend properties affected the final properties of tablets by increasing weight, decreasing hardness, and decreasing dissolution.	2014

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	Preparation of an energetic-energetic cocrystal using resonant acoustic mixing	"**Resonant acoustic mixing** (**RAM**) was applied to the preparation of an energetic-energetic cocrystal comprised of CL-20 and HMX in a 2 : 1 mol ratio. We have prepared the cocrystal using the **RAM** technology in a resource-efficient manner providing near quantitative yield. The cocrystalline product from the **RAM** preparation is consistent with the product from solution crystallization."	2014
	The role of fuel particle size on flame propagation velocity in thermites with a nanoscale oxidizer	"**Acoustic mixing** was better suited for this study due to the disparate differences between the materials..."	2014
	Thermal Imaging of Thermite Flame Propagation	"The total mass of the powder was 1 g. The container was closed and mixed using a **resonant acoustic mixer** (**LabRAM**, **Resodyn Corp**.) at 100 G acceleration for a total of 2 minutes."	2014
	An Examination of the Resonant Acoustic Mixer's Flow Field	This report details a second step made toward the high fidelity, first principles numerical simulation of the mixing for the **resonant acoustic mixer.** The current study addresses the mixing of two resins at higher, differing viscosities.	2013
	Effect of Solids Loading on Resonant Mixed Al-Bi2O3 Nanothermite Powders	"...the performance and overall quality of [**RAM**] mixing was strongly correlated to the volumetric solids loading during processing; increasing volumetric solids loading decreases separation of particles, leading to more particle interaction and more intimate mixing."	2013
	Feasibility Study and Demonstration of an Aluminum and Ice Solid Propellant	Early mixtures in this work were mixed by hand or using a Ross DPM-1Q dual planetary mixer (Charles Ross & Son Company, Hauppauge, New York). However, inconstancies in mixing and packing densities motivated other approaches. A **Resodyn LabRAM** resonating mixer (Resodyn Acoustic Mixer Inc., Butte, Montana) was ultimately selected to mix the ALICE propellant.	2012
	Processing Benefits of Resonance Acoustic Mixing on High Performance Propellants and Explosives	**RAM** can be used to effectively mix extremely viscous explosive formulations	2012

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Icons	Publication Title (Live Links)*	RAM Application Summary	Year
	ResonantAcoustic ® Mixing; Design and Process Considerations Concerning Vessel/Case Geometry and Mix versus Cure Time When Preparing Composite Solid Propellant	The mixing was performed using Resodyn Corporation's **ResonantAcoustic ® Mixers**. These mixers employ acoustic energy for mixing and do not use any blades, or paddles. This capability enables mixing in the end use container and also allows the use of a wide variety of container geometries.	2010
	Synthesis of Highly Loaded Gelled Propellants	"Typical propellant fuels, nano-particles and gelling agents were chosen to establish capability of **ResonantAcoustic®** technology to produce viable gelled propellants containing energetic metal and semi-metal nano-particles."	2003

PUBLISHED ARTICLES

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Partial (edited) selection of searched technical articles using the following search terms (articles are live links): "Resonant Acoustic Mixing" AND/OR "energetic material," "pyrotechnics," "explosives," "acoustic mixer," and "Resodyn."

Effect of resonant acoustic powder mixing on delay time of W–KClO4–BaCrO4 mixtures
Kyungmin Kwon, Seunghwan Ryu, Soyun Joo, Youngjoon Han, Donghyeon Baek, Moonsoo Park, Dongwon Kim & Seungbum Hong
By comparing the thermal conductivity of WKB mixtures mixed manually and using an acoustic powder mixer, we found that **acoustic powder mixing** resulted in minimal deviations in thermal conductivity, proving more uniform mixing. Furthermore, differential scanning calorimeter analysis and Sestak–Berggren modeling demonstrated consistent reaction dynamics with a constant activation energy as the reaction progressed in samples **mixed using acoustic waves**.

Study on the control of flow field by resonance acoustic mixing technology for purification of high performance spherical HATO crystals
Dongjie Liao, Haoxing Cao, Shijiao Li, Wangjian Cheng, Xing Yan & Chongwei An
The spheroidization of HATO has been achieved in an environmentally friendly manner by resonance acoustic mixing assisted solvent erosion technology, effectively improving its thermal properties, mechanical sensitivity, and the mechanical properties of HATO explosive columns.

Novel Solid Propellants Enabled Through In Situ Martian Perchlorates
Alexander C. C. Hoganson, Aaron Afriat, Chase M. Wernex, Robert E. Ferguson, Hetal Rathore, Dhruval N. Patel, Bryce Tappan & Steven F. Son
With evidence for the native perchlorates existing in the Martian regolith, this paper examines the feasibility and performance of propellants formed from perchlorate salts reported to be present on Mars... Mixing was carried out using a **LabRAM I** benchtop mixer...

A review on the preparation and characterization methods of spherical explosive crystals
Dongjie Liao, Minjie Li, Jiechao Wang, Minxue Zhang, Mianji Qiu & Chongwei An
Then, the RDX crystal particles with a sphericity greater than 90 % were prepared by resonance acoustic mixing assisted solvent erosion technology. Compared with the raw RDX, the thermal performance and safety performance of spherical RDX crystals were improved.

Microstructural investigation of PBX 9501: Comparing wet slurry and resonant acoustic mixing techniques
Amanda L. Duque, Larry G. Hill, Jeremy T. Tisdale, Janina A. Gielata, Joseph T. Mang & Brian M. Patterson
These initial results suggest that differences in the microstructure do exist between PBX 9501 prepared via wet slurry and **LabRAM mixin**g. Greater homogeneity in the binder prepared with **LabRAM** was confirmed by µCT and resulted in consistently higher densities when pressed under the same conditions.

Mixing Characteristics and Parameter Effects on the Mixing Efficiency of High-Viscosity Solid–Liquid Mixtures under High-Intensity Acoustic Vibration
Xiaobin Zhan, Lei Yu, Yalong Jiang, Qiankun Jiang & Tielin Shin

PUBLISHED ARTICLES

Innovative Mixing Solutions

High-intensity **acoustic vibration** is a new technology for solving the problem of uniform dispersion of highly viscous materials. In this study, we investigate the mixing characteristics of high-viscosity solid–liquid phases under high-intensity **acoustic vibration** and explore the effect of vibration parameters on the mixing efficiency... The uniform mixing of solid and liquid phases with high viscosity is a key process in the preparation of solid propellants, PBX explosives, medicines, etc., and the mixing uniformity of each component significantly affects the performance of the final product.

Preparation of NCh-B and NCh-B-Ti nanocomposites and their ignition and combustion performances

Yu-shu Xiong, Yong-qi Wang, Chong Wan, Wen-zhen Zhang, Zhao Qin, Su-hang Chen & Kang-zhen Xu

To overcome the agglomeration and insufficient combustion of nano-boron (n-B) powders, this study successfully prepared two novel types of boron-based nanocomposites using the acoustic resonance technology, namely high-substitute nitrochitosan/nano-boron (NCh-B) with ratios of 1:3, 1:5, 1:7 and 1:9, and nitrochitosan/nano-boron powder/nano-titanium (NCh-B-Ti) with Ti contents of 5 wt%, 10 wt%, 15 wt% and 20 wt%.

Difurazanopyrazine (DFP): A promising candidate for insensitive high explosive (IHE) applications

Christopher Snyder, Alexander H Cleveland, Jeremy T Tisdale, Valerie Kuehl, Jose Archuleta, Hongzhao Tian, Lisa Klamborowski, Rosemary S Burritt, Joseph T Mang, Amanda L Duque, Lee Perry, Malcolm J Burns, David E Chavez & John M Lang

DFP was formulated with a variety of binders via **resonant acoustic mixing** and spray drying and pressed into pellets up to 98 % theoretical maximum density (TMD). DFP and its formulations have TATB-like sensitivity and high thermal stabilities, while maintaining good detonation properties, making it a promising TATB-replacement material.

Parametric Effects on the Mixing Efficiency of Resonant Acoustic Mixing Technology for High-Viscosity Mixture: A Numerical Study

Imdad Ullah Khan, Rui Guo, Umar Farooq, Suraj Adhikari & Hao Zhou

Numerical investigations were conducted on the mixing efficiency of **resonant acoustic mixing (RAM)** technology using a high-viscosity mixture under vertically forced vibrations. The density distribution was analyzed for a mixture of high-melting explosive (HMX) and trinitrotoluene (TNT).

Manufacturing superfine AP by milling in a lab-scale resonant acoustic mixer (LabRAM)

Felix A. Rodriguez,J. C. Thomas &E. L. Petersen

An in-house SFAP manufacturing process was devised herein using **resonant acoustic mixing (RAM)**. A 90-µm AP feedstock was utilized to produce SFAP batches with average particle sizes of approximately 2 µm.

The impact of resonance acoustic mixing on the production of solid propellants and explosives

Ning Ma, Song Chen, Zhe Zhang, Xiaopeng Sun, Zhongyuan Xie, Weiqiang Pang, & Guangbin Zhang

In this chapter the impact forces applied by the top, bottom, and sidewall of a container are tested. The second part provides a method for the equivalence of impact force in r**esonance acoustic mixing (RAM)** and impact sensitivity data, which can convert the height data of the impact sensitivity into the corresponding impact stimulus force. In the third part, the impact forces obtained in **RAM** and impact forces obtained from an impact sensitivity testing course are compared to evaluate the safety of the process.

PUBLISHED ARTICLES

Resodyn
Innovative Mixing Solutions

Centrifugal And Acoustic Mixing Technologies For The Homogenization Of Propellant Powder Formulations
Kyungmin Kwon, Seunghwan Ryu, Soyun Joo, Youngjoon Han, Donghyeon Baek, Moonsoo Park, Dongwon Kim, Seungbum Hong
This study investigates the impact of **resonant acoustic powder** mixing on the delay time of the W-KC-lO4-BaCrO4 (WKB) mixture and its potential implications for powder and material synthesis... Furthermore, DSC analysis and Sestak-Berggren modeling demonstrated consistent reaction dynamics with a constant activation energy as the reaction progressed in samples mixed using **acoustic waves**. These findings underscore the critical role of uniform powder mixing in enhancing the thermodynamic quality of the WKB mixture and emphasize the importance of developing novel methods for powder and material synthesis.

A new ternary high-energy composite based on nano titanium powder with low sensitivity and stable combustion
Chong Wan, Zhaoqi Guo, Wenzhen Zhang, Suhang Chen, Zhao Qin & Kangzhen Xu
For solving the low combustion efficiency caused by aggregation and further promoting the application of nano titanium powder (n-Ti), a new ternary composite high-substitute nitrochitosan/nano titanium/graphene oxide (NCh/n-Ti/GO) was prepared by a resonant acoustic mixing method.

Mechanical Characterisation and Cohesive Law Calibration for a Nitrocellulose Based–Cyclotetramethylene Tetranitramine (HMX) Polymer Bonded Explosive
M. Iqbal, R. Zhang, P. Ryan, D. Lewis, S. Connors & M. N. Charalambides
The binder and the HMX crystals were mixed in the presence of a solvent using Resonant Acoustic Mixing (RAM) at a high temperature until the solvent evaporated. This process ensures that the HMX crystals are fully coated with the binder.

Preparation and Thermal Decomposition of CL-20-based Cocrystals Using Resonant Acoustic Mixing.
Hai-Jian, Chao Chen, Zhe Zhang, Xiao Xie, Ning Ma, Song Chen, Bo Jin, Ru-Fang Peng & Jian-Hua Yi
It was found that the **RAM** could use the same solvents to the solvent evaporation method, and the volume of solvents was less compared to the solvent evaporation method, and the reaction time was also shorter.

Apparent viscosity evolution law of trace RDX-based explosive ink in Resonance Acoustic-Mixing process
Pengpeng Zhang, Chongwei An, Jiaqing Mu, Fusheng Cui, Wangjian Cheng, Baoyun Ye & Jingyu Wang
To solve the problems of poor mixing consistency, low preparation efficiency and serious material waste of trace and high solid content explosive inks, this paper proposes a new preparation process by combining **Resonant Acoustic-Mixing** technology with rheological apparent viscosity. The experimental results showed that the mixing acceleration and the shape of the mixing container only affected the mixing efficiency.

The Production and Development of Acoustically Milled Reactive Ni-Al Composite Powders Consolidated via Cold Spray Deposition
Madilyn R. Fesenmaier
The objective of this research was to evaluate **acoustic milling** as a reactive powder processing method by establishing relationships between milling parameters and the resulting reactive powder... This study demonstrated that the reactive properties of Ni-Al powder can be tailored using **acoustic milling**...

PUBLISHED ARTICLES

Resodyn
Innovative Mixing Solutions

The impact of resonance acoustic mixing on the production of solid propellants and explosives
Ning Ma, Song Chen, Zhe Zhang, Xiaopeng Sun, Zhongyuan Xie, Weiqiang Pang, & Guangbin Zhang
In this chapter the impact forces applied by the top, bottom, and sidewall of a container are tested. The second part provides a method for the equivalence of impact force in **resonance acoustic mixing (RAM)** and impact sensitivity data, which can convert the height data of the impact sensitivity into the corresponding impact stimulus force. In the third part, the impact forces obtained in **RAM** and impact forces obtained from an impact sensitivity testing course are compared to evaluate the safety of the process.

3D Printing Energetics for Gun Propulsion Technology
David Bird, Elbert Caravaca, Joseph Laquidara, Nathan Peabody, Christopher Houthuysen & Nuggehalli M. Ravindra
A synergy between formulation and printing technique has led to understanding the design space for gun propellant stereolithography apparatus (SLA) and digital light processing (DLP) printing which involves understanding the cure depth to successfully print simple propellant geometries and combustion testing to gauge the performance.... To date, formulations consisting of an energetic photosensitive resin, nitrate ester plasticizer, and nitramine have been successfully mixed utilizing **Resodyn Acoustic Mixing** (**RAM**)...

Styrene-Ethylene/Butylene-Styrene (SEBS) Block Copolymer Binder for Solid Propellants
Peter J. Wilkinson, Matthew C. Weaver, Guillaume Kister & Philip P. Gill
Currently solid composite propellants are manufactured using bespoke, specially manufactured binders. This adds significant cost and obsolescence risks to their development and manufacture. This paper reports on the production of two composite propellants made from a commercially-available-off-the-self polymer as binder by means of a resonant acoustic mixer (RAM) slurry process.

Continuous flow resonance acoustic mixing technology: a novel and efficient strategy for preparation of nano energetic materials
Song Zhang, Lewu Zhan, Yifan Zhang, Jing Hou & Bindong Li
The results of the fluid visualization and 3D-Computational fluid dynamics (CFD) simulation showed that the new continuous flow resonance acoustic mixing (CFRAM) technology has better mixing efficiency than the traditional microfluidic approach.

The surface activation of boron to improve ignition and combustion characteristic
Jian Wang, Jun Wang, Yaofeng Mao, Rufang Peng & Fude Nie
B coated with nano-Al or GF were prepared by acoustic resonance and solvent evaporation methods. In a typical experiment, 40 mg of GF and 80 ml of ethyl acetate were added into the vibrating tank.

Evolution of HTPB/RDX/Al/DOA mixed explosives with 90% solid loading in resonance acoustic mixing process
Wangjian Cheng, Jiaqing Mu, Kun Li, Zhanxiong Xie, Pengpeng Zhang, Chongwei An, BaoYun Ye & Jingyu Wang
In this paper, a 90% solid polymer-bonded explosive (PBX) was prepared by **RAM**, and the evolution of materials in different mixing containers, mixing acceleration, and mixing time was studied. The binder system consisted of hydroxyl-terminated polybutadiene (HTPB)/dioctyl adipate (DOA) and was cured by isophorone diisocyanate (IPDI).

PUBLISHED ARTICLES

Resodyn
Innovative Mixing Solutions

Rational design of gradient structured fluorocarbon/Al composites towards tunable combustion performance
Yaofeng Mao, Qianqian He, Jun Wang, Zijian Li, Zhijian Yang, Fude Nie & DunJu Wang
In order to precisely control combustion reaction and energy output performance, gradient structured PTFE/Al composite (mass and diameter gradient) has been designed and constructed through 3D printing technology. PTFE/Al ink is prepared by **acoustic resonance mixing** to control rheological properties (viscosity and modulus) for 3D printing technology.

Rocket Propellant Comparison: Conventional Planetary Mixing and Resonant Acoustic Mixing
Paul C. Smith, Joel P. Huf & Christopher A. Williams
A standard HTPB/AP/Al composite rocket propellant formulation was prepared with a conventional vertical planetary action mixer and **resonant acoustic mixer (RAM)**... This result, therefore, indicates more thorough mixing in the case of the **RAM** process, but this requires confirmation...

Primary Explosive Processing in the Resonant Acoustic Mixer
Eric Beckel, Karl Oyler, Neha Mehta, Natasha Khatri, John Marin, Akash Shah, Emily Cordaro-Gioia, Robert Decker, Henry Grau & Daniel Stec III
… To date, **RAM** has been applied by the energetics community to a variety of secondary explosive …material has been qualified by the US Navy and the US Army Energetic Materials Qualification … A **LabRAM** unit was donated to DEVCOM AC by **Resodyn Acoustic Mixers** for these trials …

Resonant acoustic mixing of polymer bonded explosives
Andrew J. Claydon
However, with **Resonant Acoustic Mixing (RAM)**, PBX formulation does not have to be constrained. Instead of traditional mixing blades, mixing is achieved by the use of a vibrating platform to impart acoustic pressure waves (vibrations) into the mixture, agitating it. The added ability to mix in the end use casing (mixing 'in-situ') also renders casting obsolete in many scenarios.

Is ResonantAcoustic Mixing® (RAM) a Game Changer for Manufacturing Solid Composite Rocket Propellants?
Christopher J. Wright, Peter J. Wilkinson, Sally E. Gaulter, Donald Fossey, Andrew O. Burn & Philip P. Gill
Mixed in-situ **RAM** overcomes viscosity limitations by removing the casting process and has safety and environmental benefits, but does need to be tested at larger production scales.

Combustion of Gelled HAN/Methanol/Water Propellants
Robert E. Ferguson & Evgeny Shafirovich
However, the effect of gelling on the combustion characteristics and mechanisms of HAN-based propellants is not well understood. In the present work, an aqueous HAN/methanol solution (70.1 wt% HAN and 14.9 wt% methanol) was gelled with 1 wt% polyacrylamide in an **acoustic mixer**.

Safer Resonant Acoustic Mixing Methods for High-Volume Production of Pyrotechnics
Eric Miklaszewski, Christina M. Yamamoto, Joel T. Dunham, Anthony P. Shaw, Robert A Gilbert Jr. & Jay C. Poret
The objective of this work was to develop and mature a **resonant acoustic mixing** (**RAM**) process to reduce the

environmental, safety, and occupational health impacts currently observed in the manufacture of the high volume pyrotechnic: Magnesium/Sodium Nitrate/Epoxy.

Comparison of Propellant Processing by Cast-Cure and Resonant Acoustic Mixing
Martijn Zebregs, Alfons E. H. J. Mayer & Antoine E. D. M. van der Heijden
In this comparative study, a solid composite, AN/HTPB-based propellant was prepared by conventional processing in a mechanical mixer and by applying an advanced processing technique relying on **resonant acoustic mixing (RAM)**. After curing of the propellants, cross …

Resonant Acoustic® Mixing: Processing and Safety
Matthew R. Andrews, Christelle Collet, Aurihona Wolff & Chris Hollands
New processing technologies are allowing researchers, industry and academia to probe new materials space not previously achievable. These technologies include additive manufacturing and **Resonant Acoustic® Mixing** (**RAM**) which are being demonstrated to reduce processing times, environmental impact and of course cost.

Burning Rate Characterization of Ammonium Perchlorate Pellets Containing Nano-Catalytic Additives
Felix A. Rodriguez, James C. Thomas, David Teitge & Eric L. Petersen
Ammonium perchlorate pellets were manufactured with nano-iron oxide (nFe2O3) and nano-titanium oxide (nTiO2) at several mass loadings (0.25-1% by mass) and were burned from 3.45-34.5 MPa (500-5,000 psi) in a constant-volume strand bomb. Intimate contact between the AP and nano-catalysts was ensured using a **Resonant Acoustic Mixer (RAM)**.

Formulation via Resonant Acoustic Mixing at LANL
Ernest Leon Hartline & Amanda Lynn Duque
Up until this time only the wet slurry formulation method that had been used was from the 1940's. This wet slurry method had been and still was the standard for all explosive formulations. The possibility of an alternate method needed to be looked at to advance the process by expanding solvent choices, substrates, and reducing costs. **Acoustic mixing** had been shown to mix powders, slurries, pastes or even liquids.

Simulation of dispersion characteristics of resonant acoustic mixing with low solid content of powder
Shifu Zhu,Xiaopeng Wang, Song Chen & Xingqiang Xu
The investigation on the flow field and dispersion characteristics of **resonant sound mixing** is of great significance for the dispersion mixing of heat sensitive superfine materials.

Research on Changing Law of Resonance Acoustic Mixing Process of Plastic Bonded Explosive Simulant
Ning Ma, Zhe Zhang, Xiaopeng Sun, Neng Qin, Zhongyuan Xie & Song Chen
In order to obtain the **resonance acoustic mixing** process rule and achieve the efficient mixing of plastic bonded explosive (PBX) under the conditions of safety and low energy consumption, the effects of mixing acceleration and time on mixing process are studied for PBX simulant with 88% solid content... The mixing process can be used to guide the **resonance acoustic mixing** process of PBX and other materials with highly viscous and highly solid content.

Processing Studies of Energetic Materials using Resonant Acoustic Mixing Technology

Rosie J. Davey, James M. Wilgeroth & Andrew O. Burn
… of energetics. Land UK has been investigating the ability of **RAM** to process a range of different energetic materials, including PBXs and Low Vulnerability Ammunition (LOVA) propellant formulations. These studies have involved processing energetic materials using **Resodyn's** …

Safer Resonant Acoustic Mixing Methods For High-Volume Production Of Pyrotechnics
Dr. Eric Miklaszewski, Ms. Christina M. Yamamoto, Mr. Joel T. Dunham, Dr. Anthony P. Shaw, Dr. Robert A Gilbert Jr. & Dr. Jay C. Poret
The objective of this work was to develop and mature a **resonant acoustic mixing (RAM)** process to reduce the environmental, safety, and occupational health impacts currently observed in the manufacture of the high volume pyrotechnic: Magnesium/Sodium Nitrate/Epoxy. These formulations are found in a variety of munitions including gun- and mortar-fired illumination projectiles.

Resonant Acoustic Mixing Performance and Optimization for Energetic Materials
Aurihona Wolff, Matthew Andrews & Christelle Collet
Resonant Acoustic Mixing (RAM) is a recent technique that uses low frequencies acoustic vibrations to generate a large displacement in order to mix compounds... This report provides an overview of the simulation models for mixing cases: continuous models and discretization of elements (in particular Discrete Element Method).

Milling of Energetic Crystals with the LabRAM
Lance N. Kotter & Lori J. Groven
… Over the last decade, the **Resodyn LabRAM acoustic mixer** has been widely used for mixing of … not safe for all energetic materials and a safety assessment of the energetic materials sensitivity …However, it has been shown to be capable of processing energetics safely and more …

The Effects of Resonant Acoustic Mixing on the Microstructure of UHPC
Aileen Vandenberg & Kay Wille
We study the effects of **RAM** on the microstructure of a designated UHPC mix through back-scattering electron scanning microscopy (BSE-SEM) and mercury intrusion porosimetry (MIP). Our results show that **RAM** mixing produces a dense UHPC matrix with low porosity.

Meta-structure Enhancement of Resonant Acoustic Mixing via Embedded Additive Manufacturing
William Alexander Reach
Resonant acoustic mixing (RAM) is advantageous as a scalable, contactless energetics mixing method; however, challenges remain in connecting process parameters to post-mix performance. In this thesis, we analyzed the influence of the structural arrangement of pre-mixture ingredients (i.e., the pre-mix "meta-structure") on post-mix properties.

Evaluation of novel propellants manufactured from commercially available Thermoplastic Elastomers (TPE) using resonant acoustic mixing
Peter John Wilkinson
Traditional mixing and manufacturing techniques where not suitable for processing of propellants with TPE binders. Slurry processing (used in manufacture of pressed PBXs) was selected to coat the filler, creating a moulding

powder. This was replicated with a novel method using **resonant acoustic mixing (RAM)**.

Determination and optimisation of Resonant Acoustic Mixing (RAM) efficiency in Polymer Bonded eXplosive (PBX) processing

A.J. Claydon, A.N. Patil, S. Gaulter, G. Kister & P.P. Gill

An investigation into how the efficiency (time and energy required for homogeneity) of **Resonant Acoustic Mixing (RAM)** can be determined and optimised was undertaken... Different stages of the mixer 'intensity' profiles were found to correspond to discrete stages of mixing, as well as further rheological changes due to continued frictional heating, thus viscosity reduction, beyond homogeneity being achieved.

New mixing technology achieves more explosive power

BAE Systems

This new explosive process means we can add 20 percent more power to existing product lines – both warheads and shells. Thinking about future designs, this means less explosive can be used to achieve the same effect, reducing both space and weight. You could use this space to install more tracking hardware to increase precision, or increase the amount of propellant to add speed and range.

Vibro-Engineering in Armaments

K.P.S. Murthy

In almost every step during the life-cycle of HEMs (processing, testing, transportation, deployment, etc.), vibration engineering is associated and assumes a vital role in performance of overall systems. For instance, vibration casting for propellants and explosives, resonant acoustic mixing of propellants and pyrotechnics, oscillations of test bed in static evaluation of rockets, acoustic and non-acoustic combustion of propellants inside rocket motors, recoiling of gun during the firing of guns, generation of pressure waves in gun chamber during combustion / projectile motion etc., vibration remains an omni-present factor, influencing the product quality, performance, life and reliability.

Environmentally Sustainable Manufacturing for Energetic Formulations

Eric Beckel

In this research, we utilize **Resonant Acoustic® Mixing (RAM)** technology to generate secondary explosive pressing powder and cast-cure formulations that minimize the use of processing and cleaning solvents and reduce the amount of energetic scrap and waste. For the pressing powder work, we are developing processes for the waterless generation of these formulations that only use small amounts of non-hazardous air polluting (non-HAP) solvents that can be recovered and reused.

Mix-In-Case Green Processing with RAM

Andrew Nelson

This presentation describes the advantages of **RAM** over legacy processing techniques for preparing novel high-energy composite formulations. Process-related lessons learned and the safety steps implemented to prepare novel, high-energy composite materials will be described.

Chapter 6: Co-crystallization of Energetic Materials

S. R. Kennedy & C. R. Pulham

Also discussed are the challenges associated with distinguishing between co-crystals and physical mixtures of materials for which characterization by single crystal X-ray diffraction is not possible. Novel techniques such as resonant acoustic mixing are introduced as a means for the large-scale production of energetic co-crystals.

Green Processing of Energetic Materials Using Resonant Acoustic Mixing Technology
Andrew P. Nelson
The **RAM-based** process of mixing within the desired end item has not yet been demonstrated at the production scale for an energetic formulation.

Future Sustainable Propellants
Peter John Wilkinson
Inert formulations were created by a new novel process. This involved coating the filler with TPE using a novel slurry coating process involving a **Resonant Acoustic Mixer (RAM)**.

Development of Energetic Formulations for Additive Manufacture (2017 TechnicalInterchange presentation)
Mike O'Donnell & Matthew Thorne
EPEx1 (Extrudable Paste, Explosive 1) developed using **LabRAM II**... Use of **RAM** technology allowed high quality mixing at the small scales required.

Time for pairing: cocrystals as advanced energetic materials
Jiaheng Zhangab & Jean'ne. M. Shreeve
The major part of the discussion relates to the different types of energetic cocrystals including cocrystals composed of energetic molecules and solvents, 2,4,6,8,10,12-hexanitrohexaazaisowurtzitane (CL-20)-based cocrystals and azole-based cocrystals, et al. In addition, **resonant acoustic mixing (RAM)** technique, bead milling and spray flash evaporation technique are also introduced as means for large-scale production of nanosized energetic cocrystals.

Formation of Additive-Containing Nanothermites and Modifications to their Friction Sensitivity
Pascal Beland, Patrick Brousseau & Catalin-Florin Petre
In addition, **resonant acoustic mixing (RAM)** technique, bead milling and spray flash evaporation technique are also introduced as means for large-scale production of nanosized energetic cocrystals.

Promising CL-20-Based Energetic Material by Cocrystallization
Stephen R. Anderson, Pascal Dubé, Mariusz Krawiec, Jerry S. Salan, David J. am Ende & Philip Samuels
A novel cocrystal (NEX-1) of CL-20 and MDNT is presented herein. The CL-20:MDNT cocrystal, obtained in high yield by resonant acoustic mixing, shows new properties versus the discrete components. This is the first example of cocrystallization of CL-20 where the new material is less sensitive to friction than CL-20 itself, while demonstrating similar impact and ESD sensitivity.

RAM Mixer Technology Controls Introduction and Control at Resonance (2016 TechnicalInterchange presentation)
Brian Seaholm

Swing example: Well-timed inputs of small energy will cause a swing to maintain or increase height. The energy is supplied by the person on the ground pushing on the swing as it moves away from them. Only small synchronized energy inputs are required to keep the swing going.

Putting the squeeze on energetic co-crystals: High-pressure studies of 2(CL-20):HMX and NQ:DNP
Karl S. Hope, Daniel W. Ward, Hayleigh Lloyd & Steven Hunter
Two energetic co-crystal systems have been investigated under pressure using neutron powder diffraction – 2(CL-20):HMX, and nitroguanidine:2-hydroxy-3,5-dinitropyridine (NQ:DNP). The 2(CL-20):HMX co-crystal was prepared with a **ResoDyn LabRAM Resonant Acoustic Mixer** using a published method.

Interactions of polymers and energetic materials
Rebecca M. Levine
Trace explosive detection is the primary way for quick and easy sampling of various surfaces in a check-point environment, e.g. an airport... For calorimetry, foams were ground in a coffee grinder and sieved to particle sizes of 150-300 µm. They were mixed in a **Resodyn Acoustic Mixer** with pyrotechnic.

The Advantages of ResonantAcoustic Mixing (RAM) For Making Novel High-Energy Composite Materials (2016 Technical Interchange Presentation)
Andrew Nelson
At NAWCWD we are using our **LabRAM II** nearly everyday.

Dry Powder Coating of Energetic Materials: Feasible or Futile? (2015 Technical Interchange Presentation)
Merran A. Daniel
Dry powder or 'solventless' coating of an inert material has been successfully achieved using **RAM** technology, with little agglomeration or crystal damage1. Capece and Davé used the acoustic energy produced by the **RAM** to deform a micronized polymer over the surface of ascorbic acid crystals, forming a continuous layer. Applying the same process to energetic materials is not a simple matter, and many factors must be considered to determine whether dry powder coating can be carried out without the risk of initiating the energetic material.

Resonant acoustic mixing: Its applications to energetic materials
Karl S. Hope, Hayleigh Lloyd, Daniel W. Ward & Adam A.L. Michalchuk
Through research carried out to date, it has been established that **RAM** technology offers several advantages over traditional mixing techniques, especially where energetic materials are concerned. The main advantage lies in the relatively gentle mechanism of the **RAM** technique...

Preparation of an energetic-energetic cocrystal using resonant acoustic mixing
Stephen R. Anderson, David J. am Ende, Jerry S. Salan & Philip Samuels
Resonant acoustic mixing (RAM) was applied to the preparation of an energetic-energetic cocrystal comprised of CL-20 and HMX in a 2: 1 mol ratio. We have prepared the cocrystal using the **RAM** technology in a resource-efficient manner providing near quantitative yield …

Macro and micro characterization of powder mixing processes

PUBLISHED ARTICLES (cont.)

Resodyn™ ACOUSTIC MIXERS
Innovative Mixing Solutions

Juan Guillermo Osorio Caicedo
The work presented in this dissertation focuses on the macro- and micro-mixing characterization of a resonant acoustic mixer (RAM), and the micro-mixing dynamic characterization of bin-blending for pharmaceutical powders, with an emphasis on mixing cohesive APIs.

The role of fuel particle size on flame propagation velocity in thermites with a nanoscale oxidizer
Kyle T. Sullivan, Joshua D. Kuntz & Alexander E. Gash
… All powders were mixed using a **resonant acoustic mixer** (**LabRAM, Resodyn Corp** … **Acoustic mixing** was better suited for this study, due to the disparate differences between the fuel and … pressurization rate could vary with drying time for nano-Al/Bi 2 O 3 acoustically mixed using …

Thermal Imaging of Thermite Flame Propagation
John M. Densmore, Kyle T. Sullivan, Alexander E. Gash, & Joshua D. Kuntz
High-speed color imaging pyrometer was used to thermally map the evolution of the flame produced by Al/CuO (3.5 µm/50 nm) thermites propagating in a burn tube... The container was closed and mixed using a **resonant acoustic mixer** (**LabRAM**, **Resodyn Corp**.) at 100 G acceleration for a total of 2 minutes. It was found that mixing for longer did not further increase the reactivity.

An Examination of the Resonant Acoustic Mixer's Flow Field
Douglas Vinson Nance
This report details a second step made toward the high fidelity, first principles numerical simulation of the mixing for the **resonant acoustic mixer**. The current study addresses the mixing of two resins at higher, differing viscosities. Of interest is the time accurate vortical structure of the mixing flow field.

Effect of Solids Loading on Resonant Mixed Al-Bi2O3 Nanothermite Powders
Robert R. Nellums, Brandon C. Terry, Bryce C. Tappan, Steven F. Son & Lori J. Groven
The syringe was sealed with a strip of Airtech Flashbreaker 1 tape over the tip, inserted into an in-house polytetrafluoroethylene (PTFE) fixture (Figure 1a), clamped in a LabRAM resonant mixer (**Resodyn Acoustic Mixers, Inc.**, Butte, MT) (Figure 1b, c) and mixed at 80 % intensity …

Feasibility Study and Demonstration of an Aluminum and Ice Solid Propellant
Timothee L. Pourpoint, Tyler D. Wood, Mark A. Pfeil, John Tsohas, & Steven F. Son
Aluminum-water reactions have been proposed and studied for several decades for underwater propulsion systems and applications requiring hydrogen generation... A **Resodyn LabRAM** resonating mixer (**Resodyn Acoustic Mixer Inc.**, Butte, Montana) was ultimately selected to mix the ALICE propellant.

Processing Benefits of Resonance Acoustic Mixing on High Performance Propellants and Explosives
Andrew Nelson & Tara Cross
RAM can be used to effectively mix extremely viscous explosive formulations.

ResonantAcoustic ® Mixing; Design and Process Considerations Concerning Vessel/Case Geometry and Mix versus Cure Time When Preparing Composite Solid Propellant

James T. Miller, David A. Bode & Scott Coguill
Incorporation of this mixer, with high catalyst levels to minimize cure time into a lean cell line manufacturing process is especially promising.

Synthesis of Highly Loaded Gelled Propellants
Scott L. Coguill
… **Resodyn Corporation's Resonant- Acoustic®** agitation technology is a new approach to solving mixing and dispersion … The Table 1. Phase I metallized gel propellant mixing trials, weight fractions (wt%) of ingredients … For comparison sake, metallized gelled propellants were also …

Relevant Patents

Approved and pending applications for work involving the use of ResonantAcoustic® mixing technology.*

*With RAM as the preferred embodiment

Method of obtaining firing pastes in an acoustic resonance mixers

FR WO WO2023156729A1 Sébastien Cuvelier, Julie Perouel & Nicolas Maroncelli Eurenco
Filed 2023-02-14 • Published 2023-08-24
The present invention relates to a method for obtaining a firing paste which comprises mixing the different ingredients constituting said paste in an **acoustic resonance mixer**. The invention also relates to a method for obtaining an ignition charge which comprises the deposit of the firing paste obtained according to the above method on a combustible support, and the drying of the combustible support.
Highlighted Use: A LabRAM was used to combine black powder and collodion.

Acoustic mixing system for creating propellant mixture

US US20210205770A1 Sarah L Bolden United States Government As Represented By The Secretary Of The Army
Priority 2019-09-12 • Filed 2020-09-14 • Published 2021-07-08
The present disclosure relates to a method of creating a propellant mixture. The method includes forming an explosive composition mixture, placing the explosive composition mixture into a mixing vessel assembly, and operating an **acoustic mixing system** at an operating frequency such that the **acoustic mixing system** causes a vertical displacement of the mixing vessel. The explosive composition mixture has an explosive material, and one or more additives. The mixing vessel assembly has a closed mixing zone having a maximum vertical height. The **acoustic mixing system** is operated in a manner such that the operating frequency is substantially similar to the **resonant frequency** and a ratio of the maximum vertical height of the closed mixing zone to the vertical displacement of the **mixing vessel assembly** is 2.0 or less.
Highlighted Use: A LabRAM II H powers a system that eliminate long processing times and wastewater.

Improvements in or relating to energetic materials

WO EP US KR GB US20180305270A1 Kenneth Lewtas, Lewtas Science & Technologies Ltd
Priority 2015-10-12 • Filed 2016-10-12 • Published 2018-10-25
Energetic materials comprising active components, a polymer binder matrix and a tackifying resin are useful as propellants, fuels, pyrotechnic materials and explosives; the tackifying resin improves the adhesion and dispersion of the active components throughout the binder resin.
Highlighted Use: RAM technology mixed tackifying resin, active components and a binder matrix.

Propellant and Explosives Production Method by Use of Resonant Acoustic Mix Process

WO EP US US20100294113A1 Michael D. McPherson
Priority 2007-10-30 • Filed 2008-10-15 • Published 2010-11-25
A method to charge a container with an energetic mix is disclosed. This method includes the following steps: (a) adding a plurality of particulate energetic mix constituents and a binder to the container; and (b) mixing

Patents, cont'd.

the plurality of energetic mix constituents utilizing a non-contact mixer to form a homogeneous mixture within the container, and curing the binder to solidify the homogeneous mixture and bind the homogeneous mixture to the container. The container may be a liner or pre-form intended for insertion into a device, or may form a portion of the device itself, such as an aft portion of a rocket motor or casing for an explosive device. Because the **resonant mixer** does not have a moving impeller or other component that contacts the energetic mix and the container is not reused, there is minimal decontamination required between each mix and the manufacturer may rapidly commence assembling the next device, rather than clean-up and recertification.
Highlighted Use: RAM technology was able to coat a container with energetics.

Resonant acoustic mixing (ram) of an explosive composition

WO EP US AU CA US20200062669A1 Andy Oden Burn, BAE Systems PLC
Priority 2017-04-03 • Filed 2018-03-28 • Published 2020-02-27
The invention relates to a cast explosive composition, particularly to a pre-cure castable explosive composition comprising an explosive material, a polymerisable binder, a microencapsulated cross linking reagent, said microencapsulated cross linking reagent, comprising a cross linking agent encapsulated in a microcapsule. Providing a process for formulating a homogenous crosslinked polymer bonded explosive composition comprising the steps of:

i) forming an admixture of pre-cure castable explosive composition, said composition comprising an explosive material, a polymerisable binder, a microencapsulated cross linking reagent, said microencapsulated cross linking reagent, comprising a cross linking reagent encapsulated in a microcapsule; wherein the microcapsule, comprises at least one shell wall polymer, wherein the microcapsule's shell wall polymer comprises at least one resonant acoustic stimulus labile linkage,

ii) applying **resonant acoustic** stimulus to the admixture, causing the microcapsule to rupture and release said cross linking reagent, to cause the cure process to start.
Highlighted Use: RAM technology begins the cure process for explosives.

Process for the preparation of composite pyrotechnic products

FR FR3090629A1 Marie Coquillat, Angeline Aumelas, Sebastien Gattini, Simon Kamatchy & Philippe Lescop
Priority 2018-12-20 • Filed 2018-12-20 • Published 2020-06-26
The present invention relates to a process for the preparation of a composite pyrotechnic product containing organic energetic charges of the nitramine type in a plasticized binder, this process comprising: a) the preparation of a crosslinked polymer of the polymer type with hydroxy terminal functions; b) the preparation of a mixture of organic energetic charges of the nitramine type and of a polyol having a melting temperature of less than approximately 50 ° C. and a molar mass of less than approximately 500 g / mol; c) mixing the products obtained in steps a) and b).
Highlighted Use: RAM technolgy distributes short polyol on the surface of energy charges.

Continuous acoustic mixer

WO EP US US20210069662A1 Peter Andrew Lucon, Resodyn Corporation
GB GB2561172A Oden Burn Andy & Nicholas Stevens Matthew, BAE Systems PLC
Priority 2017-04-03 • Filed 2017-04-03 • Published 2018-10-10

Patents, cont'd.

A system for continuously processing a combination of materials includes a continuous process vessel having an outlet and one or more inlets. The continuous process vessel is configured to oscillate along an oscillation axis. An **acoustic agitator** is coupled to the continuous process vessel. The acoustic agitator is configured to oscillate the continuous process vessel along the oscillation axis. An outlet passage is in fluid communication with the outlet. At least a portion of the outlet passage or at least a portion of the continuous process vessel is disposed within a portion of the **acoustic agitator**.
Highlighted Use: RAM technology allows for the processing of materials over a longer time.

A kind of solid-propellant pulps without slurry mixing preparation method and system
CN CN108043305A Lu Zhimeng, Wen Changyan, Zuo Juntao, Zeng Qinglin, Wang Qingsong, Sun Tao, Lu Yan, Beijing Aerospace Innovation Patent Investment Center & Hubei Hangpeng Chemical Power Technology Co Ltd
Priority 2018-01-03 • Filed 2018-01-03 • Published 2018-05-18
This application provides a kind of solid-propellant pulps without paddle mixing preparation method and system, including material to be mixed is put into mixing vessel by preset quality mixing vessel is fastened with **acoustic resonance mixers** mixing vessel and material to be mixed are heated
Highlighted Use: RAM technology combines materials while heating them up.

Non-conductive pyrotechnic mixture
EP US EP3683199A1 John Fronabarger, Jason Pattison & Robert Holderman, Pacific Scientific Energetic Materials Company
Priority 2019-01-16 • Filed 2020-01-02 • Published 2020-07-22
Described are energetic compositions formed of a 5,5'-bistetrazole salt and a perchlorate salt, in which the energetic composition is a co-precipitated product. The 5,5'-bistetrazole salt and the perchlorate salt can be dipotassium 5,5'-bistetrazole and potassium perchlorate. The energetic composition can have a particle size distribution between 1-50 micron and/or a mean volume diameter of less than 30 micron. In a low energy electro-explosive device, an ignition element is at least partially surrounded by an acceptor formed of this energetic composition, and the ignition element can be a bridgewire, a thin film bridge, a semiconductor bridge, or a reactive semiconductor bridge.
Highlighted Use: A LabRAM mixer was used to sieve and blend materials without static.

Cl-20:dnmt cocrystal crystal structure
US US20150361056A1 Jerry Salan, David J. Am Ende & Stephen R. Anderson, Nalas Engineering Services Inc.
Priority 2014-03-31 • Filed 2015-03-31 • Published 2015-12-17
A cocrystal of CL-20 (2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaazaisowurtzitane) and DNMT (1-methyl-3,5-dinitro-1,2,4-triazole) was formed through a **resonant acoustic mixing** process. The resulting cocrystal comprised an essentially 1:1 stoichiometric ratio between these coformers. The cocrystal advantageously has decreased sensitivity when compared with a pure CL-20 sample, and maintains thermal stability and comparable energetic performance.
Highlighted Use: RAM technology created a new, more stable but equally energetic crystal.

RAM 5

RAM 5 Continuous

RAM 55

OmniRAM Continuous

OmniRAM H

RAM 5 H

RAM 55 H

OmniRAM

LabRAM II LabRAM I

PharmaRAM I PharmaRAM II

LabRAM II H

Resodyn™ ACOUSTIC MIXERS

Resodyn Acoustic Mixers, Inc. 130 N. Main Street, Suite 630, Butte, MT 59701
+1-406-497-5333 I info@resodynmixers.com I https://resodynmixers.com