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ANALYSIS OF THE CORROSIVE EFFECT OF HEAT TRANSFER FLUIDS ON SOLAR HEATING SYSTEM MATERIALS AND CHANGES IN THEIR PROPERTIES IN STAGNATION MODE

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Abstract. *The performance and environmental safety of solar thermal systems strongly depend on the choice of heat transfer fluids, especially under stagnation and high-temperature conditions. In such regimes, thermal degradation of fluids and corrosion of metallic and polymeric components may significantly reduce system reliability. This study compares the corrosion behavior and environmental aspects of common heat transfer fluids, including water, propylene glycol, mineral oil, nanofluids, and ethanol–water solutions. The analysis shows that water and propylene glycol exhibit notable limitations related to corrosion, scaling, and degradation at elevated temperatures. In contrast, ethanol–water mixtures demonstrate a favorable balance of thermal performance, freeze protection, and environmental acceptability. With proper material selection and corrosion inhibition, alcohol-based heat transfer fluids can be considered a promising alternative for solar thermal systems operating under stagnation-prone conditions.*

Key words: *solar heating systems, heat transfer fluids, stagnation mode, corrosion resistance, environmental safety, solar system materials, corrosion inhibitors.*

Introduction.

The active introduction of solar heating systems is seen as an important tool for decarbonising the energy sector and reducing the negative impact of traditional heating on the environment. At the same time, the environmental safety of such systems is largely determined by the stability of the physical and chemical properties of heat transfer fluids and their interaction with the materials of the structural elements of solar installations. Disruption of these interactions, especially in extreme thermal conditions, can lead not only to a decrease in the technical reliability of the equipment, but also to the formation of potential environmental risks.

The stagnation mode of solar heating systems is characterised by prolonged exposure of the heat transfer fluid to elevated temperatures, which causes intensification of corrosion processes, thermal degradation of anti-corrosion and stabilising additives, as well as changes in the acid-alkaline balance of the working environment. As a result, there is an increased likelihood of aggressive decomposition products and coolant leaks, which can pose a threat to the environment and human health, especially when organic heat transfer fluids are used.

Usually, the key factor in choosing heat transfer fluids is their thermodynamic characteristics. However, even the best thermophysical properties are meaningless if the heat transfer fluid destroys the structural elements of the solar system. Corrosion degradation of solar system materials, combined with changes in the properties of heat transfer fluids, leads to a reduction in equipment service life, an increase in waste volumes, and an increase in the resource intensity of the life cycle of installations. Accordingly, the choice of heat transfer fluid should be determined not only by its thermophysical characteristics, but also by its chemical stability and interaction with the materials of the system.

Domestic solar collectors usually contain copper and brass heat exchangers, bronze and brass fittings, steel pump housings, and polymer pipes (polypropylene, polyethylene, cross-linked polyethylene). Therefore, it is important to assess the corrosive effect of different heat transfer fluids on these materials. Taking into account the above-mentioned environmental and operational risks, it is advisable to conduct a comparative analysis of heat transfer fluids that are currently most widely used or promising for use in solar heating systems. Therefore, the objects of this study are heat transfer fluids such as water, a 40% aqueous solution of propylene glycol, 10% and 40% aqueous solutions of ethanol, mineral oil, and water-based nanofluids containing 1% Al_2O_3.

The aim of the study is to conduct a comprehensive analysis of the corrosive effect of various types of heat transfer fluids on the materials of solar heating systems and to assess changes in their physical, chemical and operational properties in stagnation mode as a component of ensuring their environmental safety and the sustainable development of energy technologies.

Main text.

A significant body of scientific literature has been devoted to the investigation of the physicochemical properties of heat transfer fluids and their interactions with structural and sealing materials used in solar thermal systems [1–7]. These studies address corrosion mechanisms, material degradation, and long-term operational stability under variable thermal conditions. Based on a comprehensive systematic analysis of the available literature and the authors' own experimental investigations, a compatibility table was developed for the selected heat transfer fluids and the typical metallic and polymeric materials commonly used in circulation loops of solar thermal systems (Table 1). The table summarizes the observed interactions and provides a practical basis for assessing material suitability under stagnation-prone operating conditions.

The following symbols are used in the table:

- 0 – compatible, no significant problems;
- + – moderate effect, monitoring and limitation of service life recommended;
- ++ – strong corrosive effect, not recommended.

As can be seen from Table 1, there is no such thing as an ideal heat transfer fluid. All of them interact in one way or another with the metal and rubber components of solar systems under certain conditions, remaining inert only to polypropylene and polyethylene, which emphasises the advantages of using these materials wherever possible, taking into account operating pressures and temperatures. From all the information on the potential interaction of heat transfer fluids with the characteristic materials of solar systems listed in Table 1, the following features are worth highlighting.

Water without special treatment is the most corrosive environment. It causes steel rusting, zinc corrosion of brass and copper pitting, and also forms scale, which reduces heat transfer [3, 5]. It can only be used after demineralisation and the addition of anti-corrosion additives [4]. It has no negative impact on the environment.

Table 1 – Compatibility of heat transfer fluids with solar system materials

Material	**Heat transfer fluid**					
	Water	Propylene glycol 40%	Ethanol 10%	Ethanol 40%	Mineral oil	Nanofluid (water+1% Al_2O_3)
Copper	+ pitting at high temperatures	0 with inhibitors, + without them	0	0	0	0 / + unstable dispersions
Brass	+ zinc corrosion	0 with inhibitors, + without them	+	++	0	0 / +
Bronze	0/+	0	0	+	0	0
Carbon steel	++ intense rust	+ without inhibitors, 0 with inhibitors	+	++	0	+
Stainless steel	0/+ at Cl^-	0	0	0	0	0
Aluminium	++	+ without inhibitors	0	+	0	+
Polypropylene (PPR)	0	0	0	0	0	0
Polyethylene (PEX)	0	0	0	0	0	0
Seals (EPDM, rubber)	0	0	+ partial ageing	++ at 40%	++ swelling	+ abrasion

Authoring

Propylene glycol is relatively safe, non-toxic and has low corrosive activity when used with inhibitors. In case of overheating or prolonged contact with metal surfaces without stabilisation, local corrosion spots may form on brass and aluminium [6]. In addition, in the event of a circuit leak, propylene glycol can escape into the environment, creating a risk of contamination of soil or water bodies, which can lead to a temporary disruption of the ecological balance [5]. Propylene glycol ($C_3H_8O_2$) is an organic compound that is actively decomposed by microorganisms. However, the leakage of large amounts of propylene glycol into the soil can change the acidity (pH) and affect the soil microflora. When dissolved in large volumes, $C_3H_8O_2$ consumes dissolved oxygen in water, which can lead to hypoxia in aquatic organisms, especially in small water bodies, and in combination with other chemical additives (corrosion inhibitors, dyes, stabilisers) can form substances that are potentially toxic to aquatic organisms.

Mineral oils do not cause electrochemical corrosion, but they have other drawbacks: they can form sludge when overheated and cause rubber seals to swell. This limits their use in domestic manifolds.

Water- or glycol-based nanofluids are generally considered safe heat transfer media; however, this is valid only under conditions of adequate stabilization and controlled composition. In the absence of proper dispersion stability, nanoparticles may agglomerate and act as catalysts for localized pitting corrosion on metallic surfaces, particularly copper and aluminum alloys. In addition, suspended solid particles may exhibit abrasive behavior, accelerating the wear of elastomeric seals, pump impellers, and bearing surfaces, which can lead to reduced system reliability and an increased risk of leakage. Therefore, the practical application of nanofluids in solar thermal systems requires continuous monitoring of particle stability, effective filtration, and strict control of fluid composition to ensure long-term operational safety and material compatibility [2].

Ethanol solutions (10–40%) are characterised by moderate aggressiveness. At a concentration of 10%, the corrosive effect is insignificant, but at 40%, the risk of brass decking (zinc leaching) increases. High-concentration water-ethanol HTFs cause galvanic corrosion due to the difference in metal potentials and the oxidation of ethanol to acetic acid, which lowers the pH to 4–6. In solar systems, this leads to sediment formation and pipe perforation [6]. The risks are exacerbated at temperatures of 20–80°C and during heating/cooling cycles. Research [1] shows that the presence of ethyl alcohol in mixtures significantly changes the corrosion activity of aluminium. In particular, the metal is prone to localised corrosion when in contact with ethanol-containing environments, which is important for assessing the impact of alcohol heat transfer fluids on the structural elements of solar systems. In addition, ethanol causes swelling and brittleness of rubber seals due to diffusion, which leads to leaks. Compatibility depends on the seal material. For example, natural rubber and NBR swell by 20–50% and become brittle, while FKM (Viton) is resistant to ethanol at temperatures up to 200°C and has minimal swelling of <5% [7]. Effective protective measures may include the use of FKM or PTFE seals, the application of protective coatings, regular inspection for cracks, and the addition of corrosion inhibitors as additives [3, 5, 6]. For water-ethanol HTFs, combined inhibitors based on NaMBT, phosphates, and silicates (e.g., NASA Inhibitor 5) can be recommended for corrosion protection, with an efficiency of >90%. To reduce flammability, $NaHCO_3$ (1–5%) or dilution with water (>60%) can be used to make the mixture non-flammable. These additives allow safe use in HVAC systems but require testing. Thus, alcohol solutions require separate research and testing for compatibility with system materials. At the same time, ethanol solutions are the most promising heat transfer fluids in terms of their environmental safety at low concentrations and the absence of corrosive effects on components when materials are properly selected.

A comparative analysis of the corrosive and environmental impact of the main heat transfer fluids used in solar heating systems has shown that none of them is a universal solution in high-temperature and stagnation modes. Water without special treatment is characterised by the highest corrosive activity and susceptibility to scaling; propylene glycol, despite its relative safety and prevalence, degrades when overheated, requires inhibitors and poses environmental risks in the event of leaks; mineral oils and nanofluids have limitations related to thermal stability, compatibility with seals and abrasive wear of system components.

In this context, water-alcohol solutions demonstrate a promising balance of thermophysical, operational and environmental properties. They provide a low freezing point, high thermal conductivity compared to glycols, no formation of persistent toxic decomposition products and easier disposal. At controlled concentrations (up to 20–30%) and with the correct selection of circuit materials (brass with protective coatings, copper, stainless steel, FKM or PTFE seals), their corrosive activity is controllable and predictable.

Summary and conclusions.

The results of this study demonstrate that the selection of heat transfer fluids for solar thermal systems must account for their potential impact on construction materials and circulation loop components. It was established that, when corrosion inhibitors are properly applied, the widely used 40% propylene glycol solution remains a reliable and well-proven heat transfer fluid for domestic hot water systems. While it is safe for humans and animals, it may pose environmental risks to soils and water bodies in the event of leakage. Water, although environmentally benign, cannot be used without appropriate treatment due to corrosion, scaling, limited frost resistance, and the risk of pipeline damage caused by thermal expansion during cold periods. Nanofluids may offer potential for the development of experimental high-efficiency systems; however, they require stabilization and filtration and remain insufficiently studied under long-term operating conditions. Ethanol-based solutions and mineral oils may be applied with appropriate limitations on concentration, careful control of sealing materials, and the use of corrosion-inhibiting additives. Considering the combined thermal properties of the analyzed fluids and the risks associated with system depressurization under external influences, ethanol–water solutions were identified as the most promising option. They can be regarded as an alternative and environmentally justified class of heat transfer fluids for solar thermal systems, particularly under elevated temperatures and periodic stagnation. Further research should focus on optimizing alcohol–water compositions, selecting effective corrosion inhibitors, and conducting long-term material compatibility assessments to expand their practical application.

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DESIGNING OPERATING PARAMETERS FOR INNOVATIVE DOUGH MIXING MACHINES FOR DOUGH PREPARATION

ПРОЄКТУВАННЯ ЕКСПЛУАТАЦІЙНИХ ПОКАЗНИКІВ ІННОВАЦІЙНИХ ТІСТОМІСИЛЬНИХ МАШИН ДЛЯ ЗАМІСУ ТІСТА

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Abstract. *Technological progress in the baking industry requires constant modernization of equipment in order to improve product quality, intensify production processes, and reduce energy consumption. Basic dough mixing machines with a spiral mixing element that has a circular cross-section are obsolete because they do not provide the required quality of mixing in a short period of time and cause excessive heating of the dough due to high energy losses. The purpose of this article is to design and justify technical solutions for an innovative high-intensity dough mixer L4-HT-2VM aimed at improving its performance.*

The main result of the design is the development of a three-bladed rotor, the profile of the blades of which is made in the form of an airplane wing with an angle of attack of 450. This innovative solution allows optimizing the mixing and plasticizing processes, significantly reducing the kneading time and minimizing the energy consumption for heating the dough, since the reduced load is compensated by the low braking resistance from the spiral grooves of the bowl. An additional advantage is the automation of dough unloading using a mechanism that tilts the bowl under its own weight without the use of a separate drive. It was concluded that the introduction of the L4-HT-2VM dough mixer in the baking industry will allow for high-quality kneading and increased production efficiency.

Key words: *innovative design, dough mixer, performance indicators, three-bladed rotor, aircraft wing profile, intensive kneading, process automation, energy efficiency, L4-HT-2VM, kneading quality.*