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PROCESSES OF DYNAMIC ACTIVATION OF LIQUID FUEL. (Sequential Dynamic Homogenization in a Modern Gasoline Engine; Potential Applications of the Dynamic Homogenization Process; Thermodynamic Effects of Using Homogenized Fuel Produced by a Dynamic Homogenization Device)

*Dmytro Kovalevskyi*¹

¹ Mechanical Engineer Nomad Freight trucking company Davie Florida USA

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Abstract:

Liquid hydrocarbon fuels and fuel compositions based on them tend to lose structural homogeneity during storage, leading to the formation of sediment and agglomerates that accumulate in storage tanks. This problem becomes particularly significant for synthetic fuels produced through the recycling of plastic waste and used automobile tires, as such fuels may contain atypical contaminants, including compounds such as formaldehyde. Ensuring homogeneous fuel composition is therefore essential for efficient and stable combustion processes. This paper presents an innovative technology for the dynamic homogenization of liquid fuels and fuel mixtures using a specialized device integrated directly into the fuel pipeline. The proposed system consists of an accelerating hydrodynamic section, a vortex-generation module, and a turbulence amplification unit connected to the inlet of the high-pressure pump of an internal combustion engine. The technology implements a sequential dynamic homogenization process in which controlled turbulence and vortex flow formation significantly reduce the particle size within the fuel mixture to below one micron. As a result, the fuel acquires properties comparable to a nanoscale homogenized emulsion, which improves fuel stability and combustion efficiency. The proposed principle can be applied not only to internal combustion engines but also to fuel supply systems in boilers, burners, turbines, and other thermodynamic equipment, where maintaining fuel homogeneity contributes to improved operational performance and energy efficiency.

Keywords: *Liquid fuel; Dynamic activation of liquid fuel; Sequential dynamic homogenization process; Thermodynamic effect of using homogenized fuel; Fuel compositions based on liquid hydrocarbon fuels; Homogenization process using an innovative dynamic homogenization device performing homogenization directly within the pipeline through which the fuel or fuel mixture flows; Transformation of the homogenized liquid fuel or fuel mixture flow into a hydrodynamic vortex tube*

The necessity of the homogenization process

Any type of liquid hydrocarbon fuel, and especially fuel compositions based on liquid hydrocarbons, tends to lose its homogeneity during storage. As a result, agglomerates and sediments form, primarily at the bottom of tanks in which the fuel or fuel mixture is stored.

Ensuring homogeneity becomes even more problematic for various types of synthetic liquid fuels, particularly those obtained through the recycling of waste plastics or used automobile tires. Such fuels often contain a wide range of additional and atypical contaminants for conventional fuel compositions, for example formaldehyde. This further increases the necessity for homogenization, at least prior to fuel injection into the combustion chamber or during the combustion process itself.

The elimination of this heterogeneity can be achieved most efficiently and conveniently through the application of a homogenization process using an innovative dynamic homogenization device that performs homogenization directly within the pipeline through which the fuel or fuel mixture flows.

Dynamic homogenization process

First, it is necessary to briefly describe the properties, operational characteristics, and technological novelty of the proposed solution.

The device for dynamic homogenization of liquid fuel and fuel mixtures consists of an accelerating hydrodynamic section transitioning into a second coaxial hydrodynamic section equipped with an integrated vortex generator. This section further transitions into a hydrodynamic turbulence amplification module connected to the inlet of the high-pressure pump of an internal combustion engine.

Within the dynamic homogenization device, the liquid fuel or fuel mixture is divided into two streams. The first stream (approximately 60% of the total flow) enters the accelerating hydrodynamic section under a pressure of at least 3 bar (45 psi). Acceleration occurs under the influence of system elements that initiate the formation of coaxial Bernoulli-type effects. The second stream (approximately 40% of the total flow) enters the second hydrodynamic section, which is

arranged coaxially with the first section, also under a pressure of at least 3 bar (45 psi).

Inside the device, a dynamic sequential homogenization of the liquid fuel or fuel mixture occurs. During the first stage, homogenization is achieved through controlled turbulence within the pipeline. Such a process is absent in all currently known homogenization devices and technologies, representing one of the principal elements of technological novelty. This novelty is confirmed in the core intellectual property documents of the company that developed and owns the technology.

After this stage, the homogenized flow of liquid fuel or fuel mixture is transformed into a hydrodynamic vortex tube due to the action of the integrated vortex generator and is directed toward the high-pressure pump of a diesel engine or any other internal combustion engine operating at pressures of approximately 2000–3000 bar (29,000–43,500 psi). At this stage, the second phase of dynamic homogenization occurs within the flow. As a result, the particle size in the homogenized stream is reduced to less than one micron. According to the key parameters of the flow, the fuel effectively becomes a homogenized liquid equivalent in properties to a nanoscale emulsion.

A similar operational principle can be applied in fuel supply systems of boilers, burners, turbines, and other thermodynamic equipment.

The homogenization process takes place in less than one second and does not disturb the natural interrelations within the homogenized liquid fuel or fuel mixture.

The process occurs at a stable temperature or, under certain operating ratios, may even lead to a reduction in the temperature of the combustible liquid or fuel mixture.

The entire dynamic homogenization process is achieved through the creation of specific turbulent hydrodynamic conditions in the fuel or fuel mixture flow, without disrupting the chemical and physical equilibrium among its components.

Positive differences of the dynamic homogenization process compared with existing technologies:

- Existing technologies do not include a stage of dynamic homogenization based on the level of turbulence, which means that current technologies cannot perform

the homogenization process directly within the fuel pipeline of an internal combustion engine;

- The second stage of the homogenization process in the proposed technology takes place under pressure that is at least twice as high as that required for homogenization at the nanoscale particle level;
- The particle (globule) sizes in the liquid fuel or fuel mixture homogenized using the proposed technology are uniform and fall within the range of 70–120 nanometers, and they do not tend to agglomerate. In existing technologies, the size distribution varies widely – from the smallest to the largest particles – by more than an order of magnitude, typically from 0.2 to 2 microns;
- All processes of dynamic homogenization can be performed directly in the fuel pipeline of an internal combustion engine, for example between the fuel pump and the high-pressure pump, and do not require any special modifications to the engine design. The same principle applies to other types of thermodynamic equipment;
- During the dynamic homogenization process, the temperature of the homogenized liquid fuel or fuel mixture does not increase;
- The dynamic homogenization device also allows, during the homogenization process, the simultaneous introduction of additional components into the homogenized liquid fuel or fuel mixture, such as water, methanol, ethanol, or synthetic kerosene;
- The dynamic homogenization device has compact dimensions and is more convenient to operate than known devices. It provides optimal conditions for installation and maintenance;
- The cost of the dynamic homogenization device for liquid fuels and fuel mixtures is significantly lower than that of existing equipment designed for similar purposes;
- The device can also be used to perform technological homogenization before introducing the fuel or fuel mixture flow into industrial processing equipment used for the production of other hydrocarbon products.

As can be seen from the presented photographs, the dimensions of the device are very

small relative to its performance capacity (the images show devices with a capacity of 1,000 liters per hour).

Original dynamic homogenization device

An original device for the dynamic homogenization of liquid fuels and fuel mixtures has been developed, manufactured, and repeatedly tested.

All components and parts of the device are manufactured using standard CNC machines, without the need for special technologies or specialized cutting tools.

Stainless steel is used as the primary construction material, allowing the device and systems based on it to be installed in corrosive environments, for example on marine vessels.

Figure 1.



The device is extremely compact and has dimensions that allow it to be integrated into virtually any internal combustion engine, including both stationary engines (for example, marine engines) and engines installed in transport vehicles (such as automobiles of all types).

The device does not require any additional elements or auxiliary components for operation and can be installed directly in the fuel pipeline of an internal combustion engine, specifically between the fuel pump and the high-pressure pump.

All inlet and outlet connection interfaces of the device are standardized. Installation of the device on an internal combustion engine does not require special preparation, tools, or equipment.

The device contains no moving parts and can be manufactured in any required dimensional scale. It can be produced using stan-

standard industrial equipment with numerical control (CNC). The manufacturing, assembly, and quality control processes do not require special technologies, materials, or specialized tools.

Thermodynamic effect of using homogenized fuel (produced using the dynamic homogenization device)

After homogenization, the fuel burns uniformly, and no local zones with larger dispersed fractions are formed within the fuel volume after injection.

As a result, the combustion process proceeds 35–40% faster, and efficient heat extraction increases proportionally. These results have been confirmed in more than 300 testing cycles on a modern production diesel engine with a 2.5-liter displacement.

The homogenization technology operates equally effectively in engines with standard configurations as well as in engines equipped with exhaust gas recirculation (EGR) systems.

In the event of unauthorized water ingress into the fuel tank, dynamic homogenization – within several milliseconds before the fuel reaches the high-pressure pump – ensures the dynamic formation of a micro-emulsion, completely eliminating any harmful effects of water contained in the fuel emulsion on engine operation. These results have been confirmed in more than 60 test cycles on a modern production diesel engine with a 2.5-liter displacement.

The resulting micro-emulsion, while maintaining the effective power output of the engine, significantly reduces the concentration of soot in exhaust gases (reduction of up to 97%) and decreases nitrogen oxide emissions (reduction of up to 35%). It also shortens the full combustion cycle and accelerates the heat extraction process. These results have been confirmed in more than 300 full reversible testing cycles on a modern production diesel engine with a 2.5-liter displacement.

Application of the homogenization system

The application of the homogenization system additionally makes it possible to obtain, at 35–45% lower pressure, the same

spray dispersion that is typically achieved at injection pressures of 1600–2000 bar.

This phenomenon allows a reduction in the power consumption required for the operation of the high-pressure pump. As an example, the same effect can be considered a potential additional efficiency factor for turbines and turbo-generators, where injection pressures are typically 30 bar or higher.

Environmental effect of using homogenized fuel.

The application of the dynamic homogenization device in the fuel systems of internal combustion engines makes it possible to significantly reduce the toxicity of exhaust gases and may allow previously manufactured vehicles, including those that have been in operation for many years, to meet modern environmental standards.

Sequential dynamic homogenization process in a modern diesel engine.

In a modern diesel engine, the device for dynamic homogenization of fuel or fuel mixtures is installed in the fuel line after the fuel pump and before the high-pressure pump.

The fuel flow leaving the fuel pump is divided into two streams. The first stream, accounting for 60% of the total fuel flow, is directed into the central axial inlet of the dynamic homogenization device. The second stream, accounting for 40% of the total fuel flow, is introduced into an integrated inlet system consisting of four radial channels.

After homogenization, the fuel burns uniformly, and no local zones with larger dispersed fractions are formed within the injected fuel volume.

As a result, the combustion process proceeds 35–40% faster, and the efficiency of heat extraction increases proportionally. These results have been confirmed in more than 60 testing cycles on a modern production diesel engine with a 2.5-liter displacement.

The homogenization technology operates equally effectively in engines with standard configurations as well as in engines equipped with exhaust gas recirculation (EGR) systems.

Sequential dynamic homogenization process in a modern gasoline engine.

In a modern gasoline engine, the device for dynamic homogenization of fuel and fuel mixtures is installed in the fuel line after the fuel pump and before the high-pressure pump.

The fuel flow after the fuel pump is also divided into two streams. One stream, accounting for 60% of the total fuel flow, is directed to the central axial inlet of the dynamic homogenization device, while the second stream, accounting for 40% of the total flow, enters the device through an integrated inlet consisting of four radial channels.

The homogenization technology functions equally effectively in engines with standard configurations and in engines equipped with exhaust gas recirculation systems.

Application of the dynamic homogenization process in internal combustion engines using a mixture of ethanol and gasoline as fuel.

Ethanol, even of high quality, contains a certain amount of water.

Before mixing (for example) with gasoline, ethanol is a relatively stable substance and the separation of water and alcohol does not occur. However, a mixture of ethanol and gasoline is not completely stable and, under certain conditions (for example at low temperatures), water may separate from the gasoline–ethanol mixture.

If a dynamic homogenization device is integrated into the engine system, the water that has separated in the fuel tank from the main hydrocarbon fraction of the fuel mixture is dynamically mixed within the device with the hydrocarbon fractions, transforming the resulting mixture into a micro- or nanoscale emulsion.

The combustion of such an emulsion typically occurs in a stable thermodynamic regime, without detonation and with reduced levels of soot and nitrogen oxides in the exhaust gases.

Application of the dynamic homogenization process in internal combustion engines using a mixture of methanol and gasoline as fuel.

Methanol, even of ordinary quality, practically does not contain water.

Before mixing (for example) with gasoline, methanol is a relatively stable substance and, after mixing, it generally does not separate from gasoline.

Nevertheless, the methanol–gasoline mixture is not completely stable and, under certain conditions (for example at low temperatures), it tends to form agglomerates or clots.

The combustion of homogenized fuel in such systems generally occurs in a stable thermodynamic regime, without detonation

and with reduced concentrations of soot and nitrogen oxides in the exhaust gases.

Application of the dynamic homogenization process in internal combustion engines using gasoline mixed with biofuel compositions

In such thermodynamic systems, the fuel consists of gasoline combined with heavier biological fuels and various viscous combustible biological materials. In these composite fuels, the formation of agglomerates occurs more intensively.

If a dynamic homogenization device is introduced into the thermodynamic system, agglomerates that have formed in the fuel tanks – consisting primarily of the hydrocarbon fraction of the fuel mixture – are dynamically mixed in the device with the remaining hydrocarbon fractions. As a result, these agglomerates are transformed into a uniform system of micro- or nanoscale particles.

The combustion of the homogenized fuel generally occurs in a stable thermodynamic regime, without detonation and with reduced concentrations of soot and nitrogen oxides in the exhaust gases.

Application of the dynamic homogenization process in fuel supply systems for burners, boilers, turbines, and other thermodynamic equipment.

In such thermodynamic systems, the fuels used typically include heavier diesel fuels and various types of fuel oil, where the formation of agglomerates from heavier fractions with high viscosity occurs more intensively.

If a dynamic homogenization device is integrated into the fuel supply and injection system of the combustion chamber, agglomerates that form in the fuel tanks – composed of the main hydrocarbon fraction of the fuel mixture – are dynamically mixed within the device with the remaining hydrocarbon fractions. This process transforms the agglomerates into micro- or nanoscale particles.

The combustion of homogenized fuel typically occurs in a stable thermodynamic regime, without detonation and with reduced concentrations of soot and nitrogen oxides in the exhaust gases.

In certain cases and under specific conditions, significant fuel savings may also be achieved.

Potential application of the dynamic homogenization process in marine engines and diesel generators.

In such thermodynamic systems, heavier diesel fuels and various types of fuel oil are typically used as fuel. In these types of fuels, the formation of agglomerates occurs more intensively due to the presence of heavier fractions.

If a dynamic homogenization device is integrated into the fuel system of a marine engine or a diesel generator, agglomerates that may form in the fuel tanks under certain conditions – consisting mainly of the primary hydrocarbon fraction of the fuel mixture – are dynamically mixed within the device with the remaining hydrocarbon fractions. As a result, these agglomerates are transformed into micro- or nanoscale particles.

The combustion of homogenized fuel typically occurs in a stable thermodynamic re-

gime, without detonation and with reduced concentrations of soot and nitrogen oxides in the exhaust gases.

Potential application of the dynamic homogenization process in propulsion systems of aircraft

In recent years, there have been reports regarding the experimental use of biofuels and fuel mixtures containing biological components in aircraft engines. It is known that fuel mixtures containing biofuel components tend to form agglomerates during storage and operation.

Dynamic homogenization of such fuels prior to injection into the combustion chamber can significantly increase the reliability of aircraft engines and may create new opportunities for the practical use of composite fuel formulations in aviation propulsion systems.

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© Kovalevskiy D.

Contact: kovalevskiymit9@gmail.com