

Advances in Energetic Materials Processing Enabled By ResonantAcoustic[®] Mixing

Testimonials • Published Articles • Patents & Patent Applications



August, 2021

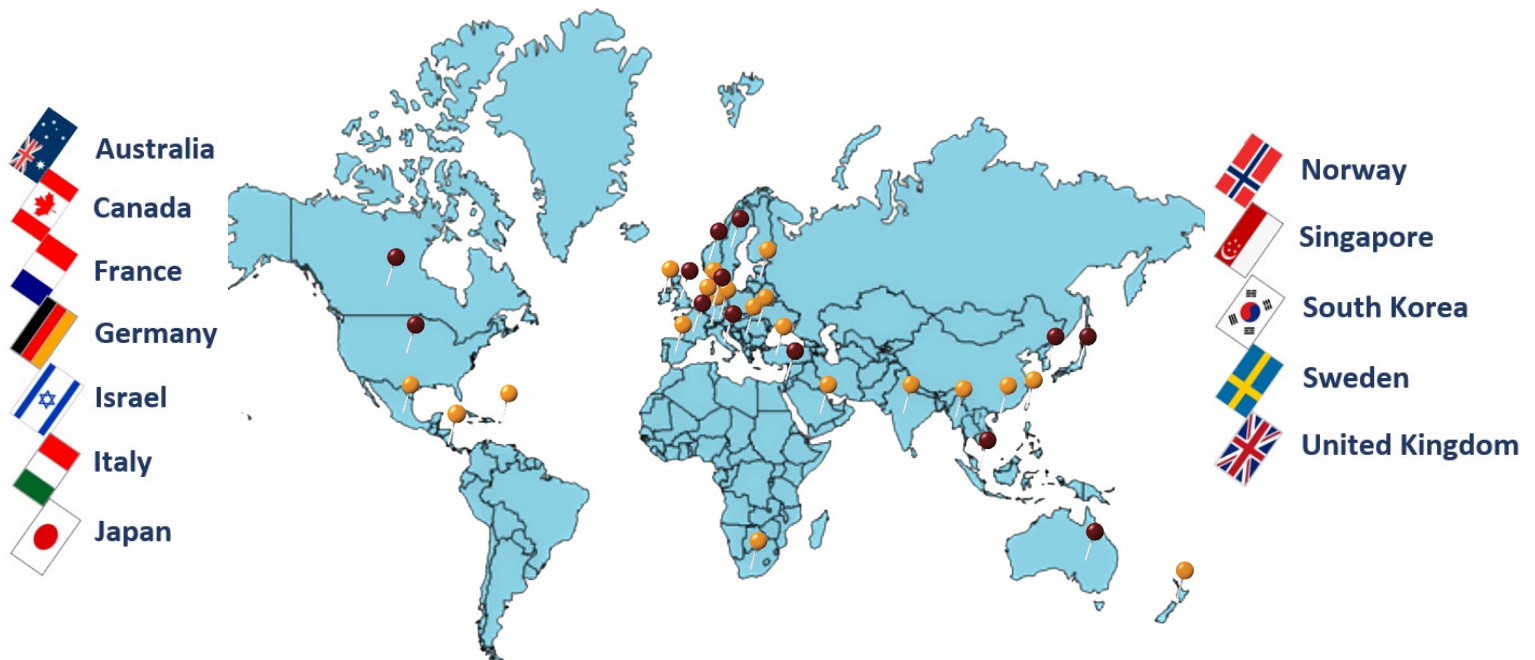
This document is a portfolio of testimonials, articles, and patents/patents pending that reference Resodyn's ResonantAcoustic[®] Mixing (RAM) technology in a variety of energetics materials industry applications. This collection of abstracts and links to published articles is intended to provide insight 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.


Energetic Materials

Energetic materials, or energetics, are a group of materials characterized by the fact they store high amounts of chemical energy that can be released either via combustion or deflagration. Modern energetics span a gamut of types and applications that generally fall under one of the following categories: explosives, propellants and pyrotechnics. Fossil fuels (i.e., gasoline and diesel) are also considered energetics, but the focus of this publication is on the previous three categories.

Modern high **explosives** are typically mixtures or molecules, that can be detonated. C-4 and TNT are well-known examples. Explosives can be formulated as cast, puttied, plastic (polymer) bonded, rubberized, or extrudable. The two main categories are primary and secondary explosives. **Propellants** are chemical propulsion materials that include solid rocket fuels, liquid monopropellants, solid/liquid hybrid propellants, and gas generation systems. **Pyrotechnics** formulations include air combat countermeasures and safety devices that produce smoke or light (e.g. aerial emergency or highway safety flares).

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



 = Energetics customers of ResonantAcoustic® Mixers



What energetics industry professionals are saying about RAM

“RAM is promising route for primer formulation processing. It minimizes safety concerns with mixing, and exhibits great potential for dry mixing...”

- Materials Scientist at a major U.S. government agency

“...[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: The Energetics Mixer of Choice











Number of RAM systems sold for energetic materials mixing: **138**
























Number of RAM energetics customers worldwide: **101**

Number of countries RAM has been sold into: **14**








PUBLISHED ARTICLES

Icon Legend













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

Icons	Publication Title (Live Links)*	RAM Application Summary	Year
   	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
  	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 Resonant Acoustic Mixer (RAM)."	2020
     	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

PUBLISHED ARTICLES

Icons	Publication Title (Live Links)*	RAM Application Summary	Year
	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
	Future Sustainable Propellants	"... we used Resonant Acoustic Mixing (RAM) as an effective and efficient manufacture method."	2018
	Resonant acoustic mixing: Its applications to energetic materials	"[RAM] has several demonstrable applications to the field of energetic materials..."	2015
	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

PUBLISHED ARTICLES

Icons	Publication Title (Live Links)*	RAM Application Summary	Year
   	The role of fuel particle size on flame propagation velocity in thermites with a nanoscale oxidizer	<p>"Acoustic mixing was better suited for this study due to the disparate differences between the materials..."</p>	2014
  	Thermal Imaging of Thermite Flame Propagation	<p>"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."</p>	2014
 	Effect of Solids Loading on Resonant Mixed Al-Bi₂O₃ Nanothermite Powders	<p>"...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."</p>	2013
  	Synthesis of Highly Loaded Gelled Propellants	<p>"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."</p>	2003

* Article links may be limited by copyright restrictions. Detailed links on following pages.

^ Results excerpted/paraphrased from articles.

PUBLISHED ARTICLES



*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.”*

Primary Explosive Processing in the Resonant Acoustic Mixer

E Beckel, K Oyler, N Mehta, N Khatri...- Propellants ..., 2021- Wiley Online Library

... 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 ...

Safer Resonant Acoustic Mixing Methods for High-Volume Production of Pyrotechnics

E Miklaszewski, MCM Yamamoto, MJT Dunham...- 2020- serdp-estcp.org

Magnesium (Mg)/Sodium Nitrate (NaNO₃)/Epoxy formulations and their derivatives are a high volume pyrotechnic that is utilized in illumination and colored flare applications for the Army, Navy and Air Force (Figure 1)[1]. Such illuminant compositions are typically ...

[Related articles](#)

Comparison of Propellant Processing by Cast-Cure and Resonant Acoustic Mixing

M Zebregs, AEHJ Mayer...- ... , Pyrotechnics, 2020- Wiley Online Library

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 ...

[Related articles](#)

Resonant Acoustic® Mixing: Processing and Safety

MR Andrews, C Collet, A Wolff...- Propellants, Explosives ..., 2020- Wiley Online Library

... Standard practice for energetics processing is to remotely operate the equipment so that in ... Several survey respondents had to separate loading of energetic materials in a suitable facility ... Within the time frame of the survey, Resodyn released a hazardous areas approved version ...

[Related articles](#)

Burning Rate Characterization of Ammonium Perchlorate Pellets Containing Nano-Catalytic Additives

FA Rodriguez, JC Thomas, D Teitge...- AIAA Scitech 2020 ..., 2020- arc.aiaa.org

... A RAM utilizes resonant ... acoustic waves that violently gyrate the powder to induce mixing ... DL, Seal, S., Petersen, EL, “Comparison of Commercially Available and Synthesized Titania Nano-Additives in Composite HTPB/AP Propellant,” Propellants, Explosives, Pyrotechnics, Vol ...

[Related article](#)

Processing Studies of Energetic Materials using Resonant Acoustic Mixing Technology

RJ Davey, JM Wilgeroth, AO Burn- Propellants, Explosives ..., 2019- imemg.org

... 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 ...

[Related article](#)

[Milling of Energetic Crystals with the LabRAM](#)

LN Kotter, LJ Groven- Propellants, Explosives, Pyrotechnics, 2019- Wiley Online Library

... 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 ...

[Related articles](#)

[The Effects of Resonant Acoustic Mixing on the Microstructure of UHPC](#)

A Vandenberg, K Wille- International Interactive Symposium ..., 2019- iastatedigitalpress.com

... The Effects of Resonant Acoustic Mixing on the Microstructure of UHPC ... 38th International Pyrotechnics Seminar, Denver, CO, June 2012 ... "Evaluation of Resonance Acoustic Mixing Technology using Ultra High Performance Concrete." Construction and Building Materials, Vol ...

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[Meta-structure Enhancement of Resonant Acoustic Mixing via Embedded Additive Manufacturing](#)

WA Reach- 2019- drum.lib.umd.edu

... Title of thesis: META-STRUCTURE ENHANCEMENT OF RESONANT ACOUSTIC MIXING VIA EMBEDDED ADDITIVE MANUFACTURING William Alexander Reach, Masters of Science, 2019 ... and mixing parameters. Resonant acoustic mixing (RAM) is advantageous as a ...

[Related articles](#)

[Evaluation of novel propellants manufactured from commercially available Thermoplastic Elastomers \(TPE\) using resonant acoustic mixing](#)

PJ Wilkinson- 2019- dspace.lib.cranfield.ac.uk

The key issues in developing a sustainable gun or rocket propellants are financial, environmental, legislative and safety. Use of commercially available off the shelf polymers, in particular, thermoplastic elastomers (TPE) as a binder for propellants could address these ...

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[Future Sustainable Propellants](#)

P Wilkinson- 2018- cord.cranfield.ac.uk

... propellant uses a relatively inexpensive binder in good supply, furthermore we used Resonant Acoustic Mixing ... The thermoplastic properties of the binder means the propellant can be ... and improved mechanical properties over traditional nitrocellulose based gun propellants ...

[Interactions of polymers and energetic materials](#)

RM Levine- 2017- digitalcommons.uri.edu

... inorganic energetics, respectively. These were sieved to control particle size to approximately 800 microns. Organic explosives 2,4,6- trinitrotoluene (TNT), 1,3,5-trinitro-1,3,5-triazacyclohexane (RDX), Pentaerythritol tetranitrate (PETN), C-4, and an inorganic energetic material ...

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[Resonant acoustic mixing: Its applications to energetic materials](#)

KS Hope, HJ Lloyd, D Ward...- 18th Seminar on New ..., 2015- researchgate.net

... case of carbamazepine-nicotinamide I", CrystEngComm, 11(3), p. 501, 2(11) 11 || S. Anderson, DJ am Ende, JS Salan, P. Samuels, "Preparation of an Energetic- Energetic co-crystal using Resonant Acoustic Mixing", Propellants, Explosives, Pyrotechnics, 39(5), p. 637-640 ...

[Preparation of an energetic-energetic cocrystal using resonant acoustic mixing](#)

SR Anderson, DJ am Ende, JS Salan...- ... , Pyrotechnics, 2014- Wiley Online Library

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 ...

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[The role of fuel particle size on flame propagation velocity in thermites with a nanoscale oxidizer](#)

KT Sullivan, JD Kuntz, AE Gash- ... , Explosives, Pyrotechnics, 2014- Wiley Online Library

... 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/Bi₂O₃ acoustically mixed using ...

[Related articles](#)

[Thermal Imaging of Thermite Flame Propagation](#)

JM Densmore · 2014 · Cited by 19 — 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. ... After the flame passes, the temperature drops a few hundred degrees and is sustained until well after the flame reaches the end of the tube.

[Effect of Solids Loading on Resonant Mixed Al-Bi₂O₃ Nanothermite Powders](#)

RR Nellums, BC Terry, BC Tappan...- ... , Pyrotechnics, 2013- Wiley Online Library

... 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 ...

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[Synthesis of Highly Loaded Gelled Propellants](#)

SL Coguill- Resodyn Corp., Butte, MT, 2009- researchgate.net

... 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 ...

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Relevant Patents

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

*With RAM as the preferred embodiment

[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.

[Propellant and Explosives Production Method by Use of Resonant Acoustic Mix ...](#)

WO EP US US20100294113A1 Michael D. McPherson Mcpherson Michael D

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 the plurality of energetic mix constituents utilizing a non-contact mixer to ...

[Resonant acoustic mixing \(ram\) of an explosive composition \(2\)](#)

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 ...

[Resonant acoustic mixing \(ram\) of an explosive composition \(1\)](#)

EP EP3385246A1 designation of the inventor has not yet been filed The BAE SYSTEMS plc

Priority 2017-04-03 • Filed 2017-04-03 • Published 2018-10-10

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 ...

[Process for the preparation of composite pyrotechnic products](#)

FR FR3090629A1 Marie COQUILLAT Arianegroup Sas

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 ...

Patents, cont'd.

[Continuous acoustic mixer](#)

WO EP US US20210069662A1 Peter Andrew Lucon Resodyn Corporation
Priority 2017-09-05 • Filed 2020-11-16 • Published 2021-03-11

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 ...

[Ram mixing](#)

GB GB2561172A Oden Burn Andy Bae Systems Plc
Priority 2017-04-03 • Filed 2017-04-03 • Published 2018-10-10

A process for formulating a homogenous crosslinked polymer bonded explosive composition comprising the steps of forming an admixture of an explosive material, a polymerisable binder and a crosslinking reagent encapsulated in a microcapsule, wherein the microcapsule comprises a shell wall polymer ...

[A kind of solid-propellant pulps without slurry mixing preparation method and ...](#)

CN CN108043305A Lu Zhimeng Wen Changyan Zuo Juntao Zeng Qinglin Wang Qingsong Sun Tao Lu Yan
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

[Non-conductive pyrotechnic mixture](#)

EP US EP3683199A1 John Fronabarger 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 ...

[Cl-20:dnmt cocrystal crystal structure](#)

US US20150361056A1 Jerry Salan 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 cofomers. The cocrystal ...



RAM 5 H



OmniRAM H



LabRAM II H



RAM 5 CAM



RAM 55