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NEW SMART MANUFACTURING TECHNOLOGIES IN THE SMART HOME INFRASTRUCTURE

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Abstract

Ensuring environmental safety in smart manufacturing technologies in accordance with current standards is an essential prerequisite for establishing and maintaining such production processes. This requirement is particularly relevant within the infrastructure and ecosystem of the smart home.

Before the widespread adoption of environmental standards with stricter limits on the concentration of substances polluting industrial waste, it was generally sufficient to perform waste treatment before disposal at designated facilities.

Today, due to the sharp tightening of environmental regulations and the emergence of smart technologies-especially within the smart home infrastructure-such treatment has become extremely costly, significantly reducing the overall economic efficiency of any production process.
Keywords: *Waste utilization; regeneration of process waste; etching process solutions; recirculation of etching solutions and other process liquids; toxic exhaust gases; transformation of toxic exhaust gases into harmless liquid; smart home ecosystem; smart home infrastructure; technologies for extracting heavy metals from waste; continuous recirculation of process solutions to extend their operational production cycle*

The need to build interconnections within the smart home infrastructure has introduced entirely new concepts and approaches into the production cycle:

- search for methods of waste regeneration within the production process, enabling subsequent recirculation and repeated reuse;
- implementation of technologies for extracting heavy metals from waste to return them to the production cycle, ensuring continuous recirculation of process solutions and extending their operational lifespan.

For example, continuous extraction of copper from etching solutions used in automatic etching lines for printed circuit boards and thin-film microassemblies allows for the permanent recirculation of the etching solution, eliminates environmental contamination by toxic copper ions, and significantly increases the economic efficiency of the etching processes:

- modification of waste structure aimed at changing the properties of polluting materials and transforming these materials and their chemical compounds into harmless or significantly less harmful substances.

This process has become highly relevant in complex technologies, where the waste products are exhaust gases that cannot be purified to the desired level within acceptable cost limits, even with the most advanced filtration systems currently available.

The author proposes, within the framework of the smart home infrastructure, the consideration of a system designed for this purpose – an alternative solution for reducing the toxicity level of atmospheric emissions generated by a standard diesel generator used as a backup power source in the smart home.

Figure 1. *The figure shows a fragment of a three-dimensional model of a vortex generator as part of a system designed for the condensation of liquid from an exhaust gas stream*

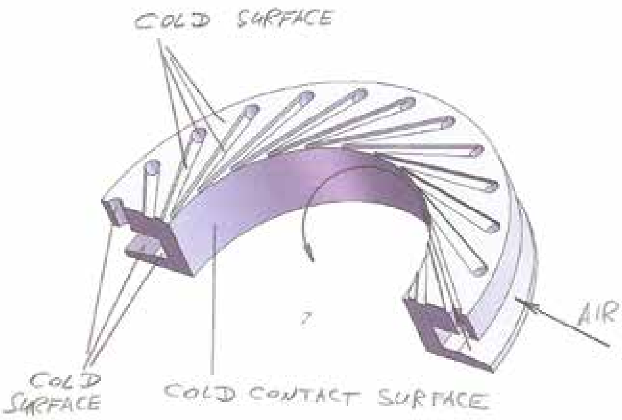
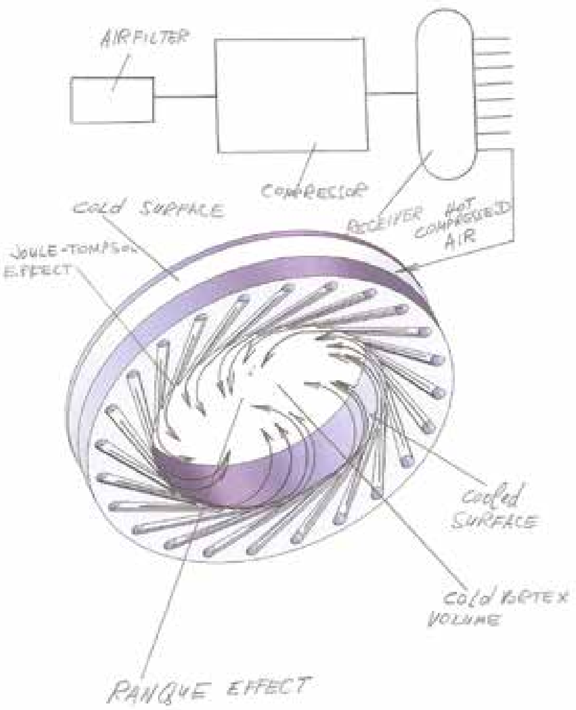


Figure 2. *The figure shows the connection diagram of vortex generators to a unit consisting of an inlet filter, a compressor, and a receiver*



For further explanation, let us assume that the discussion concerns a liquid condensation system for the exhaust gases of a diesel generator operating on Diesel Fuel No. 5 (equivalent to purified and homogenized fuel oil).

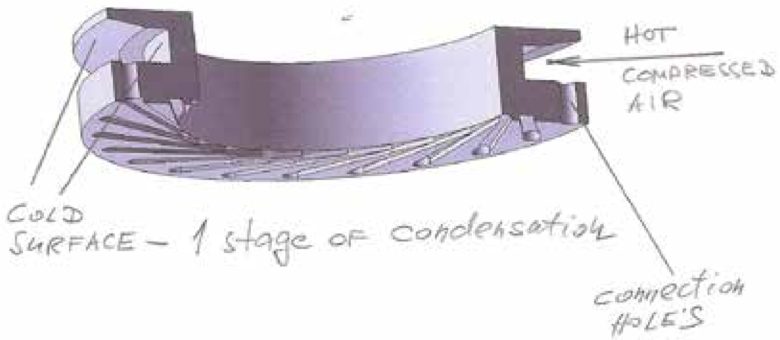
First, it is necessary to establish the condition under which condensation occurs – namely, cooling the gas to its dew point.

The following figure presents the connection diagram and model of the vortex generator, which enables efficient cooling of compressed gas (air) used in the condensation process.

Due to the fact that the vortex generator initiates the formation of a vortex tube, a significant cooling effect arises within it, in accordance with the Joule-Thomson and Ranque–Hilsch laws. This cooling occurs both at the periphery of the vortex tube (at the outlet of the injection channels of the vortex generator) and at the center of the vortex tube- known as the Ranque-Hilsch effect.

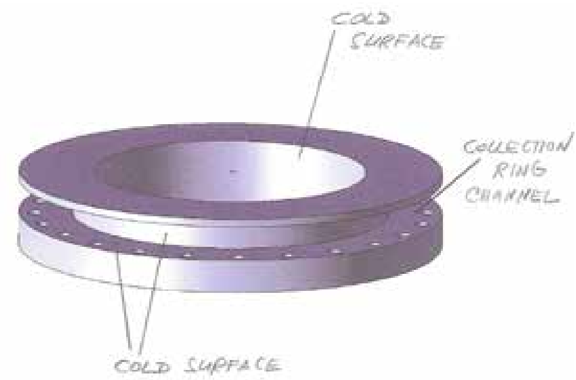
This mechanism stimulates moisture (liquid) condensation and induces structural transformation of pollutants, thereby neutralizing their harmful effects. As a result, the technology becomes more efficient, less costly, and produces an unconventional (innovative) outcome.

Figure 3. *The figure shows a fragment of the vortex generator, revealing details of its operating principle. As can be seen from the model, during the first stage of condensation, all surfaces that come into contact with the hot compressed gas (air) are cold, and upon contact with the heated gas flow, they initiate the initial phase of condensation*



As demonstrated in the following models, the liquid condensed during the first stage flows into a collection chamber, from which it can be easily removed and disposed of without causing any harm to the environment or to the technological equipment.

Figure 4. *The figure shows the reverse side of the vortex generator, where the cold surfaces are indicated. These surfaces stimulate micro-condensation, which, in combination with the vortex tube effects, transitions into an intensive condensation phase*



As can be seen from the model, the vortex generator-despite its seemingly simple design-contains several elements that can be considered innovative in many respects and embody a significant degree of fundamental novelty.

For the first time, the design of the vortex generator employs the principle of an accumulation channel-ring, into which the condensing gas is introduced. The gas then passes through transit openings into tangential channels, from which it is directed at high velocity into the central channel formed by the internal openings of all vortex generators in the system. Within this channel, a vortex tube is formed, consisting of spiral flows, the number of which corresponds to the number of tangential openings.

Such an aerodynamic structure of the vortex tube enables a significant intensification of heat exchange processes and ensures an active surface condensation process on all planes and surfaces with which the vortex spirals come into contact.

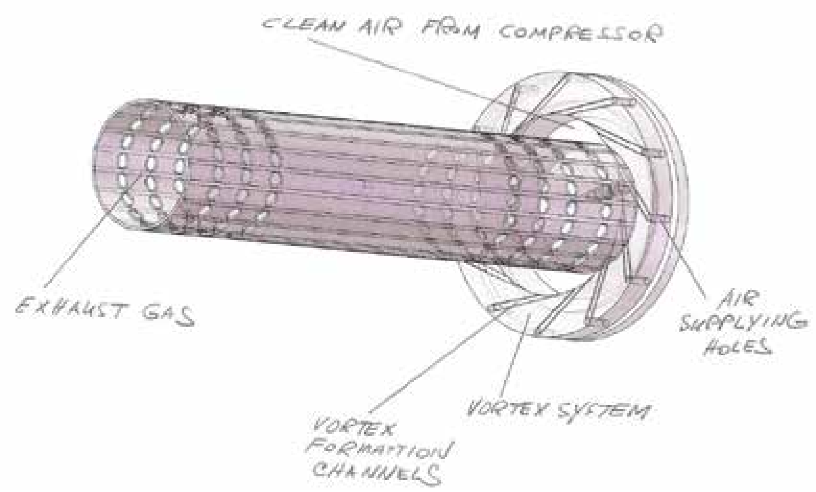
The same design and fundamental structural principles are applied both in stationary systems, such as those installed on diesel generators, and in mobile systems, which can be used on diesel engines of heavy-duty vehicles.

When discussing smart manufacturing technologies, it is important to emphasize the efficiency of the technical principle of condensing liquid from exhaust gases instead of performing deep exhaust gas purification.

This method provides significant advantages: in addition to purifying exhaust gases and drastically reducing their toxicity, it allows all pollutants to be bound within the condensed liquid, thereby reducing disposal costs by an order of magnitude.

Moreover, the energy consumption required for liquid condensation is much lower than that needed for deep filtration. Furthermore, the disposal of used filters is a far more complex and resource-intensive process than the safe disposal of condensed liquid.

Figure 5. *The figure illustrates the principle of interaction between the system components in cases where pure compressed air is used for additional cooling. This air moves through separate channels and does not mix with the exhaust gases at any stage of the cooling or condensation process*



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