



Section 5. Technical sciences in general

DOI:10.29013/EJTNS-26-1-32-39



THERMODYNAMIC APPARATUS WITH AN INTEGRATED DYNAMIC MIXING SYSTEM (Thermodynamic Apparatus with an Integrated Dynamic Mixing and Real-Time Homogenization System for Fuel Components Using Artificial Intelligence and Artificial Neural Network Elements in Control and Monitoring Lines)

*Vera Anatolievna Gribkova*¹

¹ Dean of the Faculty of Food Technologies and Bioengineering K. G. Razumovsky
Moscow State University of Technologies and Management Russia, Moscow

Cite: Gribkova V.A. (2026). *Thermodynamic Apparatus with an Integrated Dynamic Mixing System. European Journal of Technical and Natural Sciences 2025, No 1.* <https://doi.org/10.29013/EJTNS-26-1-32-39>

Abstract

Liquid hydrocarbon fuels and fuel compositions tend to lose their homogeneity during storage, leading to the formation of agglomerates, primarily at the bottom of storage containers. This inhomogeneity can be effectively eliminated through a homogenization process implemented by an innovative dynamic homogenization device that operates directly within the fuel pipeline. The proposed method enables homogenization at a stable temperature or, under certain conditions, at a reduced temperature of the fuel mixture. The process is based on the generation of specific turbulent hydrodynamic conditions in the flowing fuel without disrupting the chemical and physical equilibrium of its components.

The presented approach offers a technically efficient and energy-saving solution for maintaining fuel homogeneity and improving the stability of fuel properties during storage and transportation.

Keywords: *Thermodynamic apparatus; Integrated dynamic mixing system; Homogenization process; Hydrodynamic vortex tube; Turbulence-level homogenization; Vortex generator; Acceleration hydrodynamic section; Coaxial Bernoulli effect*

The potential applications of the dynamic homogenization process in marine engines and diesel generators are also considered

Since heavier diesel fuel and various types of fuel oil are used as fuels in the specified ther-

modynamic systems, the formation of agglomerates occurs more intensively in such fuels.

In the case where a dynamic homogenization device is introduced into the system of a marine engine or a diesel generator, agglomerates that, under certain circumstanc-

es, have formed in the fuel tanks and consist of the main hydrocarbon fraction of the fuel mixture are dynamically mixed in the device with the remaining hydrocarbon fractions, transforming the agglomerates of the mixture into micro- or nanoparticles.

The combustion of homogenized fuel generally takes place in a stable thermodynamic regime, without detonation and with reduced soot and nitrogen oxide content in the exhaust gases.

Potential Applications of the Dynamic Homogenization Process in Aircraft Powerplants

In connection with recent reports on the experimental use of biofuels or fuel mixtures for aircraft engines, and considering that fuel mixtures containing biological fuel components have a tendency to form agglomerates, the dynamic homogenization of such fuels prior to injection into the combustion chamber can significantly increase the reliability of such engines and may open the way for the use of fuel compositions in aircraft powerplants.

Mixing and Activation of a Mixture of at Least Two Liquids

The dominant component of the mixture is divided and simultaneously introduced into two inlets of the mixing and activation device at equal pressure.

Both flows of the dominant component of the mixture are transformed, prior to mixing in the device, from a flow with a cylindrical cross-section into a flow with an annular cross-section.

Both flows of the dominant component of the mixture are accelerated at the inlet to the mixing zone in coaxial conical annular capillary channels.

During acceleration, controlled cavitation-induced ruptures are formed in both flows.

Droplets of the second component of the mixture are introduced and drawn into the ruptures formed by controlled cavitation.

The cross-sections of the channels are selected such that the linear velocity of the external flow of the dominant component of the mixture in the coaxial pair of conical annular capillary channels is substantially lower than the linear velocity of the internal flow.

The cross-sections of the coaxial channels are selected such that the linear velocity of the external flow of the dominant component of the mixture in the coaxial pair of conical annular capillary channels is substantially lower than the linear velocity of the internal flow, and conversely, the turbulence level of the internal flow is substantially higher than the turbulence level of the external flow.

The second component of the mixture is introduced through at least one channel into a zone in which physical conditions of local rarefaction have been formed, arising in accordance with the criteria of Bernoulli's theorem.

Mixing takes place in the annular zone of the mixing and activation device, located between the inlet channels of the mixing and activation device.

The inlet channel for introducing the second flow of the dominant component of the mixture is integral in nature and includes at least two radial channels.

An integral hydrodynamic interface is located between the inlet channels and incorporates two conical reflectors, the apices of which are directed in opposite directions.

After mixing and activation, the mixture is transported through the internal cavity of the device via at least two channels, which are combined in at least two variants – linear and vortex; this process does not require additional energy.

In the outlet channel of the device, the mixture of at least two liquids exhibits a homogenized structure with a uniform turbulence level throughout the entire volume of the mixture.

All of the listed features contribute to achieving the following objectives:

- to homogeneously mix the components of the mixture;
- to obtain a mixture with a minimal component fraction size;
- to obtain a mixture with an encapsulated structure, in which droplets of the second, non-dominant component of the mixture are surrounded by a shell of the liquid constituting the dominant component of the mixture;
- to achieve, within the mixing and activation device, a parallel process of mixing and homogenization of the mixture with minimal energy expenditure;

- to obtain a uniform background turbulence level in the mixture, at least at the moment of mixing.

Mixing and Activation of a Mixture of at Least One Liquid and at Least One Gas

The dominant component of the mixture is divided and simultaneously introduced into two inlets of the mixing and activation device at equal pressure.

Both flows of the dominant component of the mixture are transformed, prior to mixing in the device, from a flow with a cylindrical cross-section into a flow with an annular cross-section.

Both flows of the dominant component of the mixture are accelerated at the inlet to the mixing zone in coaxial conical annular capillary channels.

During acceleration, gravitational ruptures are formed in both flows.

Droplets of the second component of the mixture are introduced and drawn into the gravitational ruptures.

The cross-sections of the channels are selected such that the linear velocity of the external flow of the dominant component of the mixture in the coaxial pair of conical annular capillary channels is substantially lower than the linear velocity of the internal flow.

The cross-sections of the coaxial channels are selected in such a way that the linear velocity of the external flow of the dominant component of the mixture in the coaxial pair of conical annular capillary channels is substantially lower than the linear velocity of the internal flow; conversely, the turbulence level of the internal flow is substantially higher than the turbulence level of the external flow.

The second component of the mixture is introduced through at least one channel into a zone in which physical conditions of local rarefaction have been formed, arising in accordance with the criteria of Bernoulli's theorem.

Mixing takes place in the annular zone of the mixing and activation device, located between the inlet channels of the mixing and activation device.

The inlet channel for introducing the second flow of the dominant component of the mixture is integral in nature and includes at least two radial channels.

An integral hydrodynamic interface is located between the inlet channels and incorporates two conical reflectors, the apices of which are directed in opposite directions.

After mixing and activation, the mixture is transported through the internal cavity of the device via at least two channels, which are combined in at least two variants – linear and vortex; this process does not require additional energy.

In the outlet channel of the device, the mixture of at least two liquids exhibits a homogenized structure with a uniform turbulence level throughout the entire volume of the mixture.

All of the listed features contribute to achieving the following objectives:

- to homogeneously mix the components of the mixture;
- to obtain a mixture with a minimal component fraction size;
- to obtain a mixture with an encapsulated structure, in which droplets of the second, non-dominant component of the mixture are surrounded by a shell of the liquid constituting the dominant component of the mixture;
- to achieve, within the mixing and activation device, a parallel process of mixing and homogenization of the mixture with minimal energy expenditure;
- to obtain a uniform background turbulence level in the mixture, at least at the moment of mixing.

Description of Illustrations and Graphic Materials of the Developments by Kristina Bessarabenko, Directed in the Same Technological Development Path as the Present Publication

The innovative developments of Kristina Bessarabenko are illustrated by technical drawings in which the figures demonstrate the design principles and the internal structure of a thermodynamic apparatus with an integrated dynamic system for real-time mixing and homogenization of fuel components.

The figures of Kristina Bessarabenko's developments also illustrate and explain the principles of apparatus control, as well as the principles and variants of structural and tech-

nological interconnections between the apparatus itself and all interfacing and control elements of the thermodynamic system in which the apparatus operates. This factor is exceptionally important, and practical implementation has demonstrated an exceptionally high level of elaboration by the author, Kristina Bessarabenko, of the technical solutions and operational principles of the entire system, which form the basis of the complex of novel features of her inventions.

In the main figure, a schematic version of the connection and control of a thermodynamic apparatus with an integrated dynamic online system for mixing and homogenization of fuel components or a liquid food product in real time is shown, installed within the internal configuration of the fuel line of a thermodynamic system.

An analysis of all features of the invention, including the non-obviousness of the solutions, the highest technical level, and the high degree of innovation, indicates and emphasizes the unique professional competence of Kristina Bessarabenko and her exceptional innovative potential realized in these innovative developments.

In the subsequent figures of the graphic materials of Kristina Bessarabenko's developments, a schematically specified version of the connection and control of a thermodynamic apparatus with an integrated dynamic online system for real-time mixing and homogenization of fuel components is shown. The apparatus is installed within the internal configuration of the fuel line of a thermodynamic system having an inlet recirculation system for excess fuel supplied to the injectors for fuel injection into the combustion chamber of the specified thermodynamic system. As a rule, for more efficient injection, the fuel pressure is increased in a high-pressure pump, from which the excess fuel is returned to the fuel line of the thermodynamic system.

In the subsequent figures, a schematically specified version of the connection and control of a thermodynamic apparatus with an integrated dynamic online system for real-time mixing and homogenization of fuel

components is shown, installed within the internal configuration of the fuel line of a thermodynamic system having a built-in recirculation system for excess fuel supplied to the injectors for fuel injection into the combustion chamber of the specified thermodynamic system. As a rule, for more efficient injection, the fuel pressure is increased in a high-pressure pump, from which the excess fuel is returned to the fuel line of the thermodynamic system. The figures also show a combined version of the return of excess fuel via two lines – into the inlet of the dynamic mixing and homogenization device and into the fuel tank of the thermodynamic system.

In additional figures, a schematically specified version of the connection and control of a thermodynamic apparatus with an integrated dynamic online system for real-time mixing and homogenization of fuel components is shown, installed within the internal configuration of the fuel line of a thermodynamic system having an original recirculation system for excess fuel supplied to the injectors for fuel injection into the combustion chamber of the specified thermodynamic system. As a rule, for more efficient injection, the fuel pressure is increased in a high-pressure pump, from which the excess fuel is returned to the fuel line of the thermodynamic system. The figures also show a combined version of the return of excess fuel via two lines – into the inlet of the dynamic mixing and homogenization device and into the fuel tank of the thermodynamic system, in which an additional fuel recirculation system is installed within the fuel tank of the thermodynamic system.

In the following illustrative figures, a schematically specified version of the connection and control of a thermodynamic apparatus with an integrated dynamic online system for real-time mixing and homogenization of fuel components is shown, installed within the internal configuration of the fuel line of a thermodynamic system having an inlet recirculation system for excess fuel supplied to the injectors for fuel injection into the combustion chamber of the specified thermodynamic system. As a rule, for more efficient injection, the fuel pressure is increased in a high-pressure pump, from which the excess fuel is returned to the fuel line of

the thermodynamic system. The figures also show a combined version of the return of excess fuel via two lines – into the inlet of the dynamic mixing and homogenization device and into the fuel tank of the thermodynamic system, in which an additional fuel recirculation system is installed within the fuel tank of the thermodynamic system, as well as an additional fuel recirculation activation system in the specified tank.

The figures also show a schematically specified version of the connection and control of a thermodynamic apparatus with an integrated dynamic online system for real-time mixing and homogenization of fuel components, installed within the internal configuration of the fuel line of a thermodynamic system having an inlet and adapted recirculation system for excess fuel supplied to the injectors for fuel injection into the combustion chamber of the specified thermodynamic system. As a rule, for more efficient injection, the fuel pressure is increased in a high-pressure pump, from which the excess fuel is returned to the fuel line of the thermodynamic system. The figures show a combined version of the return of excess fuel via two lines – into the inlet of the dynamic mixing and homogenization device and into the fuel tank of the thermodynamic system, in which an additional fuel recirculation system is installed within the fuel tank of the thermodynamic system, as well as an additional fuel recirculation activation system in the specified tank, and an additional parallel line is provided for supplying an additive mixture into the fuel tank.

In the following figures, a schematically specified version of the connection and control of a thermodynamic apparatus with an integrated dynamic online system for real-time mixing and homogenization of fuel components is shown, installed within the internal configuration of the fuel line of a thermodynamic system having a built-in recirculation system for excess fuel supplied to the injectors for fuel injection into the combustion chamber of the specified thermodynamic system. As a rule, for more efficient injection, the fuel pressure is increased in a high-pressure pump, from which the excess fuel is returned to the fuel line of the thermodynamic system.

The figures show a combined version of the return of excess fuel via two lines – into

the inlet of the dynamic mixing and homogenization device and into the fuel tank of the thermodynamic system, in which an additional fuel recirculation system is installed within the fuel tank of the thermodynamic system, as well as an additional fuel recirculation activation system in the specified tank. A supplementary parallel line is provided for supplying additional materials into the fuel tank, and local hydromechanical and electronic control and calibration systems are installed in the fuel flows on the line supplying fuel from the fuel tank to the dynamic mixing and homogenization device.

The figures also show a combined scheme of the local connection of the dynamic fuel mixing and homogenization device to the local fuel line of the thermodynamic system, including an axial longitudinal cross-section of the specified device and a schematic representation of the local fuel infrastructure of the thermodynamic system.

The figures also show a combined scheme of the local connection of the dynamic fuel mixing and homogenization device to the local fuel line of the thermodynamic system, including an axial longitudinal cross-section of the specified device and a schematic representation of the local fuel infrastructure of the thermodynamic system, wherein the fuel tank of the specified system includes a hydromechanical activation device.

The figures also show a combined scheme of the local connection of the dynamic fuel mixing and homogenization device to the local fuel line of the thermodynamic system, including an axial longitudinal cross-section of the specified device and a schematic representation of the local fuel infrastructure of the thermodynamic system, wherein the fuel tank of the specified system includes a hydromechanical activation device and an additional hydromechanical recirculation activation system.

In addition, the figures show a comprehensive combined scheme of the local connection of the dynamic fuel mixing and homogenization device to the local fuel line of the thermodynamic system, including an axial longitudinal cross-section of the specified device and a schematic representation of the local fuel infrastructure of the thermodynamic system, wherein the main fuel tank of the

specified system includes a hydromechanical activation device that forms part of an additional hydromechanical recirculation activation system and is connected to the fuel excess recirculation system by an additional collector tank.

In the graphic figures, a comprehensive combined scheme of the local connection of the dynamic fuel mixing and homogenization device to the local fuel line of a thermodynamic system is shown, including an axial longitudinal cross-section of the specified device and a schematic representation of the local fuel infrastructure of the thermodynamic system. The main fuel tank of the specified system includes a hydromechanical activation device forming part of an additional hydromechanical recirculation activation system and connected to the excess fuel recirculation system by an additional collector tank. The main fuel tank also includes an additional internal local recirculation system that eliminates the formation of dead zones in the peripheral parts of the internal volume of the specified tank.

The figures also show a comprehensive dynamic configuration for online mixing and simultaneous real-time homogenization of the resulting mixture, consisting of two parallel lines, each of which is equipped with one device for dynamic mixing and homogenization of fuel mixtures. In these figures, one of the specified devices is shown in axial longitudinal cross-section, while the other is shown in a general view. Both devices are shown with transverse cross-sections at the locations of the integral inlets and the fixing and orienting pins, and all elements of the fuel line schemes of the thermodynamic system are shown in schematic form.

The figures also show, in axial longitudinal cross-section with transverse sections at the locations of the integral inlets into the working chambers and in a general view with transverse sections in the zones of the fixing and orienting pins and in the zone of the integral radial inlets for additional materials, the internal structure of the device for dynamic online mixing and homogenization of fuel or fuel compositions in real time.

The figures show, in axial longitudinal cross-section with transverse sections at the locations of the integral inlets into the working chambers and in a general view with

transverse sections in the zones of the fixing and orienting pins and in the zone of the integral radial inlets for additional materials, the internal structure of the device for dynamic online mixing and homogenization of fuel or fuel compositions in real time, indicating the zones for mixing fuel components with the formation of multilevel fuel capsules and their simultaneous online homogenization according to at least two criteria: the turbulence level at all points of the flow cross-section and the unification of the dimensional characteristics of the capsules in a three-dimensional coordinate system.

In the original figure, a system consisting of two devices for dynamic online homogenization and simultaneous mixing and three-dimensional uniform transformation of a fuel mixture or fuel composite into capsules is shown. The specified system is depicted in two mutually perpendicular planes, in which the working sections of the specified devices are indicated, differing in functional application within the overall thermodynamic system and all of its internal functional interconnections and causal relationships.

In other additional figures, a parallel thermodynamic system consisting of two parallel devices for dynamic mixing and simultaneous instant online homogenization of fuel mixtures is shown, with the output from the combined and integrated processing zone in the specified devices being an encapsulated and three-dimensionally homogenized fuel mixture, with control of all principal proportions between the components and their hydrodynamic, chemical, and geometric parameters at the outlet of the specified system.

The figures also show a parallel thermodynamic system consisting of two parallel devices for dynamic mixing and simultaneous instant online homogenization of fuel mixtures, with the output from the combined and integrated processing zone in the specified devices being an encapsulated and three-dimensionally homogenized fuel mixture, with comparative analytical control of all principal proportions between the components and their hydrodynamic, chemical, and geometric parameters at the outlet of the specified system and at the midpoint of the fuel capsule formation process.

In addition, the figures show a parallel thermodynamic system consisting of two par-

allel devices for dynamic mixing and simultaneous instant online homogenization of fuel mixtures, with the output from the combined and integrated processing zone in the specified devices being an encapsulated and three-dimensionally homogenized fuel mixture, with controlled and regulated heating of the fuel mixture at the midpoint and at the end of the processing and transformation process.

For maximum clarity of perception, the figures show a parallel thermodynamic system consisting of two parallel devices for dynamic mixing and simultaneous instant online homogenization of fuel mixtures, with the output from the combined and integrated processing zone in the specified devices being an encapsulated and three-dimensionally homogenized fuel mixture, with controlled and regulated heating of the fuel mixture at the point of mixture input and at the midpoint of its processing and transformation into a structure with three-dimensional uniformity of its encapsulated and secondarily homogenized flow.

In the subsequent figures, a thermodynamic fuel application consisting of two devices for dynamic homogeneous mixing and simultaneous instant online homogenization of fuel mixtures, installed in parallel in the fuel line of a thermodynamic system, is shown, with full control and calibration of the parameters and three-dimensional criteria of the encapsulated fuel structure of the mixture, along with simultaneous and instant online resonant and non-contact control of the initial state of the base fuel component of the mixture.

The figures also show a thermodynamic fuel application consisting of two devices for dynamic homogeneous mixing and simultaneous instant online homogenization of fuel mixtures, installed in parallel in the fuel line of a thermodynamic system, with full control and calibration of the parameters and three-dimensional criteria of the encapsulated fuel structure of the mixture, along with simultaneous and instant online resonant and non-contact control of the initial state of the base fuel component of the mixture. In addition, the specified application includes a comprehensive proportional tracking and regulating module that performs online monitoring of all component inlets of the mixture.

In the figures of Kristina Bessarabenko's developments, a thermodynamic fuel application consisting of two devices for dynamic homogeneous mixing and simultaneous instant online homogenization of fuel mixtures, installed in parallel in the fuel line of a thermodynamic system, is shown in detail, with full control and calibration of the parameters and three-dimensional criteria of the encapsulated fuel structure of the mixture, along with simultaneous and instant online resonant and non-contact control of the initial state of the base fuel component of the mixture. In addition, the specified applications include a comprehensive proportional tracking and regulating module that performs online monitoring of all component inlets of the mixture. Furthermore, the application additionally includes a sequential software-based tracking, comparative, and online regulating function for all mixture flow parameters at the midpoint and at the final stage of the mixing and homogenization process.

In the final figures, a thermodynamic fuel application consisting of two devices for dynamic homogeneous mixing and simultaneous instant online homogenization of fuel mixtures, installed in parallel in the fuel line of a thermodynamic system, is shown, with full control and calibration of the parameters and three-dimensional criteria of the encapsulated fuel structure of the mixture, along with simultaneous and instant online resonant and non-contact control of the initial state of the base fuel component of the mixture.

In addition, the specified application includes a comprehensive proportional tracking and regulating module that performs online monitoring of all component inlets of the mixture.

Furthermore, the application additionally includes a sequential software-based tracking, comparative, and online regulating function for all mixture flow parameters at the beginning, midpoint, and final stage of the mixing process, capsule formation, and homogenization.

All control functions are concentrated in a comprehensive autonomously programmable controller that is interconnected via an interface system with all control-and-analytical elements of the application.

List of References, Patent and Licensing Information

Intellectual Property Related to the Integrated Technology of In-Line Vortex Mixing of Gaseous Fuel Components

United States Patent No. 9,708,185

Device for Producing a Gaseous Fuel Composite and System of Production Thereof

Issued: July 18, 2017.

United States Patent No. 9,400,107

Fluid Composite, Device for Producing Thereof and System of Use

Issued: July 26, 2016.

United States Patent No. 9,399,200

Foaming of Liquids

Issued: July 26, 2016.

United States Patent No. 9,310,076

Emulsion, Apparatus, System and Method for Dynamic Preparation

Issued: April 12, 2016.

United States Patent No. 8,715,378

Fluid Composite, Device for Producing Thereof and System of Use

Issued: May 6, 2014.

United States Patent No. 8,746,965

Method of Dynamic Mixing of Fluids

Issued: June 10, 2014.

United States Patent No. 9,144,774

Fluid Mixer with Internal Vortex

Issued: September 29, 2015.

United States Patent Application No. 20110126462 (A1)

Device for Producing a Gaseous Fuel Composite and System of Production Thereof

Published: June 2, 2011.

United States Patent Application No. 20170184055 (A9)

Device for Producing a Gaseous Fuel Composite and System of Production Thereof

Published: June 29, 2017.

submitted 14.01.2026;

accepted for publication 29.01.2026;

published 30.01.2026

© Gribkova V.A.

Contact: support@chill-services.com