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ILMIY AXBOROTNOMA

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PROSPECTS FOR USING SORPTION REFRIGERATORS IN SYMBIOSIS WITH BIOGAS COMPLEXES IN THE CLIMATIC CONDITIONS OF CENTRAL ASIA

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Abstract. This article examines the potential for integrating sorption (absorption/adsorption) refrigeration units with biogas complexes in Central Asia. The climatic and socioeconomic factors that make this combination highly effective in the region are analyzed. The operating principles of a symbiotic system are described, where waste heat from a cogeneration unit (or biogas combustion) is used to generate cold. The technical, economic, and environmental benefits of the system are presented, including heat recovery, increased overall energy efficiency of the biogas complex, and reliable cold storage for agricultural produce and pharmaceuticals. The technology is found to be highly valuable for decentralized energy and cold supply in rural and remote areas of the region.

Keywords: sorption refrigerator, absorption, adsorption, biogas plant, cogeneration, heat recovery, Central Asia, decentralized energy supply, product storage.

Markaziy Osiyo iqlim sharoitida sorbsion sovutgichlardan biogaz komplekslari bilan simbiozda foydalanish istiqbollari

Annotatsiya. maqolada Markaziy Osiyo sharoitida sorbsiya (absorbsiya/adsorbsiya) sovutish qurilmalarini biogaz komplekslari bilan integratsiya qilish imkoniyatlari ko‘rib chiqilgan. Ushbu kombinatsiyani yuqori samarali qiladigan mintaqaning iqlim va ijtimoiy-iqtisodiy shart-sharoitlari tahlil qilinadi. Sovuqlik ishlab chiqarish uchun kogeneratsion qurilmaning chiqindi issiqligi (yoki biogazni yoqish) ishlatiladigan simbiotik tizimning ishlash printsiplari tasvirlangan. Tizimning texnik-iqtisodiy va ekologik afzalliklari, jumladan, issiqlikni utilizatsiya qilish, biogaz kompleksining umumiy energiya samaradorligini oshirish, qishloq xo‘jaligi mahsulotlari va dori-darmonlarni saqlash uchun ishonchli sovuqlikni ta’minlash keltirilgan. Mintaqaning chekka hududlarini markazlashtirilmagan energiya va sovuqlik bilan ta’minlash uchun texnologiyaning yuqori amaliy qiymati haqida xulosa qilingan.

Kalit so‘zlar: sorbsion sovutgich, absorbsiya, adsorbsiya, biogaz qurilmasi, kogeneratsiya, issiqlikni utilizatsiya qilish, markazlashmagan energiya ta’minoti, mahsulotlarni saqlash.

Перспективы использования сорбционных холодильников в симбиозе с биогазовыми комплексами в климатических условиях Центральной Азии

Аннотация. в статье рассматривается потенциал интеграции сорбционных (абсорбционных/адсорбционных) холодильных установок с биогазовыми комплексами в

условиях Центральной Азии. Анализируются климатические и социально-экономические предпосылки региона, делающие эту комбинацию высокоэффективной. Описаны принципы работы симбиотической системы, где отходящее тепло когенерационной установки (или сжигание биогаза) используется для выработки холода. Приведены технико-экономические и экологические преимущества системы, включая утилизацию тепла, повышение общей энергоэффективности биогазового комплекса, обеспечение надежного холода для хранения сельхозпродукции и лекарств. Сделан вывод о высокой прикладной ценности технологии для децентрализованного энерго и хладоснабжения сельских и удаленных районов региона.

Ключевые слова: сорбционный холодильник, абсорбция, адсорбция, биогазовая установка, когенерация, утилизация тепла, децентрализованное энергоснабжение, хранение продукции.

Introduction. Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) is characterized by a sharply continental climate with long, hot summers (temperatures ranging from 30 to 45°C), high insolation, water shortages, and a significant rural population. These factors pose two key challenges: 1) the need for energy-efficient and affordable refrigeration to preserve agricultural products (fruits, vegetables, milk, and meat) and pharmaceuticals; 2) the need to process organic waste from the agro-industrial complex (AIC) to generate energy and improve the environmental situation [1]. Biogas technologies successfully address the second challenge, producing methane (biogas) and high-quality organic fertilizer (digestate). However, the standard biogas utilization scheme, using a cogeneration plant (mini-CHP), generates electricity and, importantly, a significant amount of thermal energy (up to 50-60% of the total energy potential of the biogas) [1, 2]. In the warm climate of Central Asia, heat is often wasted (especially in summer) and dissipates into the atmosphere, reducing the overall efficiency of the system. Sorption refrigeration units (SRUs) using absorption (ammonia vapor/water, lithium bromide/water) or adsorption (water/zeolite, methanol/activated carbon) cycles are ideal for utilizing this low-potential heat (temperature range 70-120°C) [1,3]. Their integration with a biogas plant (BGP) creates a closed-loop symbiotic system that improves the energy and economic efficiency of both systems [4].

Generator: Heating an ammonia solution from a biogas burner; ammonia evaporation	Condenser: Converting ammonia to a liquid state	Heat exchanger: The cold is transferred from the ammonia to the object to be cooled.	Recovering gaseous ammonia and dissolving it in water to create an ammonia-rich solution	Repeating the cycle in the same way, i.e. heating the biogas with a burner again and evaporating the ammonia

Figure 1. Schematic diagram of the operation of a hybrid plant: biogas - sorption refrigerator.

Operating principle and configuration of the symbiotic system (Fig. 1).

The "BGTU + SCM" system operates according to the following scheme:

1. Biogas unit: Organic waste (manure, litter, plant residues) is anaerobically digested, producing biogas (~60% CH4, ~40% CO2) and digestate. [2,5].

2. Power plant: Biogas is used in a cogenerator to produce electricity (powering the BGTU equipment, lighting, and household needs) and a significant amount of hot water or steam for the engine cooling system and exhaust gas recovery (Fig. 2) [6].

3. Sorption refrigerator: Coolant from the cogenerator (hot water 85-95°C) is fed to the SCM generator, serving as the energy source for the refrigeration cycle. The refrigeration machine produces cold with an output temperature from -10°C (for freezing) to +7°C (for cooling) [7].

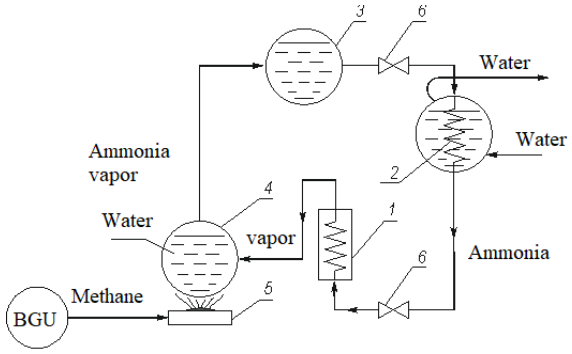


Figure 2. Operation diagram of a sorption refrigeration unit (The diagram was developed by the authors of this article): 1-evaporator; 2-condenser; 3-ammonia vapor accumulator; 4-absorber; 5-gas burner; thermostatic valve; BGU-biogas plant..

When absorber 4 is heated by gas burner 5 of the biogas plant, ammonia boils out of the solution (like water from a sponge) and escapes as vapor into ammonia vapor accumulator 3. The ammonia vapor from accumulator 3 then enters condenser 2, where cold water constantly circulates. In the condenser, the ammonia vapor cools, turning into liquid, and enters evaporator 1 of the refrigerator. Evaporator 1 has low pressure, and the ammonia again evaporates vigorously, returning to the solution. This evaporation requires a lot of heat, which it takes from the freezer, thus achieving the cooling process. The resulting ammonia vapor from evaporator 1 is absorbed (sorbed) by the lean solution of absorber 4. During absorption, heat is released, which is dissipated through radiators on the rear wall. The solution again becomes rich in ammonia, and the cycle is ready to repeat.4.

Cold consumers: Cold can be sent to:

- Refrigeration/freezer rooms for storing agricultural products.
- Air conditioning systems for administrative or industrial buildings.
- Medical facilities for storing vaccines and medications.

Specific application examples worldwide.

1. Pilot and research projects. Germany, the "BiogasHeatCool" project (Fraunhofer Institute for Solar Energy Systems, ISE): German researchers are actively promoting this idea. They are implementing systems on farms and food processing plants where heat from a biogas cogenerator drives ammonia-water absorption chillers (refrigeration units). These chillers produce cold for cooling milk, storing fruits and vegetables, or air-conditioning farm premises. Italy, agricultural cooperatives: In regions producing Parmesan and mozzarella cheese, there are examples where biogas plants powered by cheese factory waste and manure provide energy for the entire process, including cooling milk and ripening cheeses using absorption refrigeration units. India/China Research Initiatives: Universities and research institutes in these countries are exploring the possibility of using small-scale biogas plants (at the household or small village level) to generate cold for storing perishable foods and vaccines in remote areas.

2. Commercial and Semi-Commercial Implementations. Pig and Dairy Farms in the EU (Denmark, Austria, France): The most common example. The farm invests in a biogas plant (BG) to utilize manure and generate "green" electricity at a "green" tariff. Heat from the cogenerator is often used for space heating, but if heat demand is low in the summer, an absorption chiller is a logical addition. Companies such as Sortech (Germany) or Robur (Italy) offer absorption chillers that can be integrated into such systems. Food industry: breweries, wineries, processing plants: The company installs a BG to process its own organic waste. The heat from the plant is used for process needs and for cooling (for fermentation and product storage). This creates a closed-loop system.

Latest developments and trends.

1. Improving the efficiency of sorption cycles:

New working pairs: Research in the field of adsorption systems using hybrid porous materials (such as MOFs – metal-organic frameworks) and ethanol or water. These systems enable the production of cold from heat at temperatures as low as 50-65°C, further simplifying integration with biogas plants [7, 8].

Three-stage and hybrid cycles: Development of more complex absorption cycles that utilize biogas heat with maximum efficiency, significantly increasing the coefficient of performance (COP).

2. Intelligent control and integration (Smart Grids):

Systems are learning to flexibly distribute energy: biogas can either be burned in a cogenerator to simultaneously produce electricity (during peak grid demand) and cold, or sent directly

to a boiler to produce only cold (when electricity prices are low). This increases economic efficiency.
3. Miniaturization and modularity:

The emergence of compact, plug-and-play modular sorption refrigeration units with capacities of a few kilowatts makes the technology accessible to medium-sized and even small farms, not just large agricultural holdings. [1, 2, 3]

4. Focus on "green" refrigeration in developing countries:

Projects supported by the UNDP and the World Bank are exploring such hybrid systems as a way to solve three problems simultaneously: waste disposal, energy production, and ensuring a cold chain for food and medicine in remote areas without a stable power grid.

5. Using CO2 from biogas:

An innovative approach is not simply burning biogas, but purifying it into biomethane. The CO2 recovered in this process can be used as a refrigerant in a transcritical CO2 cycle, which is also powered by heat from the biogas plant. This creates a completely emission-free waste-to-energy refrigeration system [3, 8, 9].

Advantages of the system for Central Asian conditions.

1. Energy autonomy and efficiency: The system operates on local raw materials, reducing dependence on unstable power grids. Waste heat recovery increases the overall energy efficiency of biogas from ~40% (electricity only) to 80-85% (electricity + refrigeration). This is critically important in the context of rising energy tariffs [3].

2. Climate adaptation: High summer temperatures increase the load on compression refrigerators, reducing their efficiency and requiring more electricity. Conversely, refrigeration systems operate more efficiently in hot weather. Their performance directly depends on the temperature of the cooling water (condenser/absorber), which, in conditions of water shortage, can be achieved using dry cooling towers or geothermal heat exchangers, which are effective in dry climates.

3. Economic impact: Product losses are reduced (up to 30-40% in the region's agricultural sector), increasing shelf life and, consequently, market value. Farmers can sell their produce not only in season but also in the off-season at higher prices. This creates added value locally.

4. Environmental and social impact: Waste recycling, fertilizer production, reduced methane emissions from landfills, and reduced load on power grids (and, consequently, emissions from thermal power plants) contribute to environmental improvements. Providing reliable refrigeration for medical purposes improves the quality of life in rural areas [10].

5. Technological compatibility: CCMS have few moving parts (solution pumps), ensuring low noise levels, high reliability, a long service life, and ease of maintenance—key factors for remote areas [4].

Challenges and barriers to implementation.

High capital costs: The cost of storage systems, especially low-power ones, is higher than that of compression-based alternatives. Targeted government or international co-financing programs (green loans, grants) are needed.

- Lack of awareness and expertise: The technology is new to the region. Training of personnel (engineers, technicians) and demonstration projects are required.

- Seasonality optimization: It is necessary to design cold storage systems (ice batteries) or combine them with solar collectors to ensure year-round operation with the fluctuating heat load from the biogas plant [11].

Efficiency calculation (example for a small biogas plant).

For a biogas plant producing 100 m³ of biogas per day (equivalent to ~60 kWh of electricity from a cogenerator):

- Available heat output from biogas recovery: ~90 kW.

- Using 70% of this heat in an absorption unit with a COP (cooling coefficient) of 0.7 yields ~44 kW of refrigeration capacity.

- This is sufficient to provide cold (0°C) for a refrigeration chamber of ~100-120 m³ for storing fruits and vegetables.

Advantages of a hybrid: Use of free "waste" heat, which would otherwise dissipate into the atmosphere. This increases the overall efficiency of the system to 80-90%. The refrigerator operates silently, reliably, and can use environmentally friendly refrigerants (e.g., ammonia/water) [11].

Conclusion. The "biogas + sorption refrigerator" hybrid is not a futuristic concept, but a proven technology, particularly cost-effective in sectors where there is a simultaneous need for organic waste disposal and refrigeration (agriculture, food industry). The integration of sorption refrigeration units with biogas plants represents a highly promising approach for the sustainable development of

rural areas in Central Asia. This symbiotic system ideally addresses the region's climate and economic challenges, transforming problems (excess heat, organic waste, product spoilage) into opportunities (energy, refrigeration, fertilizers, income). Successful implementation of such projects requires the development of adapted technical solutions, government support through energy efficiency and renewable energy development programs, and the creation of pilot demonstration facilities. The implementation of the "biogas + sorption refrigerator" technology [4] has the potential to significantly contribute to energy and food security, diversify the rural economy, and [12-17] improve the environmental situation in Central Asia. The main barriers to widespread adoption are the high initial cost of sorption machines, a lack of awareness among potential users, and the need for custom design for each site. However, with rising energy prices and stricter environmental regulations, interest in such integrated, energy-saving solutions will only grow. Recent advances are aimed at reducing costs, increasing efficiency, and improving ease of implementation.

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