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ENERGY STORAGE METHODS AND DEVICES

TEXTBOOK

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ENERGY STORAGE METHODS AND DEVICES.
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O‘quv qo‘llanma oliy o‘quv yurtlarining 60712100 - Qayta tiklanuvchi energiya manbalari ta’lim yo‘nalishi talabalari uchun mo‘ljallangan. Ixtisosliklari bo‘yicha sirtqi bo‘limlarining bakalavr mutaxasisliklariga ma’ruza va amaliy mashg‘ulotlarda foydalanish uchun mo‘ljallangan. O‘quv qo‘llanma energiyani saqlash usullari va qurilmalari bo‘yicha asosiy qonuniyatlar, tushunchalar, issiqlik va elektr energiyalarni yig‘ish texnologiyalari to‘liq yoritilgan.

Учебное пособие предназначено для студентов образовательных направлений высших учебных заведений 60712100 - Возобновляемые источники энергии. Предназначена для использования в лекционных и практических занятиях бакалавриата заочных отделений по специальностям. Учебное пособие полностью охватывает основные закономерности способы и устройства хранения энергии, концепции, технологии накопления тепловой и электрической энергии.

The textbook is intended for students of educational areas of higher educational institutions 60712100 - Renewable energy sources. Intended for use in lectures and practical classes of undergraduate correspondence departments in specialties. The textbook fully covers the main regularities, methods and devices for storing energy, concepts, and technologies for storing thermal and electrical energy.

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INTRODUCTION

Currently, the use of alternative fuels in providing the population with heat and electricity is developing year by year, and the negative impact of fuels on the environment is significantly less compared to other types of fuel.

Due to similar circumstances, there is a great interest in alternative fuel and energy sources worldwide. These types of energy, namely those known for their clean ecological purity and convenience, are photovoltaic batteries, biogas, hydrogen, biofuel, alcohol, and briquette energies.

In recent years, large-scale work has been carried out in the sectors of the economy and the social sphere of the republic to increase energy efficiency and expand the use of alternative fuel energy sources.

According to the press service of the Ministry of Energy of the Republic of Uzbekistan, electricity generation at thermal power plants using natural gas will be ~66%, coal - ~20%, and the share of hydroelectric power plants - ~14%. By 2030, natural gas consumption in these indicators will decrease to ~45%, and coal consumption to ~6%. 17% will be replaced by solar energy, 11% by wind energy, 8% by nuclear power plants, and 13% by hydroelectric power plants. The level of urbanization and urbanization in our country is also increasing, and the saved natural gas is intended for providing autonomous gas boiler systems directly to the population and apartment buildings. It is known that centralized heating centers are a technology of past centuries, and due to high energy losses and decreased efficiency, the rate of self-sufficiency is decreasing. For example, In England, centralized heating systems are not used at all; each Briton uses autonomous heating and heating in their

home. In many Israeli cities, at the end of the last century, the roofs of multi-story buildings were equipped with solar water heating collectors for hot water supply. Energy saving and energy management are perceived as their daily way of life.

This textbook provides information on the accumulation of electricity and heat, from the basic concepts of the course on accumulation and generation of thermal and electrical energy to the parameters of precise calculations.

The course of accumulation and generation of thermal and electrical energy is a branch of science and technology that develops technical means, methods, and scientific foundations for the use of natural products for obtaining electricity, heat, and other types of energy and determines the scale and area of effective use of alternative fuel energy in the country's economy.

The materials presented in the textbook are intended for all bachelor's degree programs in the specialty "Accumulation and Generation of Heat and Electrical Energy"

This textbook will also serve as a useful guide for students studying in many fields in the field of energy.

Chapter I

TYPES OF ENERGY STORAGE

1.1. Introduction to the Subject “Energy storage methods and devices”. Basic Concepts and Quantities.

Resolution of the President of the Republic of Uzbekistan dated January 14, 2022 No. PP-88 On measures to implement the investment project “Construction of a photovoltaic power plant with a capacity of 200 MW in the Nurata district of Navoi region.”

Resolution of the President of the Republic of Uzbekistan dated January 14, 2022 No. PP-87 “On measures to organize the construction of a 220 MW photovoltaic station in the Kattakurgan district of the Samarkand region.”

Resolution of the President of the Republic of Uzbekistan dated January 14, 2022 No. PP-86 “On measures to organize the construction of a photovoltaic power plant with a capacity of 220 MW in the Gallyaaral district of the Jizzakh region.”

Resolution of the President of the Republic of Uzbekistan dated January 14, 2022 No. PP-85 “On measures to organize the construction of a photovoltaic power plant with a capacity of 456.6 MW in the Sherabad district of Surkhandarya region.”

Presidential Decree No. PP-72 of December 30, 2021, “On Approving the Investment Program of the Republic of Uzbekistan for 2022-2026 and Introducing New Approaches and Mechanisms for Managing Investment Projects,” has been approved.

The growth of energy consumption is a characteristic feature of modern humanity. Until recently, the development of energy faced the

main difficulties, since the growth of energy production was mainly associated with an increase in the extraction of minerals (natural gas, oil, coal), which is very convenient for consumption. Currently, more than 75% of electricity is generated by burning mineral and organic fuels.

At the current level of energy consumption, global oil reserves will decrease over 50 years, natural gas - over 75 years, and coal - over 150 years. Graph of the dependence of energy consumption per capita on the social development index Figure 1.1.

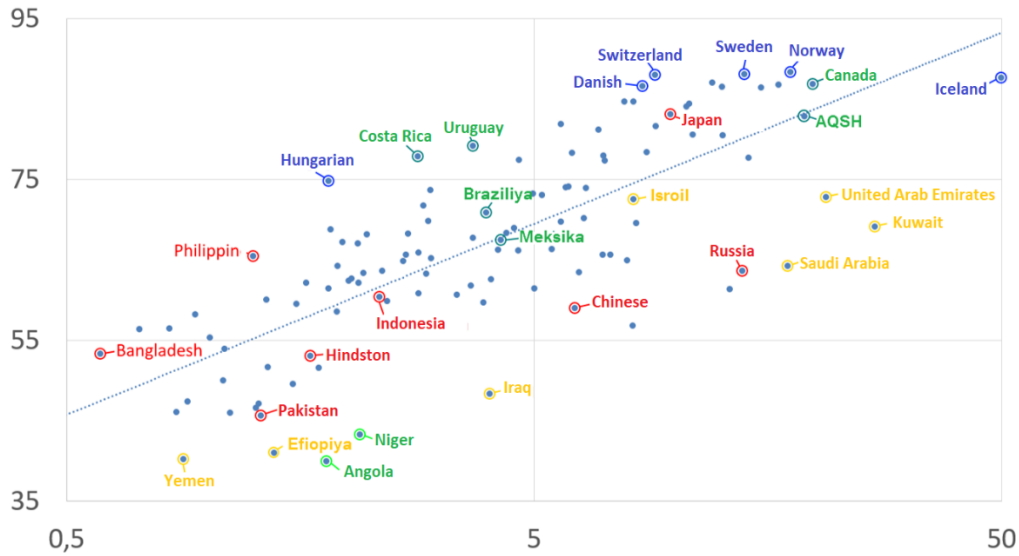


Figure 1.1. Graph of the dependence of energy consumption per capita on the social development index.

Today, in all countries with developed and developing sectors of the economy, in the context of a decrease in global reserves of hydrocarbon raw materials, intensive work is being carried out on the practical use of alternative energy sources as the most important factor in the sustainable development and increasing the competitiveness of the economy.

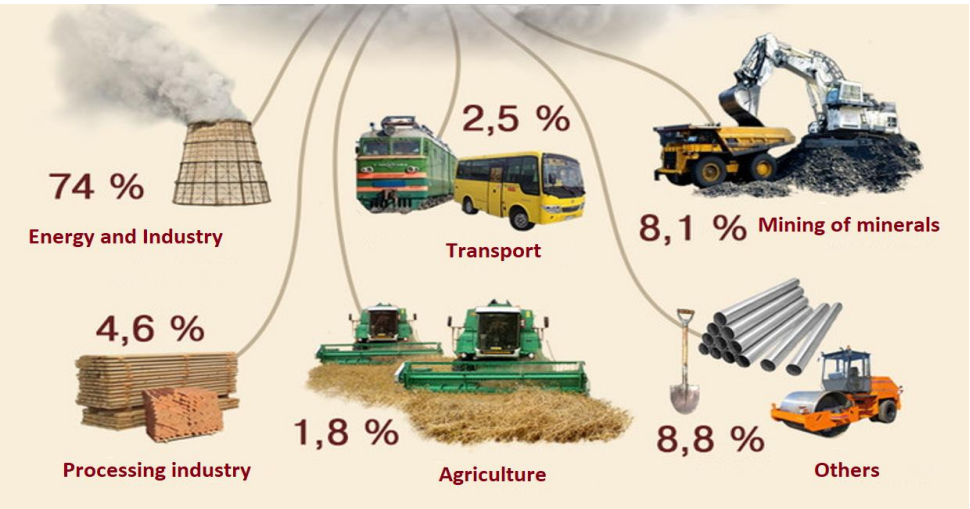


Figure 1.2.Damages caused by humanity to the environment.

Uzbekistan has accumulated significant experience in conducting scientific and experimental research in the field of using alternative energy sources, primarily solar energy, which has been developing for several decades. A unique scientific and experimental center in Central Asia - the “Physics-Sun” Scientific and Production Association of the Academy of Sciences - has been established in the republic, and the results of its research have received worldwide recognition.

Control questions.

1. Provide information about the resolutions of the President of the Republic of Uzbekistan on alternative energy sources.

2. What do you know about energy consumption?

3. What do you know about the damage caused by humanity to the environment?

1.2. Battery types of electricity

Accumulator (Lat. Accumulator) - a device that accumulates energy for subsequent use. There are electrical, thermal, hydraulic, and inertial types. A galvanic system that converts chemical energy into electrical energy under the influence of electric current. An electric battery consists of a positive electrode, a negative electrode, and an electrolyte. A potential difference arises on the surface of the electrode in contact with the electrolyte. This difference is called the EMF (electromotive force).

During the expenditure of accumulated energy, chemical energy is converted into electrical energy, and during the expenditure of energy, electrical energy is converted into chemical energy. Depending on the electrolyte composition, accumulators are divided into acidic and alkaline types.

Lead-acid batteries are used in automobile transport, aviation, and communications. Depending on the type of electrode, batteries are divided into cadmium-nickel and iron-nickel, silver-zinc and silver-cadmium. A cadmium-nickel battery is made with a positive electrode made of nickel oxide mixed with graphite, and a negative electrode made of iron mixed with cadmium.

Lead-acid battery is the most common type of battery. It was invented long ago - in 1859. This mechanism is mainly used in road transport, as well as in emergency power sources. The operating principle of a lead-acid battery is based on the electrochemical reactions of lead dioxide and lead in sulfuric acid. Energy arises from the interaction of sulfuric acid and lead oxide. Research conducted very long ago yielded the following result: approximately 60 reactions (at least) occur inside this battery, and

one-third of them occur without electrolytic acid. During emission, lead oxidation begins at the cathode and lead dioxide decreases (only at the anode). When charging, reverse reactions occur. Thus, if the lead-acid battery is discharged, then sulfuric acid is consumed (and the density of electrolytes decreases). Internal view of a lead-acid battery Figure 1.3.

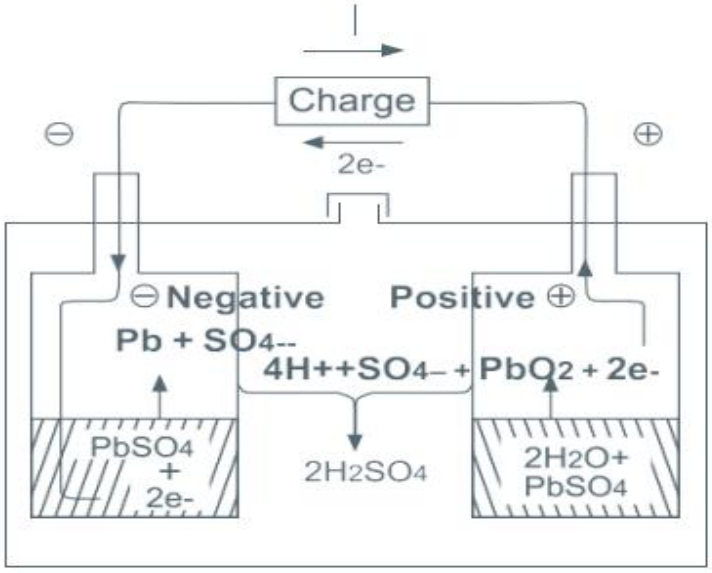


Figure 1.3. Internal view of a lead-acid battery.

Lead-acid batteries can be classified according to various properties and parameters:

• Maximum service life;

• Battery capacity;

• Number of charging cycles;

• Self-charging parameters;

• Dimensions;

• Temperature operating level;

• Ability to perform accelerated charging;

• Maximum shelf life.

Nickel-cadmium batteries Figure 1.4. Here, the reagents are nickel hydroxide and cadmium alternately, and the electrolytes are potassium hydroxide solutions, in this respect they are also called alkaline batteries. They are divided into lamellar, lamellar, and hermetic. Nickel-cadmium batteries are very inexpensive and characterized by durability.

Figure 1.4. Appearance of nickel-cadmium batteries.

Sealed batteries are characterized by a high degree of discharge and the ability to operate at low temperatures, but they are more expensive and have a memory effect. They are used to power portable equipment, household appliances, and children’s toys. A major disadvantage of these batteries is the disadvantage of spent cadmium.

Figure 1.5. Sealed batteries.

Nickel-iron batteries Figure 1.6. The problem described above was eliminated using iron instead of cadmium. Batteries do not contain cadmium, are cheaper, have a longer lifespan, and have higher power. However, hydrogen is released at the beginning of the charge. Characterized by low energy production, it is used as a power source.

Figure 1.6. Nickel-iron batteries.

Nickel metal hydride batteries Figure 1.7. Here, the active substance of the electrode is an intermetallic compound that adsorbs hydrogen, i.e., it is actually a reduced-state hydrogen electrode in the absorbed state. The battery has the same charge curve as nickel-cadmium batteries, but 1.5-2 times higher energy and specific power, plus they don’t contain toxic cadmium! Manufactured in various sealed designs (cylinder, prism, disk). They are used for charging equipment and portable devices.

Figure 1.7. Nickel metal hydride batteries.

Nickel-zinc batteries. These are zinc electrode hydroxide batteries. Their specific energy is 2 times higher than that of nickel-cadmium. They are characterized by high power density and very low cost, but their resources are very limited, so they have not entered mass use.

Silver-zinc and silver-cadmium batteries. In them, silver oxide, zinc, and cadmium are active substances, and alkalis are electrolytes. They are characterized by high energy and forces, low self-loading, but therefore they are expensive. Silver-zinc has a small power source, they are produced in the form of prisms or discs, they are used to power portable devices, as well as military equipment.

Control questions.

1. What do you know about batteries?
2. What types of batteries are there?
3. Operability of batteries?

1.3. The use of electrochemical batteries in the accumulation of electrical energy

Studying the characteristics of the battery allows us to understand under what conditions the device can be used, what parameters should be maintained.

• Power of a regular car battery. This feature allows you to determine how much energy a device can provide. Such verification should be performed periodically to understand the status of the load fork or other autonomous devices and unit that you can use to track this value.

- Manufacturers apply this parameter to all batteries. Knowing what current is in the battery, car owners maintain this indicator.
- **Electromotive force.** Shows voltage at terminals at a specific time. Multimeters are used to determine the characteristics of batteries. It largely depends on the density and composition of the electrolytes.
- **Resistance level.** This property depends on temperature, charge size, and the condition of the plates and fasteners. For an automaton, the technical characteristics are not so important.
- **Polarity.** The cars are equipped with batteries with reverse (European models) or direct (Russian models) polarization. Determining the type of car power supply is not difficult. For this, pay attention to the location of the terminals.
- **Storage and expiration date.** The conditions are defined in the technical documentation. To increase them a little, you need to take a responsible approach to the use process and follow the rules of service. The correctness of implementing the established rules determines the condition of the batteries and their characteristics.

- When choosing new batteries, all of the above characteristics must be taken into account.
- Characteristics of technological parameters
- When studying the characteristics of batteries, you should pay attention to the technological design. All batteries are divided into the following models:

Self-discharge of the battery

- The process of power reduction when the power supply is off is called automatic power loss.
- The main reason for its occurrence is oxidation-reduction processes occurring at the electrodes. In addition, pollution can cause self-release.

Car battery device

- Many passenger vehicles are equipped with lead-acid batteries. At the same time, the car battery device is constantly being modernized and improved. Studying the main components of the device eliminates the complexity.
- The basis of any battery is a galvanic cell consisting of two electrodes that differ in polarization.

Many of the disadvantages of ordinary lead-acid batteries (rapid drop in electrolyte levels, rapid wear of positive polar plates, spontaneous discharge, etc.) arise from the presence of 5-7% antimony in the plate grids. The water in the antimony electrolyte acts as a catalyst for electrolysis. Water reduces the potential for decomposition into hydrogen and oxygen to the operating voltage of the generator, accelerating the release of gases from the sliding accumulator. As a result, the electrolyte

level in the battery decreases relatively quickly, and the released gases lead to corrosion of positive plate grilles and metal parts of automobiles.

In order to eliminate the above-mentioned shortcomings of ordinary batteries, “non-service” batteries were developed. Research in the development of a “non-service” battery was mainly aimed at completely eliminating or reducing the amount of antimony in the composition of gas-retardant plates. The results of scientific research have shown that the amount of gas released from the accumulator is very small if the plate grilles are made of an alloy of lead, calcium, or tin.

Currently, in industrial batteries of the “non-service” type, negative plate gratings are cast from lead, to which approximately 0.06-0.09% calcium and 0.1-1.0% tin are added. The lattice of the positive plates consists of lead, 1.25% antimony, and 1.5% cadmium.

The manufacture of plate grilles from a lead-calcium-tin alloy requires a complete transformation of the battery production process. Therefore, while maintaining the established technological process in battery production, to improve its properties, the amount of antimony in the plate grates is reduced to 2.0-2.5%, and the addition of alloying additives intended to increase the strength of the grates is limited to copper (0.02-0.05%), sulfur and selenium (up to 0.01%) and tin (up to 0.01%). Batteries manufactured using this method are called “low-service” batteries, and their gas emission is several times lower compared to conventional batteries.

Transition devices made for lead are used to connect individual parts of the power supply and create lead. Almost all manufacturers include them in the battery pack. Lead differs in size, therefore the probability of

incorrect connection is reduced. The body is designed to create a complete design and ensure the ease of operation of the car battery. Raw materials with certain qualities are used for its production:

Stiffness - the state of matter does not change under the influence of chemicals, moisture, or temperature.

Reliability - like radiators, it can withstand certain loads. Companies that upgrade car batteries use polypropylene and other synthetic materials with similar properties in base fabrication.

Additional elements. In operating power sources, chemical reactions occur that contribute to gas formation. To mitigate its negative impact, some manufacturers prevent gas leaks from the battery. It all depends on what type of power source is used to fill the car and where it is located.

Basic concepts. As soon as consumers connect to the battery, the plates react with the lead electrolyte (sulfuric acid) from which they are made. As a result, water, as well as lead sulfate, is formed. Due to the formation of water, the electrolyte becomes less dense.

Use a special device for charging - a network device or a generator. The second option is used more often, since the generator maintains the maximum flow, the received power. When using network equipment for charging, it is necessary to monitor temperature indicators, humidity levels, flow and voltage values.

Discharge the battery. The process of discharging a power source is the transfer of electricity to the onboard network. In parallel, the proportion of water present in the electrolyte increases, and the sulfuric acid level decreases. The discharge of the new battery takes longer than the old one.

Rules for using a car battery. Following several rules allows the battery to last longer.

1. Complete discharge of a car battery is not permitted. The normal operation of the power supply is constantly charged. If it is impossible to prevent a full charge of the battery, it is necessary to start charging quickly. Otherwise, opportunities will begin to decline rapidly.

2. The voltage from the generator varies within the range of 13-14 V, whichever operating mode is chosen. The voltage in the power supply terminals is 13 V and higher. The degree of charging of unused car batteries is also insignificant.

3. Do not connect to the power source when the engine is not running. This car quickly drains its battery. Climate control, headlights, acoustics are in first place among consumers.

4. Oxides that complicate the engine start-up process must be removed from the terminals. They contribute to voltage drops and power problems.

5. Vibrations damage the battery. Therefore, you should periodically check the fasteners. Minimal displacements cause distortions, the appearance of defects.

6. Maintenance and the study of the operating principle of a modern car battery are carried out only with a disconnected “mass.”

7. A fully or partially discharged battery should not be left outside at low temperatures. Because the electrolyte contains distilled water, it freezes in the cold.

8. Electricity supply is transferred annually to the service center. Inspections and repairs will be carried out here.

9. The service life of an alkaline, acidic car battery depends on the following.

Battery device. A battery is a single cell that forms a battery when combined with similar cells. In a standard 12-Volt battery, six batteries are combined to produce 2 Volts each. All of them are located in a common housing, ensuring the integrity of the entire structure.

Principles of work. The battery's operating principle is based on the reaction between a positive plate of lead dioxide, a negative plate of spongy lead, and a solution of sulfuric acid with water. This solution is an electrolyte with a density of 1.28 g/sm^3. An electric current is generated simultaneously with the formation of lead sulfate on the negative plate. Water separates from the electrolyte, its density decreases.

Battery device. Usually used in cars. Let's look at their device. All elements are located in a polypropylene housing. The housing consists of a tank divided into six chambers and a cover equipped with a drainage system for pressure relief and gas evacuation. The cover shows two poles (terminals) - positive and negative.

Control questions.

1. What should be considered when storing and using batteries?
2. What do you know about the rules for using a car battery?
3. Explain the operating principles of a battery device.

1.4. Forms of energy storage

There are various ways to accumulate energy: in the form of chemical, thermal, electrical, potential, and kinetic energies. In energy, energy accumulation is not a new concept. Fossil fuels are also considered high-density chemical energy accumulators prepared by nature. However, as fossil fuel reserves decrease, they become more distant and increasingly expensive. Consequently, there is a need to develop other methods of energy accumulation. For example, the production of renewable fuels.

Biological accumulation. The biological form of energy accumulation is the production of plant mass and oxygen through photosynthesis and the accumulation of solar energy. Due to electromagnetic processes, the energy of photons is converted into the excitation state of electrons, and energy is accumulated in chemical compounds, resulting in the formation of high-energy organic substances. When biomass burns, accumulated energy is released. The main producers of biological mass, i.e., biofuel, are agricultural and forestry enterprises. During the processing of biomass, liquid (ethanol), gas (biogas), and other secondary fuels are obtained.

Chemical accumulation. In the bonds of many chemical elements, energy can be stored and released during exothermic reactions. The most well-known exothermic reaction is the combustion process. Many inorganic compounds are good accumulators, and their combustion in air releases energy.

One of the methods of chemical energy accumulation is the generation of hydrogen, which can be stored, transmitted over a distance,

and burned to generate heat. Water is the natural product of hydrogen combustion, and no pollutants are produced. Hydrogen can be produced by electrolysis using any current source. The efficiency of such a process is 60...80%.

The main disadvantage of hydrogen production and its use as fuel is the problem of storing it in large volumes. Even at high pressures, large volumes are required to hold hydrogen. The boiling point of hydrogen is 253°C, therefore maintaining it in liquid form during maintenance is a complex technology.

Accumulation of electrical energy. Electricity is the most perfect form of energy. Therefore, the creation of inexpensive and efficient methods of electricity storage is an important scientific and technical problem. Devices that ensure the collection and release of electrical energy are called electric accumulators. The operation of electric accumulators is based on reversible electrochemical reactions. In all photovoltaic and wind energy installations, electric batteries are the main components. Work is underway to create efficient batteries for vehicles.

From a theoretical point of view, the energy capacity of an ideal electric battery can be Wi=600 kJ/kg. In real batteries, the energy density Wr is much smaller than the theoretical Wi and is Wr≈0.15...0.25Wi. Currently, lead-acid batteries are most commonly used. Nickel-cadmium and silver-zinc batteries are also used, which are much more efficient than lead-acid ones, but have a higher cost.

Mechanical accumulation. In reservoirs, hydropower plants are powered by the potential energy of water collected from precipitation. Reservoirs serve as structures for accumulating the potential energy of

water. The work generated by the fall of the water flow is determined by formula 1.1:

$$YE = \rho\ g\ G\ H\ \eta\ (J); \qquad (1.1)$$

Here ρ- water density, kg/m^3;

g - acceleration due to gravity, m/s^2 ;

G - water consumption, m^3/s;

H - water drop height, m;

η - UWC of the hydraulic structure.

Thus, the capacity of the hydraulic structure depends on the water flow rate and the descent height.

Hydro-accumulating power plants (HACs) are used to accumulate the potential energy of water. Such devices have two reservoirs (upper and lower) and operate in two modes. When there is excess power in the power grid, the water is discharged into the upper pool. When energy consumption increases, water is transferred through the turbine to the lower pool, and electricity generation is ensured.

Figure 1.8. HAPP.

In practice, HAPP use units operating in two modes (as pumps and turbines). Currently, large hydroelectric power plants are used to correct fluctuations in energy consumption. This ensures the operation of traditional nuclear power plants and thermal power plants in an efficient mode with a constant load. The efficiency of hydroelectric power plants is 60-80%.

Control questions.

1. What types of accumulation exist?
2. What do you know about biological accumulation?
3. What do you know about mechanical accumulation?

Chapter II

ENERGY STORAGE SYSTEMS

2.1. Thermal energy storage systems

The use of low-temperature heat constitutes an important part of global energy consumption. In countries located in the northern mid-latitudes, up to 50% of the total energy consumption is spent on heating houses in winter (maintaining the temperature at 18°C). It is not necessary to use high-temperature energy sources for heating; it is advisable to use them for technological purposes. For heating, it is advisable to use solar energy and heat accumulators along with thermal waste from various heat-technological installations. For the most efficient use of solar energy in heating, batteries that retain heat from several days to three months are necessary.

$$T_a(\tau)-T_0 = [T_a(0)-T_0] \exp(-\tau / mcR). \quad (2.1)$$

From the equation, it can be seen that the efficiency of a heat accumulator is expressed by its mass m, the specific heat capacity of the accumulator material c, and the quality of thermal insulation R.

Creating a three-month heat-reserved battery for heating homes is a problem that can be easily solved. When creating heat accumulators, it is necessary to observe the following requirements:

1) creation and implementation of an effective project, taking into account the architectural and operational requirements of the heated facility;

2) automatic control of the heating and ventilation system;

3) use of highly effective heat-accumulating materials, ensuring high-quality thermal insulation;

4) the use of all heat emissions from lighting, food preparation, and the life activities of residents.

Soil, water, various rocks, and materials with low spatial transition temperatures (30-40°C) are used as heat-accumulating materials. The main disadvantage of heat-accumulating devices is the need for large volumes of heat-accumulating materials.

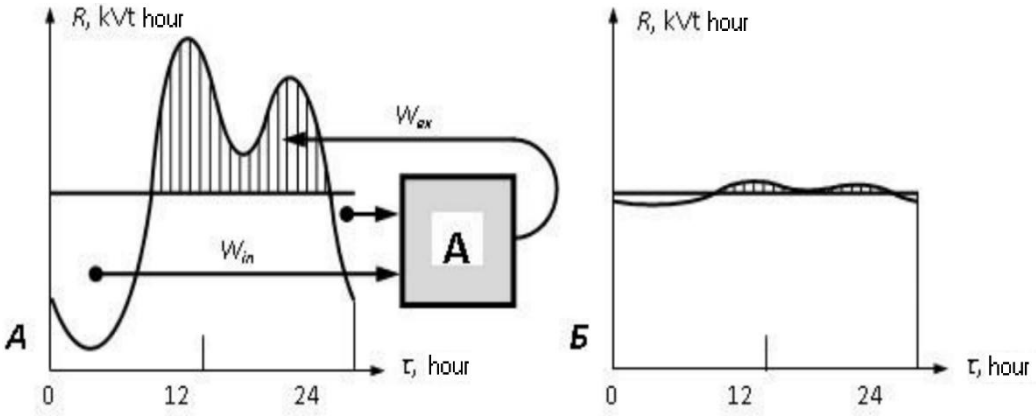
Accumulation systems of non-traditional and renewable energy sources. Non-traditional heat energy conversion devices are based on the processing of natural energy flows with low intensity and dissipation, changing in time and space independently of consumers. Natural energy flows that exist in nature cannot be controlled and managed; they can only be extracted. These factors limit the possibilities of widespread use of non-traditional and renewable energy sources.

On the other hand, the energy consumption modes of various consumers have a daily and seasonal period. Thus, a discrepancy arises between the intensity of energy production and the mode of its consumption. There are two ways to eliminate such differences:

1) adaptation of the consumption load of a non-traditional heat source to the intensity of the transformed energy;

2) accumulation of energy and its use when necessary.

High-performance batteries are primarily necessary for autonomous vehicles. Therefore, there are problems with energy accumulation and transmission over distances. Devices for non-traditional thermal energy conversion differ in terms of energy storage and transmission requirements compared to devices operating on traditional and nuclear fuels.



2.1-figure. A-accumulation of energy during the nighttime minimum load Win (A) and smoothing of the daily load graph by the method of compensating the accumulated Wex energy for peak daytime loads; B - graph of uniform load due to energy accumulation.

Thanks to the use of reliable and efficient energy storage systems, the stability of energy systems based on renewable energy sources increases. At the same time, not only the stable and uninterrupted supply of energy to consumers, but also the accumulation of peak and low-potential energy will lead to an increase in the utilization rate of energy equipment. Low-potential energy cannot be used by consumers without appropriate conversion.

NTRES the main functions of energy accumulators in power systems based on:

a) uninterrupted supply of consumers with energy through the accumulation of excess energy and its subsequent use during periods of its absence or insufficiency;

b) ensuring optimal operating modes of energy sources and consumers due to the smoothing of vibrations in the energy system;

c) raising the energy potential to the required level when accumulating low-potential energy;

d) conversion of one type of energy into another, depending on the needs of consumers.

When choosing energy storage facilities for a specific NTRES power system, it is necessary to equally consider equipment based on renewable energy sources and consumers, as well as the energy and operational indicators of energy storage facilities.

Key characteristics:

- specific capacity,
- specific energy,
- specific value of the energy storage device,
- charging-discharging time,
- service life,
- EWC,
- self-discharge,
- security,
- simplicity of service,
- the type of energy produced and consumed.

Of the many batteries that can be used in various technical systems, only those that are most suitable for use in non-traditional energy systems with NTRES in terms of their properties and characteristics are selected for use in non-traditional energy.

Experience with the use of renewable energy sources shows that currently, the most realistic and optimal is the use of electrochemical, thermal, and mechanical energy accumulators, as well as hydrogen-based accumulation.

For the accumulation and storage of electricity from renewable sources at peak energy and subsequent power supply facilities of non-traditional energy and industrial power grids, electricity storage systems are used. Currently, almost all energy systems based on renewable energy sources are equipped with lead-acid and alkaline batteries produced on an industrial scale. The service life of lead-acid batteries is up to 10 years (regular full discharge is recommended, uneven electricity consumption reduces the service life).

Their main disadvantage is the materials used: highly toxic electrodes (lead) and sulfuric acid as an electrolyte. Within the framework of environmental safety considerations, such technologies, despite a number of advantages, are considered inadequate. However, alternative developments either lose in terms of prices or have other negative properties.

Currently, active scientific work is being carried out in the world to find ways to improve both known and new energy batteries. Work is underway in Japan, Germany, the USA, and other countries to create systems designed for electricity storage. Power systems with 10...40 MW batteries based on lead-acid batteries are used. In addition, work is underway to use nickel-cadmium, lithium-ion, sodium-ion, and other batteries.

When choosing electricity storage systems, the following issues are resolved:

- selection of effective batteries;
- optimization of battery charging modes;

- development of methods and devices for ensuring optimal modes and conditions of batteries in energy systems with energy-generating equipment based on renewable energy sources;

- development of tools and methods for express analysis of the state during the long-term operation of each battery.

Systems for accumulating electrical energy with electric generator equipment based on NTRES smooth out the daily fluctuations arising during operation in a constant charging mode and provide consumers with electrical energy in a stable mode.

Electricity storage systems collect excess electricity at night when working with industrial electrical networks and provide consumers with electricity when disconnected.

To reduce labor intensity and increase the efficiency of electricity storage systems, an automatic operating mode control system is implemented.

Figure 2.2. Sodium-ion battery block.

A device (or set of devices) that ensures reversible processes of accumulation, storage, and release of thermal energy in accordance with

consumer requirements is called a heat accumulator. Any body heated above the ambient temperature can be considered a heat accumulator. This body, having cooled and released heat, is capable of performing work, and therefore possesses energy.

Heat accumulation processes are carried out by changing the physical properties of the heat-accumulating material (HAM), as well as by using the binding energy of atoms and molecules of the substance.

According to the first law of thermodynamics, the characteristics of a heat accumulator in an open system with a constant chemical composition depend on mass, volume, pressure, enthalpy, and the internal energy of the material, as well as their various combined transformations.

Technical and practical methods of heat accumulation can be divided into the following:

a) direct heat accumulation - the accumulating material is simultaneously a heat carrier;

b) indirect heat accumulation - the heat-accumulating and heat-transferring media are different;

c) various combinations of the listed methods.

The change in enthalpy of HAM can occur with or without a change in its temperature (during phase transformations).

Existing technologies allow for the implementation of any known method of heat accumulation. The expediency of using any method is determined by its positive effect. First of all, economic efficiency is achieved, that is, the lowest cost of the battery. This, with other equal conditions, is determined by the mass and volume necessary to ensure the given parameters of the process.

In the real process of heat accumulation, the accumulated energy density is significantly lower than the theoretical value (due to heat loss, temperature field equalization, and losses during charging and discharging). The ratio of the actual and theoretical values of the accumulated energy density determines the efficiency of the heat accumulator. One of the important indicators determining the possibility and expediency of heat accumulation is the ability to release the necessary amount of energy to the consumer. In the case of direct heat accumulation, this requirement is always met. The performance of such batteries does not depend much on the output power, which is determined by the consumption of HAM and is limited only by the requirements for design and strength.

With an increase in the power released during indirect accumulation, the temperature gradient and HAM increase, which leads either to an increase in the heat exchange surface or to incomplete utilization of the accumulated heat. In any case, this property reduces the battery's efficiency.

Liquid heat accumulators.

Liquid heat accumulators (HA) are considered the simplest and most reliable heat-accumulating devices because in them, the functions of heat-accumulating material and heat carrier are performed by the liquid.

Liquid HA is performed in several main structural variants.

During the charging process, one housing is filled with hot HAM, and the other is emptied. During operation, the hot HAM is transferred to the consumer, and after use, the cold HAM is filled into the housing. The main advantage of such HAs is the isothermal nature of each housing,

which eliminates thermal stresses and heat losses during heating and cooling.

At the same time, it is inevitable that the volume of the housing is used inefficiently and is almost twice the volume of the HAM. In cases where the difference between hot and cold temperatures of HAMs is large, the use of such HAs is advisable, especially when using salt HAMs and liquid metals. Main types of liquid HA figure-2.3.

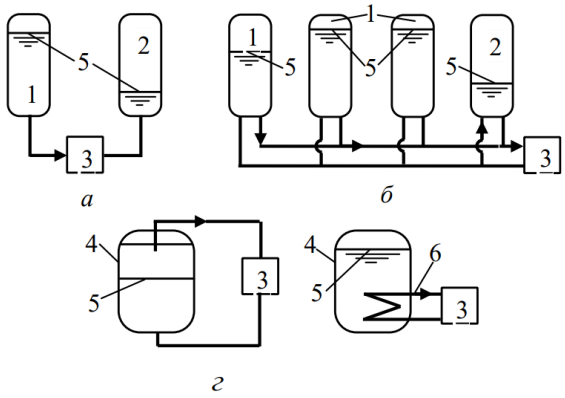


Figure 2.3. Main types of liquid HA (main arrows are shown in discharge mode).

a-two-body; b-multi-body; c-with displacement; d-with sliding temperature; 1-hot HAM; 2-cold HAM; 3 - consumer; 4 - single housing; 5 - liquid level; 6-intermediate heat carrier.

In order to optimize the use of battery capacity, multi-body options have been proposed, in which several bodies are filled with hot HAM and one is empty (cold) (Fig. 2.3, b). During the charging process, the empty housing is filled first, and then, as the hot housing is emptied, it is filled. This process leads to the appearance of thermal stresses and heating losses in all bodies (except for one).

When using a single housing filled with hot HAM at the beginning of the process, the volume of the heat accumulator is used most optimally

(Fig. 2.3, c). During operation, hot HAM is taken from the upper part of the HA, and the used cold HAM is sent down the HA. Such liquid in batteries is called a displacement. Due to the difference in the density of hot and cold liquids, their mixing can be minimal (the “thermal bubble” effect). The efficiency of the exhaust fuel assembly decreases due to thermal conductivity and mixing between the volumes of hot and cold fuel assemblies, heating of the housing, and other heat losses. This type of HA is used for liquids with a large coefficient of linear expansion.

Slide-temperature batteries are used when the HAM has special properties or when it is acceptable for the consumer to use the HAM as a heat carrier (Fig. 2.3, g). In this case, the intermediate heat exchanger HA can be placed inside or outside the housing. During the charging process, an intermediate heat carrier or electrical energy is used to heat the HA.

In the cooling process, heat removal is carried out through an intermediate heat exchanger. One of the characteristic examples of such HA is the “solar pool.” In this case, the release of HAM disrupts the reverse gradient of salinity of the water, therefore, the release of HAM is inappropriate.

The design of a liquid heat accumulator is largely determined by the properties of the heat-accumulating materials. Currently, water and salt solutions, high-temperature organic and silicon-organic heat carriers, salt and metal solutions are most widely used.

In the range of operating temperatures from 0 to 100 °C, water is considered the best liquid HAM in terms of a complex of thermal and physical properties, as well as economic indicators. Increasing the working temperature of the water significantly increases the pressure,

which complicates the design of the housing and increases its cost. Various high-temperature heat carriers are used to ensure low operating pressures of HAMs. In such cases, the following problems arise: selecting the structural material of the heat accumulator and the entire system, using special devices, preventing the hardening of the HAM in operating modes, tightly sealing the HA, etc. In addition, the most widespread use of exhaust fuels is associated with a complex of constructive and operational measures that ensure minimal energy losses. In order to reduce losses due to the mixing of hot and cold HAM volumes, various devices are used that reduce the flow rate of the liquid in the short inlet and outlet pipes to a few centimeters per second and ensure a uniform distribution of the HAM across the battery cross-section.

In residential buildings, water accumulators can be used as daily batteries. A daily water battery is placed inside the building, including the possibility of installing it in the walls between rooms. The battery is in the form of a hollow wall, inside which are tanks filled with water.

Smoke from the furnace passes through these tanks and heats the water in the tank. In addition to the furnace, solar air heating and solar water heating systems can be used for heating water batteries. The external thermal insulation of the accumulator (wood, brick, aerated concrete, etc.) serves to reduce the temperature of the heated surfaces to approximately 40°C. To maintain an optimal temperature in the room, thermal insulation ensures the slow cooling of the storage tank**.**

Table-2.1

Thermal-physical properties of liquid HAMs.

HAM	Temperature, K			Density, 10^3 kg/m^3	Specific heat capacity, Dj/(kg K)	Coefficient	
	hardening	maximum	boiling			Thermal conductivity, Vt/m K	Viscosity, 10^{-6} Pa s
Water at a pressure of 0.1 MPa	273	373	373	1	4,19	0,67	5,5
Tetrachlorordephinyl	266		613	1,44	2,1	0,17	1000
Diphenyl mixture	285	673	531	0,95		0,12-0,08	
Polymethylsiloxane	213	593		0,9	1,5	0,1-0,14	5-20
Lithium	455	1600	1623	0,48	4,36	52-66	8-13
Natrium	371	1150	1155	0,8	1,33	52-75	14-22

Heat accumulators with a solid heat-accumulating material. Solid-state heat accumulators are currently the most common. First of all, this is due to the use of cheap materials, simple and proven technical solutions.The cheapest materials are used as HAM: gravel, feolite (iron ore), construction material residues, etc.

Usually, thermal accumulators with stationary and movable matrices (molds) are considered. When using stationary matrices, the maximum simplicity of the design is ensured, but large-mass HAMs are required. In addition, the temperature of the heat carrier at the outlet changes over time, which requires additional systems for maintaining constant parameters by the transfer method. Currently, technical solutions for such batteries with several characteristic features are being considered (Figure 2.4).

Batteries with a porous matrix are mainly used in many solar heating systems (Fig. 2.4a). Such HA is usually designed with minimal hydraulic resistance, which allows the use of free-convective exchange processes. During charging, the hot gas is pumped to the upper part of HA, which cools down. During the discharge period, the cold gas HA enters from the bottom, is heated, and exits from the top. Thus, it is possible to design a heat supply system that requires only a heat energy source.

Channel HAs are widely used in electrical heating systems that use non-peaked electrical energy (Fig. 2.5b, c)

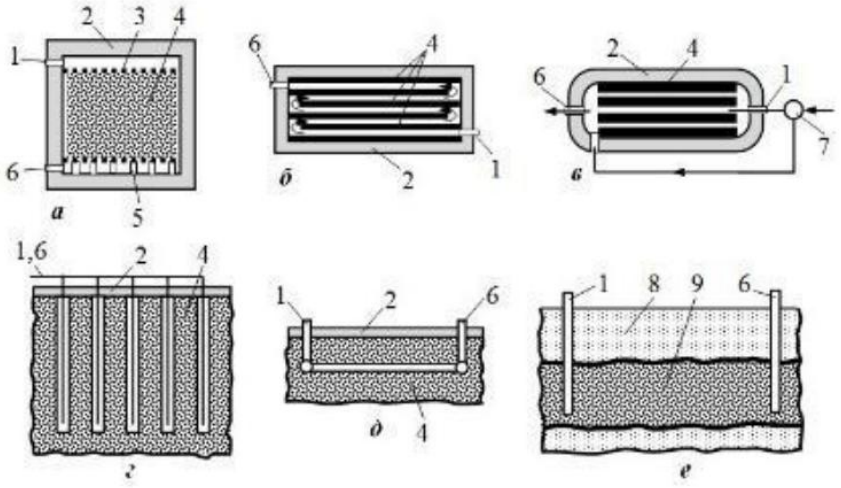


Figure 2.4. The main types of HA with a solid HAM are:

a - with a porous matrix; b, c - with channels; d, e - with vertical and horizontal underground channels; f - in the aquifer;

1 - inlet of the heat carrier; 2 - thermal insulation; 3 - dividing grate; 4 - HAM; 5 - supports; 6 - heat carrier output; 7-separation of flows; 8 - waterproof layer; 9 - water-retaining layer.

During the period of minimum electricity consumption, the heat-accumulating material (chamotte, refractory brick, etc.) is heated, which allows smoothing the load graphs of power plants. In the process of

passing through the matrix, heating of the rooms is carried out with heated air. Heat-graphite batteries are solid-state heat exchangers with a special type of channel and are used as an energy source in autonomous power plants. Their heating temperature can be up to 3000 K, which ensures good mass and overall characteristics.

Heat accumulators with underground vertical channels are usually used for storing seasonal heat. The length of a single channel can be up to one hundred meters, and the total energy volume can be up to a thousand kilowatt-hours.

Heat accumulators with underground horizontal channels are used for heat accumulation for several months. Heat accumulators with a movable matrix are usually made in the form of a rotating regenerator, a falling ball structure, etc. Such batteries are used in heat energy regeneration devices and have small dimensions due to short working cycles. At the outlet of the gas with a movable matrix IA, it is possible to maintain a constant temperature. The main characteristics of the most widely used rigid HAMs are presented in Table 2.2.

Table-2.2
Basic properties of solid HAMs.

HAM	Temperature, °C	Density, kg/m^3	Specific heat capacity, kDj/(kg K)	Coefficients	
				Thermal conductivity, Vt/m K	Temperature conductivity, 10^{-6} m^2/s
Gravel	400	2500-2800	0,92	2,2-3,5	0,8-1,5
Feolite	400	3900	0,92	2,1	2,5

Concrete	400	1900-2000	0,84	1,2-1,3	0,76
Chamotte	1700	1830-2200	1,1-1,3	0,6-1,3	0,21-0,65
Graphite	3500	1600-2000	2,0	40-170	12-54
Red brick	1000	1700-1800	0,88	0,7-0,8	0,5
Sand		1460-1600	0,8-1,5	0,3-0,2	

To reduce the amplitude of oscillations of the cold gas temperature, several simultaneously operating batteries are used, discharged into a common channel. In this case, the amplitude of oscillations decreases proportionally to the number of operating HAs. To maintain a constant gas temperature, their number must be infinite, which is achieved in a rotating regenerator.

Thermal accumulators based on phase transitions.

When using melting heat for heat accumulation, a high density of stored energy and a stable temperature of the HA at the outlet are ensured with a small temperature difference. However, most HAMs in molten state are corrosive active substances, mainly have low thermal conductivity, change volume during melting, and are relatively expensive. Currently, many substances that provide accumulation temperatures from 0 to 1400 °C are known. It should be noted that the widespread use of HA with melting media is primarily limited by the economic considerations of the devices being created. At operating temperatures up to 120°C, the use of crystal hydride inorganic salts is recommended, since this is primarily associated with the use of natural substances as HAMs. The disadvantages of crystal hydrates include their high corrosive activity.

Table 2.3

Basic properties of HAMs based on crystal hydrides

Material	Pure salt				Working mixture				Mineral raw materials
	Ter, S	Q_{er}, kDj/kg	ρ_{qb},10^3 kg/m^3	ρ_{su}, 10^3 kg/m^3	IAM, %	Suv, %	Ter, °C	Q_{er}, kDj/kg	
$CaCl \cdot 6H_2O$	29,7	170	1,71	1,52					
$Na_2SO_4 \cdot 10H_2O$	32,4	251	1,46	1,48	68,2	31,8	31	244	Glauber salt
$Na_2SO_4 \cdot 5H_2O$	48	210	1,6						Hyposulfide
$CH_3COONa \cdot 3H_2O$	58,2	260	1,45		90-95	10-5	52-58	290-20	
$MgCl2 \cdot 6H_2O$	116	165	1,57						Bischofite

The use of organic substances practically completely solves the problems of corrosion destruction of the housing, ensures high energy density and positive economic indicators. Methods of surface treatment of organic substances developed up to this period (crafts - polymerization - transformation, etc.) allow the creation of structures without clearly visible heat exchange surfaces. However, when organic substances are used, a decrease in the heat of fusion occurs due to the destruction of long chains of polymer molecules. The use of organic materials requires

developed mass transfer surfaces due to the low thermal conductivity coefficient of the IAM.

Table 2.4

Basic properties of organic soluble HAMs

Material	Melting point, K	Heat of fusion, Q, kDj/kg	Specific heat capacity kDj/(kg K)	Density, kg/m^3		Coefficient	
				ρqt	ρsu	Thermal conductivity, Vt/(m K)	Viscosity, 10^{-3} Pa s
Polyethylene glycol	293-298	146	2,26		1100	0,16	11,5
Octadecane	301	244	2,18	744		0,15	3,9
Paraffin 46-48	320	209	2,18	800		0,34	3
Naphthalene	353			1170		0,8	
Acetamine	355			1160			

At high operating temperatures, light metal compounds and alloys are usually used. The low thermal conductivity coefficient of metallic compounds, corrosive activity, and volumetric changes during melting are significant disadvantages.

Heat accumulators, energy storage devices used for storing heat or cold. These batteries can store energy by converting electrical energy into heat and, if necessary, convert it back into electrical energy.

Heat accumulators can be used in heat-intensive processes, such as in houses, commercial buildings, and industrial facilities. In addition, it can be used in the assembly of new energy sources.

Heat accumulators should typically consist of a closed metal tank located in a thermal reserve, a heat exchange material, and a temperature control device. Stored thermal energy is monitored using a temperature control device and recovered when required.

Thermal batteries are used from an economic perspective due to their greater energy capacity compared to other energy storage devices and their long-term applicability. However, due to high prices, it is not yet widespread.

Due to the high financial burden on heat accumulators, they are not yet more widespread. This situation can change by supporting important economic cooperation in the field of energy storage and its reuse.

Heat accumulators are ideal for high-processing and pleasant heat-intensive processing. At the same time, they are very valuable and economical in themselves, being used in conjunction with alternative energy sources. And for good enterprises, it can be used not only as a leader, but also through the protection of the socio-environmental system.

Thermal accumulators, energy-carrying systems, and operating systems are important areas of development, the development and use of which will reduce external conflicts in the field of energy processing in the future.

The development of heat accumulators is accompanied by technological innovations and the introduction of reformed technological additives. This will allow their prices to decrease and be used more in the future.

Heat accumulators, through the development of cooperation and joint work, will occupy their place in the field of energy storage and use in the

future, primarily through the development of interaction. This provides many opportunities for the development of conveniences, energy storage, improvement of operating systems, and energy production.

Heat accumulators are ideal not only for storing energy but also for various heat-intensive processes. This opens the way for improving the energy consequences, energy efficiency, and operating systems that include them.

Heat accumulators require large payments for large-scale construction and production, but they have great potential for development in the future. This includes indicators of direct impact on the commissioning of operating systems, optimization of heat and cold requirements, energy storage and its reuse, and many others.

The large-scale creation of heat accumulators and their integration with interaction and additional innovations will contribute to the improvement of future functioning systems for storing and using energy. This will increase energy security, protect the socio-ecological system, and raise energy storage and reuse to key indicators.

The largest of heat accumulators in the future could lead to improvements in operating systems and increase energy storage. This increases various amenities, energy security, and reduces comfort and investment costs. The development of heat accumulators and their development is the first indicator of energy consumption for all future operating systems. The strong thermal effects of heat accumulators, high prices, and large investments for their inclusion indicate that they need to be developed through mutual cooperation and innovation. Such

development facilitates the storage and use of energy for all industries and paves the way for important indicators of energy in the future.

Including the possibility of storing and using thermal energy, heat accumulators become convenient and cost-effective energy systems for large corporations, businesses, and other entrepreneurs. At the same time, it opens the way for them to protect the socio-ecological system, increase energy security, and increase energy storage and reuse.

Control questions.

1. What types of heat accumulations exist?
2. What do you know about heat accumulation?
3. Explain the concept of heat accumulators based on phase transitions.

2.2. Energy harvesting using pumped storage power plants

The first hydro-storage power plant (HAPP) will be built in Uzbekistan in cooperation with the French company EDF. This was announced at a meeting on April 14 between the management of JSC “Uzbekgidroenergo” and responsible representatives of EDF, the largest producer of electricity in France. The design capacity of the Khojakent HPP, which is planned to be built in the Bostanlyk district of the Tashkent region, is 200 MW.

A hydroelectric power station (HPP) is a complex of hydraulic structures and energy equipment that converts the energy of water flow into electrical energy using hydraulic turbines. Hydraulic structures are divided into dam-side, derivation, and mixed types. At hydroelectric

power plants near the dam, the water level is raised using the dam to create the necessary pressure.

The HPP building is located in 3 ways:

1) near the dam;

2) away from the dam;

3) below the dam, in the riverbed.

In hydroelectric power plants built near dams and in riverbeds, water pressure is generated by dams. Such hydroelectric power stations are built on mountain rivers with high water levels and even flow, in places where ravines narrow. These include the Kayrakkum, Tuyamuyun, and Chardara HPPs. Derivation hydroelectric power plants (where water is supplied to the station node of the hydroelectric power plant through pipelines, channels, or tunnels) are medium and high-pressure, and the pressure is generated using a derivation channel. Such HPPs include the Charvak, Farhad, and Bozsu Canal HPPs. In mixed hydroelectric power plants, pressure is mainly generated by hydraulic structures on the river and partially by the derivation channel. The complex of HPP structures includes the main structure (dam) that creates pressure by blocking the riverbed, the canal supplying water to the HPP building, the station pressure unit (PSU) or pressure water pipeline, structures consisting of automatic devices for regulating water level and flow, removing excess water (etc.), a machine hall with a hydraulic unit (turbine and generator) that directly converts water energy into electrical energy, and structures for removing used water. Electrical energy is generated as a result of the rotation of the turbine’s impeller, the shaft installed on it, and the generator connected to the shaft by water supplied to the turbines of

hydroelectric power plants by special hydraulic structures. Electricity is supplied to consumers by means of special devices. Currently, the operation of all hydroelectric power plants is automated. Several automated hydroelectric power stations are controlled remotely (from a neighboring hydroelectric power station or from a power system control panel). Based on the installed capacity of HPPs, they are divided into low (up to 5 MW), medium (5-25 MW), and high (over 25 MW) capacities. To more fully utilize the river's energy resources, hydroelectric power plants are arranged in a cascade, i.e., at a certain distance along the river's flow. Such cascades of hydroelectric power plants include the Tashkent (Bozsuv, Bo'rijar, Oqtepa, Shayxontohur HPP); Qodriya (Qodriya, Qibray, Salar, Oqqovoq-2); Chirchiq (Tovoqsoy, Oqqovoq); Quyi Bozsuv (HPP-14, HPP-18, HPP-19, HPP-22, HPP-23); Middle Chirchiq (Chorvoq, Hojikent, Gazalkent); Shahrixon (HPP5A, HPP-6A, HPP-YUFK-1, HPP-4A YUFK-3); Samarkand (HPP-1B, HPP2B, HPP-ZB, HPP-5B) HPP cascades. Among HPPs, hydro-accumulating power plants (HAPP) and uplift hydroelectric power plants (PES) hold a special place. Hydroelectric power plants are built in large energy systems to replenish energy during peak periods. The energy-accumulating property of a hydroelectric power plant is based on the use of electrical energy, which is available at a certain time interval in the energy system. During this time, the hydroelectric power station operates in pump mode, pumping water from the lower pool to the upper pool; during peak hours, it generates electricity from the collected water. As a result of the attraction of water by the gravitational forces of the Moon and the Sun, the level of sea or ocean water rises and falls twice a day. The PES converts the energy

of this rising water into electrical energy. There is no significant difference in electricity generation. A separate HPP or cascade of HPPs, as a rule, operates in the same system as a condensing power plant (CPP), a thermal power plant (TPP), a nuclear power plant (NPP). In this case, depending on its participation in covering the load graph in the power system, the HPP can be base-based, operating during high-energy (peak) times. Along with providing electricity, hydroelectric power plants protect the riverbed from turbidity and allow irrigation of many sown areas.

Hydro-accumulating power plant. Pump-storage power plant - a hydroelectric power plant that converts (accumulates) electrical energy from other power plants into the potential energy of water, and then, if necessary, converts it back into electrical energy, transferring it to an energy system (energy system). The hydraulic structures of the hydroelectric power plant mainly consist of two high-altitude reservoirs and connecting pipelines. Hydraulic units in the HAPP building can be three- or two-machine. In the first case, an electric machine (engine-generator), a hydroturbine, and a pump are mounted on one shaft, and in the second case, an electric machine and a hydraulic machine. Depending on the direction of rotation, the hydraulic machine works as both a pump and a turbine. Newly constructed hydroelectric power plants will be equipped with economically efficient two-machine units. When there is an excess of electricity in the electrical networks (respectively, at night), this excess energy is used to raise water for the hydroelectric power plant from the lower pool to the upper, accumulating pool. When more energy is required in electrical networks, water from the upper pool is sent from

the pipes to the turbine-operating hydraulic units of the hydroelectric power plant. The current obtained at the hydroelectric power plant is returned to the electrical networks. The water collects in the lower pool. The amount of accumulated electricity depends on the volume of the reservoir and the operating pressure of the hydroelectric power plant. The upper pool can be artificial or natural (lake); the lower one can be a reservoir formed on a dam installed on a river. F.I.C. of the HAPP does not exceed 0.66. Nuclear power plants have been built in the USA, England, Germany, Austria, France, Japan, Russia, and other countries. In a few minutes, it is possible to start the hydroelectric power station and change the operating modes.

The main function of a hydroelectric power station is to collect water energy using pumps installed on it and use it to generate electricity when necessary. As is known, most thermal power plants (including nuclear power plants abroad) are currently used to generate electricity. In our republic, thermal power plants (TPPs) produce 82-85% of all energy.

One of the features of the operating mode of thermal power plants is that their nominal (installed) capacity differs significantly from the minimum required capacity at night. Therefore, at night, it is necessary to reduce the capacity of the TPP to 25-50%, and to completely shut down some units. This has many negative aspects, for example, frequent stopping and starting of units, changing their power leads to equipment malfunction, premature failure.

Hydroelectric power plants (HPPs) are significantly cheaper, more efficient, and more promising than other devices performing the same function (gas turbine, steam-gas turbine). In some cases, a hydroelectric

power station can participate not only in the daily distribution of energy, but also in the weekly accumulation of energy.

In this case, water energy is accumulated on two days off (days with low energy consumption), and for the remaining five days it is used for the production of electricity.

The following class groups of HAPP exist.

1. By pressure value - low pressure (N≤100m), medium pressure (N=100-700m), high pressure (N≥700m)
2. By type of installation - pure HPP, HPP-HPP, HPP-NS
3. Diagram of the location of the HAPP building along the pipeline - located at the beginning, located in the middle, located at the end.
4. By the number of reservoirs where water is collected - single-reservoir, two-reservoir, three-reservoir.
5. By building type-above ground, underground, semi-underground.
6. According to the unit scheme - two-machine, three-machine, and four-machine.

Basic diagrams of hydroelectric power plants.

• As mentioned above, by device type, HAPP can have schemes such as pure, HPP-HAPP, HPP-NS.

• Pure HAPP, or simply accumulation.

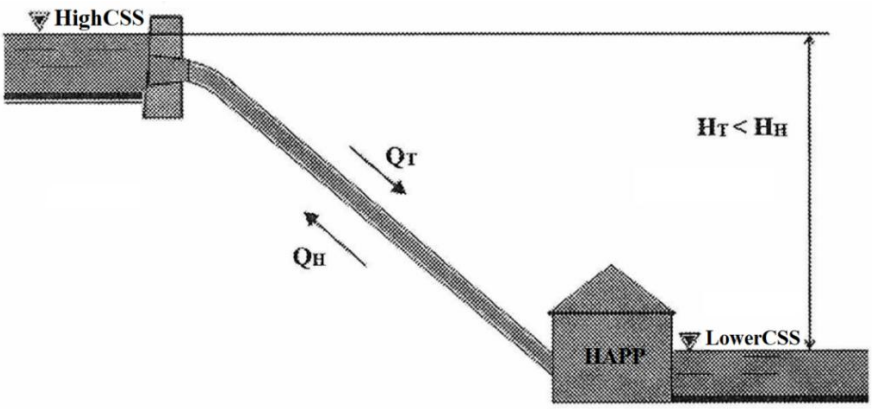


Figure 2.5. Diagram of a pure HAPP.

This scheme is the most widespread scheme, where water circulation in the device is carried out by pumping it into the upper basin using pumps installed in it and transferring it from there to the lower basin through turbines.

One of the features of this scheme is that the upper basin is not supplied with water from another source. A smaller volume of water used for filtration is filled in the lower reach. According to the 40 HPP - HPP scheme, in addition to conventional units, additional energy-generating turbines are installed in the HPP building in the HPP mode. These turbines operate at the expense of the additional amount of water flowing into the upper water body (Fig. 2.6).

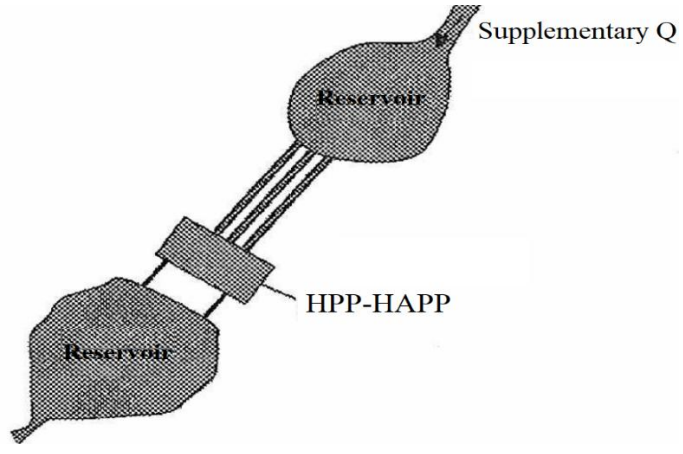


Figure 2.6. HPP-HAPP diagram.

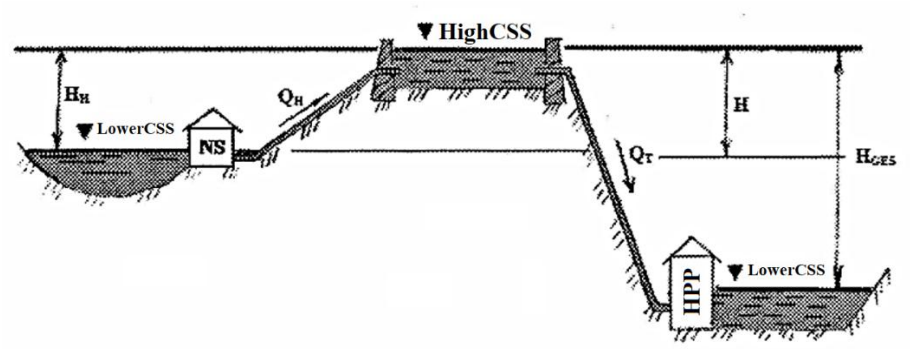


Figure 2.7. HPP-PS diagram.

In the HPP-PS scheme, in addition to the two traditional reservoirs, the third reservoir also participates in energy production (Figure 2.7). For this purpose, a certain amount of water is transferred from the upper body of water to a third, higher body of water using an PS.

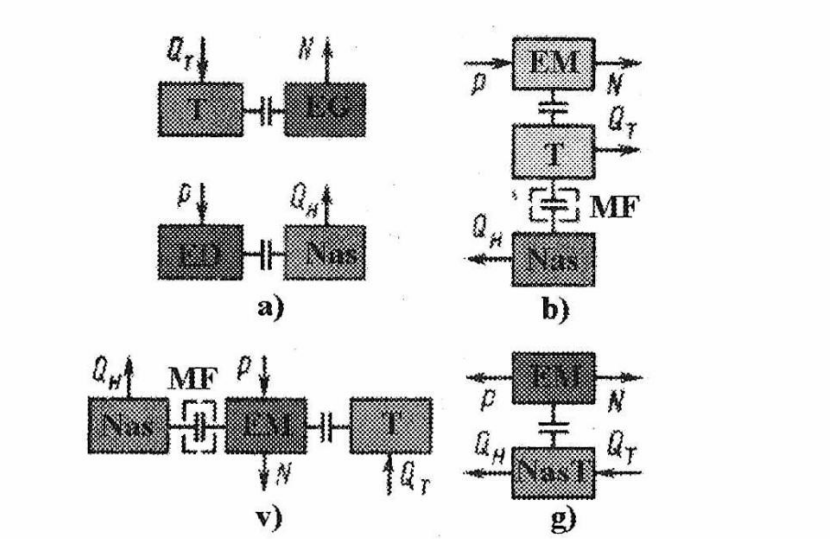


Figure 2.8. Diagram of HAPP units.

a - separate four-machine; b) and d) three-machine (vertical and horizontal); g - two-machine; EH - synchronous electric machine (hydrogenerator); E D - electric motor; EM - synchronous electric machine (engine-generator); T - hydroturbine; Pump; NasT - pump turbine; SC - special coupling; Qr - turbine flow rate; Qn - pump flow rate; N - generated capacity; P - consumed power.

2.3. Main parameters of the HAPP

The main parameters of a HAPP plant are its head, capacity, daily electricity production, and efficiency.

HAPP pressure. The difference between the upstream water level and the downstream water level is called the geometric head. The total head of a hydroelectric power plant is called its geometric head. The total head of a hydroelectric power plant depends on its geometric head and the value of head loss in the pipelines. The value of the total head in pump mode is greater than in turbine mode, i.e.

The main parameters of the HAPP are its head, power, daily electricity production, and efficiency.

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The reason for this can be seen from the formulas for determining the total head of the pumping station and HAPP, $H_p=H^G +\Sigma\Delta h_k$ va $H_{tur} = H^G - \Sigma\Delta h_k$.

HAPP capacity. The power value depends on the flow rate of water passing through the unit and the pressure value. At night, during the time T, pumping units operate with a water discharge Q_h and consume power $N_{P.M.}$ During peak hours, the turbine reaches $N_{T.M}$ power.

$$N_{P.M} = \frac{\rho \cdot g \cdot Q_N \cdot H_N}{\eta_{PM}}; \text{ Vt} \qquad (2.2)$$

Here η_{PM} - pump mode HAPP efficiency coefficient (EWC).

HAPP, as noted, Q_p= (0,75....0,8) Q_t, The head values, as shown above, are: $H_p > H_t$ Therefore, the power values in both modes are different.

$$N_{N.R} = \frac{\rho \cdot g \cdot Q_T \cdot H_T}{\eta_{TR}}; \text{ Vt} \quad (2.3)$$

In this, η_{TM} - turbine mode EWC

The amount of energy produced by the HAPP per day is determined in the following order:

$$E_{T.M}=N_T \cdot T_T = \frac{V \cdot H_T \cdot \eta_{TM}}{367}; \text{ kVt·hour} \quad (2.4)$$

Here, V - volume of water used in turbine mode in the upper basin,m^3; H_T - average turbine head, m; η_{TR}- - turbine mode; N_T - installed power of the HAPP in turbine mode, kVt. T_T - the time spent by the hydroelectric power plant on the production of electricity per day, in hours t) η_{TM} = 0,86...0,87 It is indicated that T_T= 3....5 hours.

HAPP Efficiency. HAPP EWC is determined depending on the values of generated and consumed electrical energy.

$$\eta = \frac{E_{TM}}{E_{PM}}; \quad (2.5)$$

Here E_{PM} - electricity consumed in pump mode, (kWh).

$$E_{P.M}=P_P \cdot T_P = \frac{V \cdot H_P}{367 \cdot \eta_{PM}}; \quad (2.6)$$

Here, P_P - installed capacity of the HAPP in pumping mode, kVt; T_p - HAPP operating time in pump mode per day, hours.

In modern large HAPPs, the efficiency value is 75-78%. The efficiency of HAPPs depends on many other factors.

Control questions.

1. Name the types of HPPs.
2. What do you understand by the term HAPP?
3. Name the efficiency coefficients of HAPP.

2.4. Construction of a solar greenhouse with a heat accumulator and water heater, operating modes

One of the solar installations using accumulated solar energy is a solar greenhouse. At one time, various types of heat accumulators were proposed for solar greenhouses. It is heated using solar energy, and in this battery, the air heated by daytime solar energy is pumped through channels drawn from the soil heap on the north side of the greenhouse, and heat is collected.

At Karshi State University, T.A. Sadikov developed two versions of solar greenhouses with heat accumulators in the 1960s-1970s. The first experimental variant, equipped with a whetstone battery, is oriented southward. Its cross-section is shown in Figure 2.9

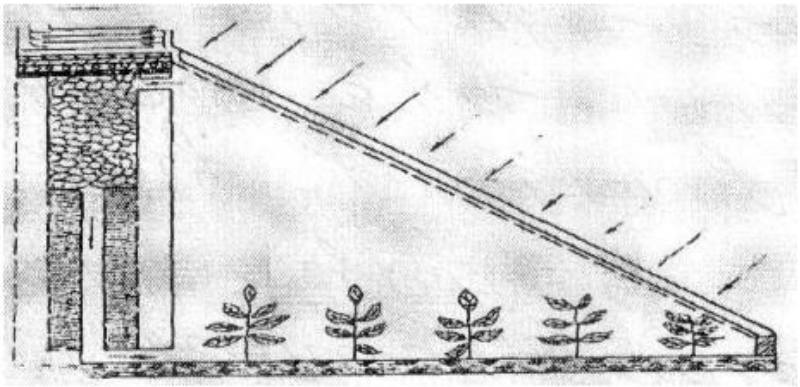


Figure 2.9. Diagram of the cross-section of a whetstone heat accumulator.

The area of the useful part of the solar greenhouse occupied by the battery is 3.7 m x 7 m = 26 m^2. The area intended for production is taken as 3.7m x 65m = 240m^2. The heat accumulator consists of a chamber measuring 0.3m x 1m x 6.5m, divided into three sections and filled with crushed stone. In the accumulator, the hot air from the greenhouse passes through the upper channel into the chamber, gives heat to the grindstones, and, cooled, passes through the lower opening back into the greenhouse. At night, the air moves in the opposite direction. Cold air passes through the lower opening into the chamber, where it warms up and passes through the upper opening back into the greenhouse. Due to the insufficient amount of accumulated substance in the chamber, its accumulation capacity is low, and the main part of the heat is concentrated in the greenhouse soil, structural elements, walls, and plants. A water battery was also tested in the solar greenhouse. For this, a tank with a volume of 0.25 x 1 x 2 m is made, water is poured into it, and the water tank is placed at a height of 1 m in front of the greenhouse wall. When the water battery was working, the flint battery didn’t work. Experiments have shown that an accumulator with water accumulates more energy than an accumulator with a whetstone, and the air temperature amplitude decreases.

T.A. Sadykov conducted research on the use of a soil accumulator in solar greenhouses, and soil shelves were placed on the north side of the solar greenhouse as a heat accumulator.

The cross-section of this solar greenhouse is shown in Figure 2.10. Total accumulating volume of soil

$V=F\times h\times n=13m^2\times 0.25m\times 5=12m^3$

where: F - surface area of each accumulating layer; h - soil thickness; n - layers;

However, there will be difficulties in constructing and operating such solar greenhouses with soil and water accumulators in large working areas.

In recent years, scientists of the Scientific Production Association “Quyosh” of the Turkmen Academy of Sciences have developed and tested designs of water and soil accumulators for single-slope solar greenhouses. The transparent surfaces of these greenhouses were oriented in such a way as to ensure the passage of the largest amount of solar energy in winter and early spring. Under the influence of solar energy entering the greenhouse, the air temperature rises and circulates through natural convection.

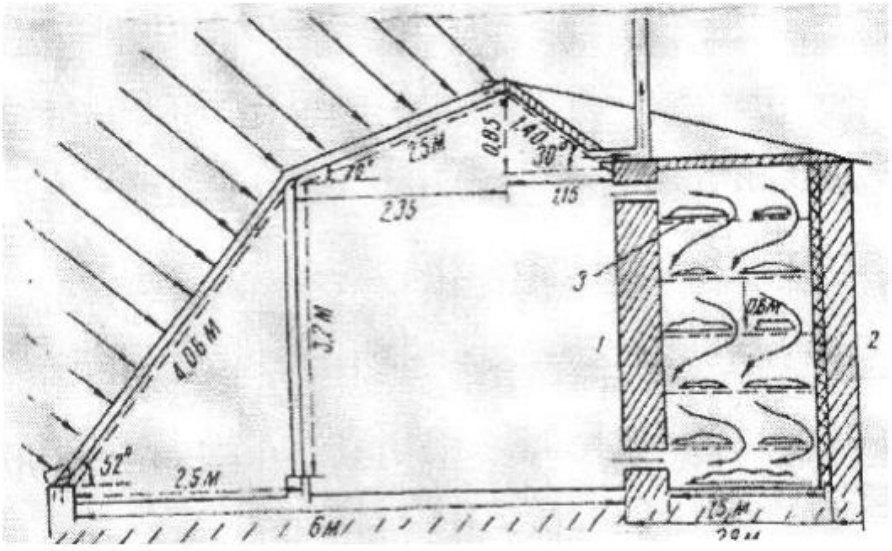


Figure 2.10. Diagram of the cross-section of a solar greenhouse with a soil accumulator, developed and experimentally tested by T.A. Sadykov.

As hot air passes through the moist soil layers located on the northern side of the greenhouse, it accumulates during the day, and at night, this accumulated heat ensures normal air temperature inside solar greenhouses. To ensure maximum energy transfer and accumulation in the solar greenhouse under construction in the conditions of Turkmenistan, the optimal dimensions of the structure were determined experimentally.

In 1971, a soil-accumulator greenhouse developed by L. Rybakova and A. Mezilov with a single slope, clear surface with an inclination to the horizon of 450 and a working area of 100 m^2 was tested. In this solar greenhouse, solar energy is stored in soil accumulators and in the soil, walls, plants, and structural elements of the greenhouse.

With the help of special calculations, the optimal size of the soil-bearing heat accumulator, in which the maximum energy can be accumulated, was determined. In this case, using E. Schmidt's method of extreme differences, the passage of temperature waves in the surface layer of soil heat accumulators was calculated, taking into account the constant change and absorption of solar energy in the air temperature inside the solar greenhouse. From an economic point of view, the construction and commissioning of such solar greenhouses will bring good benefits to small farms.

As a result of scientific research, the optimal design dimensions of a solar greenhouse with a soil accumulator were determined: width l = 10.0 m, height h = 5.0 m, inclination of the transparent solar surface relative to the horizon $a_x = 45^0$, inclination of the transparent surface relative to the horizon $a_c = 20^0$. Also, the second option of a solar greenhouse: optimal

length l = 11.0 m, height h = 5.0 m and slopes of the main and additional surfaces relative to the horizon a = 45^0, $a_c = 20^0$.

On the north side of the greenhouse with a soil accumulator, boxes with moist soil 1 m long and 0.25 m thick are placed in 15 rows at a distance of 0.40 m from each other.

In such solar greenhouses, the energy stored during the day is used at night. On continuous cloudy days, a backup is used as an additional energy source. For $1m^2$ of such a solar greenhouse, the volume of a heat accumulator with moist soil should be equal to $0.18m^3$ or $0.15m^3$ when using a water accumulator.

In recent years, scientists have developed the optimal design of a solar greenhouse-water desalinator for desert zones with a working area of 1000 m^2. The transparent surface of this device consists of a single layer of glass, fresh water is collected in concrete water pools located at the bottom of the slopes on the sides.

In the conditions of Turkmenistan, the average annual output of this solar greenhouse-water desalinator is 770 l/m^2, with an area of 1 hectare, it is possible to obtain 1000 m^3 of desalinated water per year. Such a solar greenhouse, along with high economic efficiency, allows saving 150 thousand m^3 of water per year. In 1965-1970, D. Bayramov developed and tested the design of an experimental helio-greenhouse with a water basin. Y. Yakubov checked the heat accumulators of the chamber installed north of the solar greenhouses, dividing them into several stages.

The first stage: in March and April, concrete, raw and fired bricks with different heat capacities were used. He checked how much heat accumulates during this season.

Experiments show that as a result of the accumulation of baked bricks, the temperature of the internal air is 2-3°C higher than the heat accumulated in other materials.

The second stage: the experiment was conducted in July-August, and shelves with baked bricks and sand in heat accumulators were replaced with concrete with tank water. Under the same external conditions, compared to batteries made of sand and raw brick, when using a water battery, the air temperature varied by 8-10°C during the day and 7-10°C at night. This shows that accumulating solar energy in water with high heat capacity yields good results.

The third stage: the experiment is conducted in May and the amount of heat accumulated in heat accumulators is studied depending on the location of the accumulator chamber. In this case, raw brick heat accumulators were prepared, and a special gap was left between them.

The fourth stage: the experiment was conducted in July and the heat accumulators of the raw brick wall and underground canal were checked. Experiments have shown that it is advisable to use raw bricks and water accumulators for single-slope greenhouses. In 1977-1978, a solar greenhouse with a heat accumulator made of raw brick with a working area of 25x6=150m^2 and an accumulation coefficient of P-0.7 was built and tested at the “Madaniyat” farm in Bukhara district. In the heat accumulator of this solar greenhouse, the brick thicknesses are 6, 9, 12, 15, 18. They were placed in sizes of 21, 24, 27, and 30 sm.

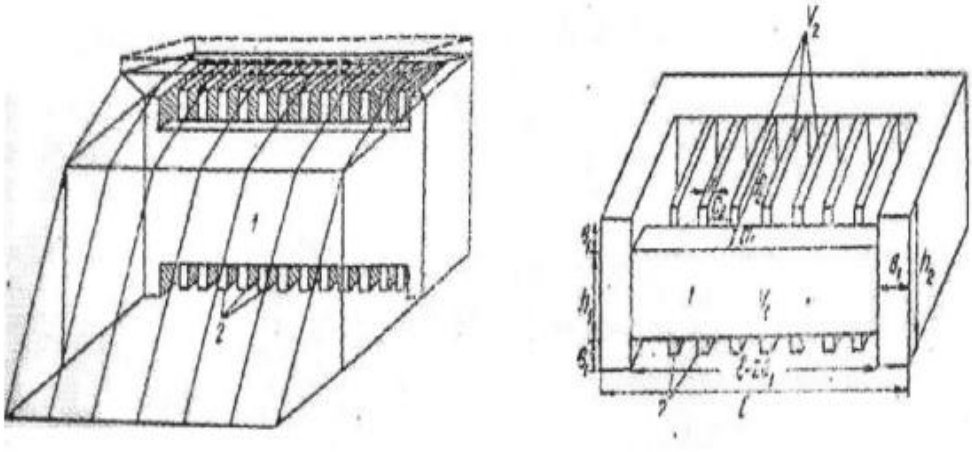


Figure 2.11. Cross-sectional diagram of a solar greenhouse with a single-slope brick battery.

The conducted experiments showed that the temperature of the surface and center of the heat accumulator, tx/2, and the temperature of the heat carrier air tf, the temperature of the air entering the accumulator, tyu, the temperature of the air exiting, tn, are parameters characterizing the maximum amount of energy stored in the heat accumulators.

Scientists of the Physical-Technical Institute (PTI) of the Academy of Sciences of Uzbekistan have developed the next version of an improved solar greenhouse. In this variant, the heat accumulators are located under the soils of the solar greenhouse. Using whetstone as an accumulating substance, air circulation through it was carried out using special fans. PTI scientists estimate that such underground heat accumulators retain 55 percent of the heat, while electricity costs accounted for only 20 percent of the heat generated from solar energy.

On the other hand, the advantage of such accumulators lies in the fact that they have favorable conditions for the development of plant root systems. However, building such solar greenhouses over large areas requires significant effort to deliver and place a large quantity of crushed

stone. Scientists from developed foreign countries have developed a number of solar greenhouse designs, the cross-sectional diagram of which is shown in Figure 2.12.

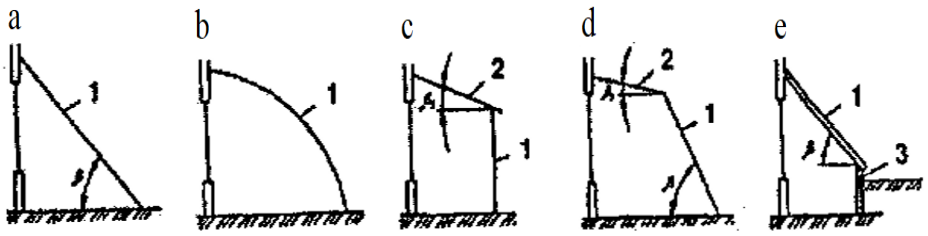


Figure 2.12. Cross-section of solar greenhouses of various designs:

a) made of a wall inclined to a transparent surface; b) made of a wall with a cylindrical transparent surface; c) the attic part and an open wall facing south are made of transparent glass; d) slopes facing south are made of transparent glass; e) the front wall is made of heat-insulating material; 2 - attic with a clear surface; 3-heat-insulating wall.

These are solar greenhouses of various types, built in geometric shapes, differing from each other in the energy of light passing through the transparent surface and the efficiency of its use. The slope of the south-facing clear surfaces of solar greenhouses depends on the geographical latitude of the location, and the latitude of Russian territory is 50.....600, and for such latitudes, the clear surface area of the attic of the solar greenhouse is calculated in the range of 20.....350. The ratio of the working area of the solar greenhouse to the transparent surface covering is calculated in the ratio of 1:1.5.

Therefore, the energy intake and supply balance of such solar greenhouses, i.e., the efficiency of passing solar energy through the transparent surface and heat loss through the walls of the installation, is adjusted according to the level of use in the volumetric air cover.

However, the passage of solar energy through the walls with a vertical transparent surface facing south is not maximal.

From 1985 to 1990, three types of heat accumulators were installed in Canada. Projects of solar greenhouses were developed and experimentally tested. The transparent surface of such solar greenhouses facing south is covered with single-layer glass, installed at an angle of 450° to the horizon, and the working area is 50 m^2 (length 10 m, width 5 m). The bottom part of the transparent surface of the first solar greenhouse consists of a base with a width of 0.6 m and a height of 0.5 m, where a metal cylindrical pipe is placed, and energy is accumulated by the hot air inside the greenhouse. The north side is covered with a porous heat-insulating panel.

In the second variant, porous composite building materials with a northern side were used as a heat accumulator.

In the third option, the solar greenhouse is equipped with a sandstone battery underground. The hot air above the solar greenhouse moves through a natural circulation underground accumulator, collecting heat during the day, and at night and on cloudy days, the temperature inside the solar greenhouse is regulated by this energy. However, there are many problems with the construction and operation of such solar greenhouses in large working areas.

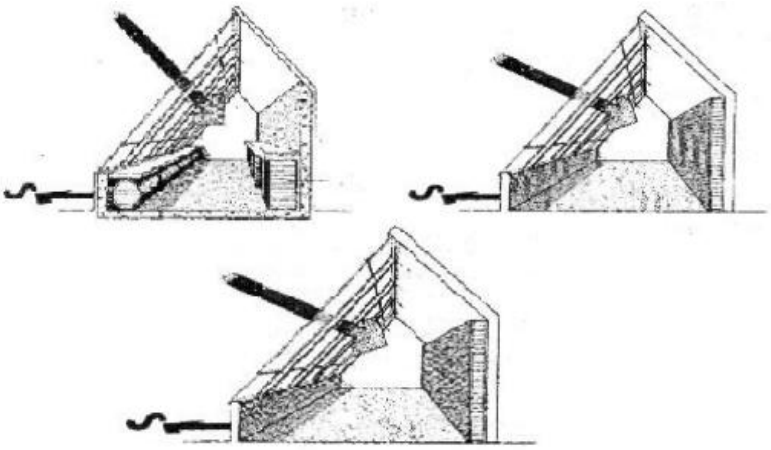


Figure 2.13. Diagram of cross-sections of solar greenhouses with water heaters and heat accumulators, built and tested in Canada.

Such a solar house greenhouse structure with light-transmitting layers is the two-story D. Balcomba house (USA, New Mexico), built based on a very perfect design. Also, a solar house-greenhouse is one of the perfectly designed installations designed for maximum use of solar energy.

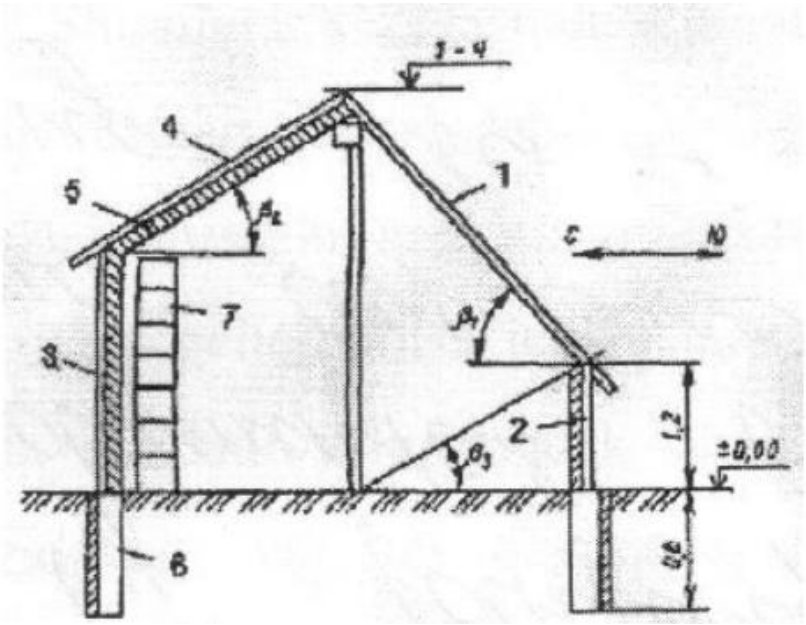


Figure 2.14. Cross-section of a single-slope transparent solar greenhouse facing south.

1-transparent transparent surface; 2 - heat-insulating front wall; 3-thermal insulation wall on the north side; 4 - section of the northern inclined heat-insulating roof; 5-heat-insulating layer; 6-heat-insulating foundation; 7 - heat accumulator.

The 1st southern side of this solar greenhouse is located on a transparent light-transmitting surface at an angle β_1, and the 2nd is located on a heat-insulating wall. The wall on the north side and the roof, located at an angle β_2, are walls lined on the inside with heat-insulating materials (glass fiber cotton), which reduce heat loss to maintain the normal temperature of the internal air of the solar greenhouse, and also the area around the foundation is covered with a heat-insulating coating to reduce heat loss in the hot air of the solar greenhouse. Due to the energy of light passing through the transparent surface of the solar greenhouse, the temperature of the indoor air increases. To accumulate this air heat, barrels filled with water are placed on the north side of the solar greenhouse. The slope of the transparent transparent surface of the solar greenhouse is selected in accordance with the angle of inclination of the sun's height in winter to ensure the passage of the maximum amount of solar energy. It is also recommended that the construction site of this solar greenhouse be built in a longitudinal house in the east-west center in places where the maximum passage of sunlight through a transparent surface is ensured, where the wind flow does not cast a shadow on the light, does not change frequently.

Figure 2.15 shows a cross-sectional diagram of a solar greenhouse with a threshing stone heat accumulator located on the north side. The transparent surface of this solar greenhouse is also directed south, and it

is built at an angle of inclination, which provides for the maximum penetration of radiant energy into the solar greenhouse. The north side is made of heat-insulating materials, and a sandstone heat accumulator is placed along the inner part of this wall. This heat is coated with black fuel oil, taking into account the maximum absorption of light and heat by the grinding stones used as a heat accumulator.

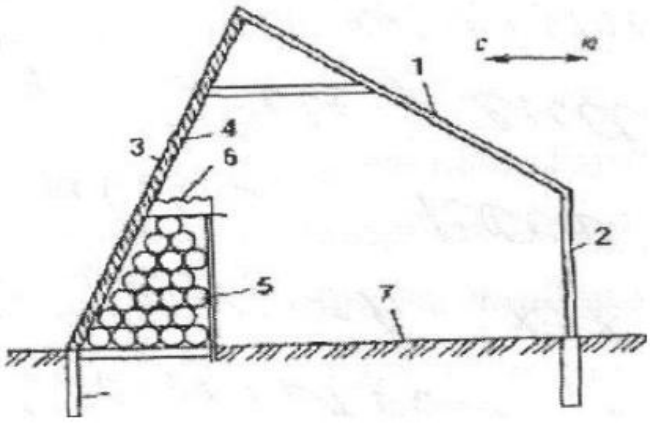


Figure 2.15. Cross-sectional diagram of a solar greenhouse with a whetstone heat accumulator.

1-transparent transparent surface; 2-supporting wall; 3-north wall, reducing heat loss; 4-thermal insulation wall on the north side, made of cotton and fiberglass; 5 - battery with a whetstone; 6 - box for growing seedlings on a heat accumulator; 7-working area of the solar greenhouse for growing plants; 8-heat-insulating foundation.

In all countries, the cultivation of vegetables, greens, and seedlings under protected soil is increasing year by year. For this purpose, various greenhouse designs have been developed. For example, in Scandinavian countries, the Netherlands, and Germany, the consumption of 1-1.5% of the total energy consumed by the population for heating greenhouses has currently increased by 20-35%. If regular greenhouses are converted to

solar greenhouses, the focus on biological and heat engineering processes in these devices will increase. Because under the influence of sunlight falling on the leaves of plants grown in solar greenhouses, the light energy passing into the solar greenhouse is accumulated, and carbon dioxide and water particles are broken down into carbohydrates and oxygen molecules under the influence of sunlight. This plays an important role in the development of plants. Due to the large transparent surface area of conventional greenhouses, internal air heat losses are also significant, requiring replenishment from the heat supplied by the heating system. This requires burning 50-70 kg of coal, depending on the external air temperature, to heat $1m^2$ of the working area at normal temperature.

This solar greenhouse operates on the basis of a passive heating system. To increase its efficiency, it is necessary to use a heat accumulator. The transparent light-transmitting surface is coated with two layers of glass with an air coating 5-6 sm apart. The north side is covered with a heat-insulating material made of fiberglass cotton, placed on a slope that returns the incident light energy inside the solar greenhouse, and a soil heat accumulator is installed.

Sunlight energy falls on a transparent surface, and part of it penetrates inside, heating the air. Another part heats the air between two layers of transparent glass. This heated hot air naturally rises as shown in the figure, passes through polyethylene pipes located on the north side of the solar greenhouse, circulates, and through an underground accumulator moves at a v-speed and rises into the solar greenhouse near the vertical wall to the south.

During the day, the temperature of the hot air rises to 38-40°C, and as heat passes through the accumulator, the temperature of the soil accumulator rises to 25-30°C. At night and on cloudy days, a low-temperature airflow (10-12°C) passes through a soil accumulator and heats the solar greenhouse. However, the construction and operation of such solar greenhouses over large areas presents significant challenges.Therefore, typical solar greenhouses have a semi-cylindrical shape covered with polyethylene film, and heat accumulators are placed underground.

Control questions.

1. Explain the concept of whetstone heat accumulators.

2. Name the types of solar greenhouses developed by T.A. Sadykov.

3. Explain the concept of single-slope brick-battery solar greenhouses.

Chapter III

ALTERNATIVE ENERGY RESOURCES

3.1 Compressed gases

Gaseous fuel for automobile engines is used in compressed or liquefied form. Methane is compressed to a pressure of 20 MPa and stored in thick-walled cylinders. Ethane, propane, and butane transition to a liquid state at a pressure of 1.6 MPa and are stored in cylinders in the same form.

Natural gas, compressed to 20 MPa, is used as fuel in cars. Natural gas, extracted from gas fields. Its main component is methane. When compressed gas burns, a large mass unit of heat (49.9 MJ/kg) is released, but due to its very low density, even when compressed to 20 MPa, the volumetric heat released is at least 3 times less. The small amount of volumetric heat released during combustion does not allow a sufficient amount of gas to be stored in the car, even at high pressure. Therefore, in gas-cylinder cars running on compressed natural gas, the spare mileage is half that of cars running on gasoline or liquefied petroleum gas.

The octane number of methane, determined by research, is around 110. Since compressed natural gas reserves are large and inexpensive, it is advisable to use this gas instead of gasoline. When using compressed gas as fuel for vehicles, its indicators are influenced by the component composition of the compressed gas and substances that adversely affect the operation of the gas cylinder apparatus and accelerate engine ignition. Component composition of gas. Compressed gas intended for use in vehicles in all seasons must contain at least 90% methane, no more than 4% ethane, small amounts of other combustible hydrocarbon gases:

carbon monoxide up to 1%, oxygen up to 1%, nitrogen no more than 5%. The amount of harmful impurities in the gas and compressed air is limited: hydrogen sulfide should not exceed 2 g/100 m^3, mechanical impurities should not exceed 0.1 g/100 m^3, and very small amounts of moisture may be present.

The gas industry is the extraction of natural gas from the earth's interior, the production of artificial gas from solid and liquid fuels, the supply of gas through pipelines for the population and industry, and the production of chemical products from gas. The main type of gas is combustible natural gas, which is found in porous rocks of the Earth's interior at a depth of 200-7000 m. Its composition is methane (CH_4). 1 m3 of natural gas provides 8000-8500 kcal of heat. There are also gases separated from oil, which are released from oil fields together with oil. Such gases release up to 10,000 kcal/m^3 of heat. Artificial gases are produced as a result of the thermal processing of solid and liquid fuels and the underground gasification of coal.

Generator gas, coke oven gas, etc. are considered artificial gases. 1 m^3 of generator gas provides 1000-1050 kcal of heat. Gas fuel is delivered to consumers through main gas pipelines, complex compressor units that supply gas at a certain pressure, and underground gas storage facilities.

The gas industry began to take shape at the end of the 18th - beginning of the 19th century, when the use of coal-fired gas for city lighting was established in such countries as Great Britain, France, and Belgium. Later, in the second half of the 19th century, a device for obtaining gas from coal - a gas generator - was created. In addition, petroleum gases were also used until the 1920s. However, until this time, natural gas reserves had

not yet been identified and were not being utilized. The detonation resistance of a gas-air mixture is higher than that of a gasoline-air mixture. This allows increasing the engine's compression ratio and improving its economic performance. In gas engines, the mixture burns almost completely, and due to the lower toxicity of exhaust gases, the environment is less damaged.

The use of gases eliminates the erosion of the oil film from the piston and liner walls, reduces the formation of soot in the combustion chambers, prevents oil from burning from the cylinder liner walls due to the absence of gasoline vapors, and, as a result, increases the engine's service life and oil replacement period by 1.5-2 times.

However, in gas-cylinder vehicles, the fuel supply system is complex, and the requirements for fire and explosion safety are high.

Because gas occupies a larger volume when mixed with air compared to gasoline, the power of gas engines is 10-20% less than that of carburetor engines.

Engines operating on compressed or liquefied gases are mainly created on the basis of carburetor engines. For this purpose, the carburetor engine is equipped with special gas apparatus and cylinders. At the same time, it retains its ability to work on gasoline. In this case, the high detonation resistance of gases with an octane number greater than 100 units is not advantageous, since the compression ratio of the engine is selected in accordance with the octane number of gasoline, which is significantly less than the octane number of gasoline.

Equipment operating on compressed gas. Eight cylinders (Fig. 3.1), combined into two groups, are placed under the body platform, each group

is equipped with a valve. Therefore, gas can be consumed simultaneously from two groups or separately from each. A filling valve is used for filling cylinders with gas.

Gas from the cylinders enters the heater through the exhaust valves. This heater is designed to protect the system from freezing due to a significant drop in gas temperature due to gas expansion in a high-pressure reducer. A main exhaust valve is installed between the gas heater heated by heated gases and the cylinders. A control lamp sensor is installed in the high-pressure gearbox. This lamp lights up when the gas pressure in the gearbox drops below 0.45 MPa, warning the driver about gas remaining in the cylinders for 10-12 km.

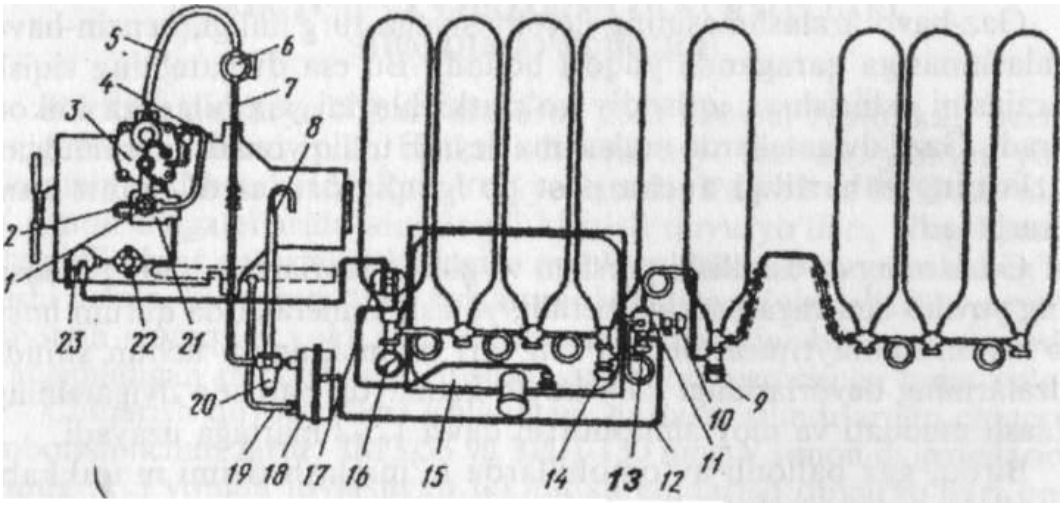


Figure 3.1. The main form of a gas cylinder fuel system with gas cylinder fittings on the left.

Gas from the reducer enters the electromagnetic valve with a filter. This valve opens when starting the engine, and the gas enters the low-pressure reducer through the tube. The reducer is two-stage, and the pressure in it decreases almost to atmospheric pressure. During engine operation, if the gas is in idle mode during carburetor mixing, it enters

directly into the rear throttle cavity through the hose. The low-pressure reducer reduces the gas pressure entering the carburetor-mixer, cleans the gas to prepare a mixture of the required composition, and disconnects the gas main when the engine stops.

Gas from the reducer enters the electromagnetic valve with a filter. This valve opens when the engine starts, and the gas enters the low-pressure reducer through the tube. The reducer is two-stage, and the pressure in it decreases almost to atmospheric pressure. During engine operation, if the gas is in idle mode during carburetor mixing, it enters directly into the rear throttle chamber through the hose. The low-pressure reducer reduces the gas pressure entering the carburetor-mixer, cleans the gas to prepare a mixture of the required composition, and disconnects the gas pipeline when the engine stops.

Fluid from the bracket cavity is directed through a hose to the cab heater radiator, and then to the engine cooling system pump. To ensure fire safety in case of accidental rupture of the high-pressure reducer membrane, the gas is removed from the cap and safety valve through separate pipelines outside the under-hood cavity.

Gas cylinder equipment operating on liquefied gas. Liquefied gas from the cylinder (Fig. 3.2) enters the evaporator, which is heated by the liquid in the engine cooling system, through the exhaust valve, main valve, and gas duct, then passes through the filter and enters the reducer. Here its pressure decreases to almost atmospheric pressure. Control of the system’s operation is carried out using pressure gauges (pressure in the cylinder, pressure in the reducer).

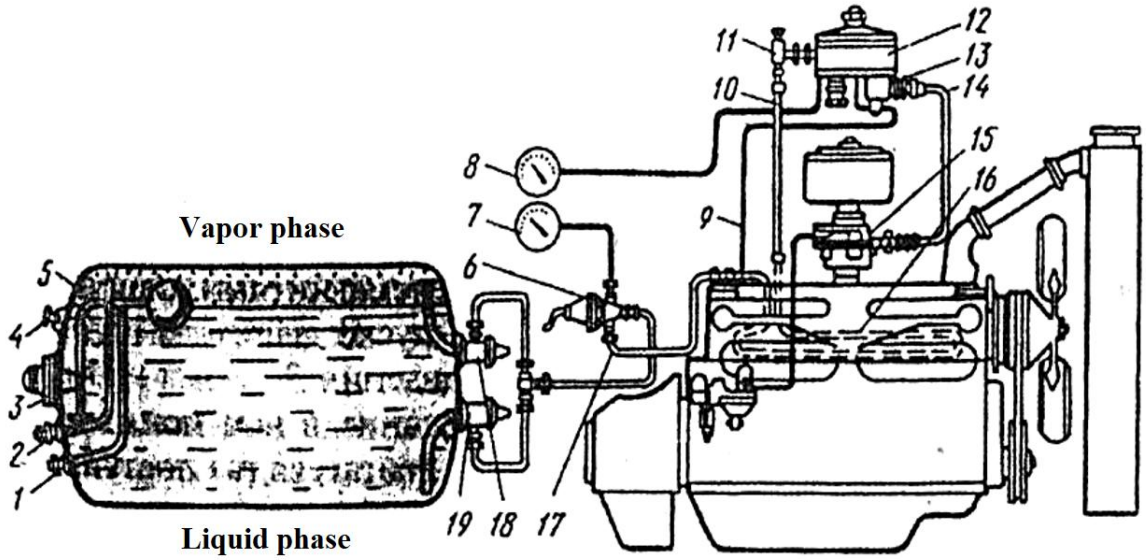


Figure 3.2. The shape of a gas cylinder equipment operating on liquefied gas.

1-valve-indicator of the maximum level; 2 - safety valve; 3 - indicator of the liquid level in the tank; 4-filling valve; 5-low-pressure cylinder; 6 - main valve; 7-manometers; 8-unloading device tube; 9-10 - gas pipelines; 11 - filter; 12-two-stage reducer; 13 - economizer; 14 - gas pipeline; 15-carburetor-mixer; 16-evaporator; 18,19 - valves for steam and liquid.

Starting and heating the engine is carried out in the vapor phase of the gas. For this, the steam and main valves are opened. A short-term engine shutdown is carried out by turning off the ignition line. When stopping for 1-2 hours, the main valve is closed. At the bottom of the cylinder are a safety valve (opens at 1.68 MPa), a filling valve with a check valve, a valve for determining the maximum filling of the cylinder, and a liquefied gas level sensor.

A valve is used to fill the cylinder, and only 90 percent of its volume is filled so that the cylinder does not burst due to the heating of the gas. During filling, the liquid gas level is monitored using the valve indicator tube. The driver monitors the amount of gas using an indicator. Filling gas

cylinder equipment is allowed only at gas filling stations when the engine is not working. When filling cylinders with liquefied gas, it is necessary to be careful not to freeze. Operation of gas-cylinder vehicles with faulty gas appliances and gas leaks is prohibited. If the gas release cannot be eliminated, then it is released into the atmosphere (far from people and fire sources).

Driving and servicing gas-cylinder vehicles are permitted for persons who have undergone special training and passed the technical minimum and safety exam.

Control questions.

1. What types of gaseous fuels do you know?
2. What is the composition of compressed gas?
3. Name the gases in a liquid state.

3.2. Repeated chemical reactions. Hydrogen.

Hydrogen is the most abundant element in the universe (92%). In its free state and under normal conditions, hydrogen is a colorless gas, odorless, and tasteless. It is usually found in combination with other elements such as oxygen in water, carbon in methane, and organic compounds. Since hydrogen is chemically very reactive, it rarely occurs as an unbound element. Liquefied hydrogen occupies 1/700 of the gaseous state. Hydrogen, when combined with oxygen, has the highest energy content per unit mass: 120.7 GJ/t. Therefore, it is used as fuel for rockets and in the energy of spacecraft, for which the low molecular weight and high specific energy of hydrogen play an important role. When hydrogen burns in oxygen, heat and water are released, which makes the use of

hydrogen environmentally friendly. Under normal conditions, hydrogen is almost 15 times lighter than air. It has a very high thermal conductivity, comparable to metals. This is due to the high speed of movement of hydrogen molecules due to their lightness. Hydrogen has a very high combustion temperature - 2800 °C. Hydrogen is an excellent reducing agent. The use of hydrogen in modern industry and the national economy is diverse: from the production of ammonia, urea, and methanol to its use as highly efficient fuel for rocket engines, with the development of technology and industrial production, new directions of practical use of hydrogen are emerging, and the need for it is significantly increasing. Every year, it increases by 8-10% worldwide.

It is believed that hydrogen was first discovered in 1766 by English chemist and physicist Henry Cavendish. It was first identified as a separate element by British scientist Henry Cavendish after zinc metals reacted with hydrochloric acid to produce hydrogen gas. At a demonstration to the Royal Society of London, Cavendish placed a spark in water emitting hydrogen gas. This discovery later led him to discover that water (H_2O) consists of hydrogen and oxygen. Cavendish himself named the unknown gas obtained in his experiments “Burning Air.” Cavendish himself observed the formation of water when “burning air” was burned, but he could not draw a final conclusion on this matter because he relied on the doctrine of phlogiston in scientific reasoning. The fact that hydrogen is a separate chemical element was first scientifically proven through experiments conducted jointly by French chemist Antoine Lavoisier and engineer Jean Mennier using special gasometer equipment. Lavoisier also proposed the name “Hydrogenum” for the element. The

term “hydrogen” which entered the Uzbek language through Russian, was introduced to science in 1824 by the Russian chemist M. Solovyov.

In 1800, English scientists William Nicholson and Sir Anthony Carlisle discovered that hydrogen and oxygen gases are formed as a result of applying electric current to water. This process was later called “Electrolysis.”

In 1838, Swiss chemist Christian Friedrich Schoenberg discovered the fuel cell effect, which combines hydrogen and oxygen gases to create water and electric current.

In 1845, the English scientist and judge Sir William Grove demonstrated Schoenbein’s discovery on a practical scale by creating a “gas battery.” He was awarded the title “Father of the Fuel Chamber” for his achievements.

In 1889, Ludwig Mond and Charles Langer attempted to create the first fuel cell device using air and industrial coal gas. They named the device the fuel cell.

In the 1920s, the German engineer Rudolf Erren transformed the internal combustion engines of trucks, buses, and submarines into the use of hydrogen or hydrogen mixtures. British scientist and Marxist writer J.B.S. Helden introduced the concept of renewable hydrogen in his article “Science and the Future” and “have great power plants where, in windy weather, excess power is used for the electrolytic decomposition of water into oxygen and hydrogen.”

In 1937, after ten successful transatlantic flights from Germany to the United States, a hydrogen-filled Hindenburg dirigible crashed while landing in Lakewood, New Jersey. The secret of the crash was revealed

in 1997. Studies have shown that the explosion occurred not as a result of hydrogen gas, but as a result of a static electrical discharge depending on the air, which was treated with a silver-colored canvas outer coating of the airship with the main components of solid rocket fuel.

In 1958, the United States established the National Aeronautics and Space Administration (NASA). NASA's space program currently uses the world's most liquid hydrogen, primarily as fuel for rocket propulsion and fuel cells.

The idea of widespread use of hydrogen as an artificial fuel obtained by electrolysis of water appeared in Jules Verne's science fiction novel "The Mysterious Island" (1874). The first attempts to implement it date back to the 1920s-1930s, when commercial production of hydrogen-alkali began. He developed electrolyzers and adopted the first program in the field of creating hydrogen energy systems based on primary electricity generated at hydroelectric power plants. This program was implemented until 1936, after which it was shortened due to the shift in the priority of the Canadian energy system market to one hundred.

It has been shown that the use of hydrogen with a corresponding change in the fuel system (transition to the formation of an internal mixture) allows increasing engine power by 10% or more.

The use of hydrogen as an additive to traditional motor fuel has made it possible to reduce harmful emissions into the atmosphere and increase the efficiency of engines. In total, during this period, from 1 to 4 thousand cars were converted into non-traditional fuel, including hydrogen, and the cost of such conversion, as calculated later, did not exceed several hundred US dollars per unit (in 1970). These developments, the main

contribution of which was made by the German engineer R. Jorren, became an important foundation for subsequent work on the use of hydrogen in vehicles, which resumed in the 1970s.

It is noteworthy that during the years of the Second World War, research and development in this and related fields became even more active. It is known that in Germany during the war years, synthetic motor fuel produced as a result of coal hydrogenation was widely used. Since 1942, the naval forces of different countries have shown particular interest in hydrogen development (an autonomous energy system for a diesel submarine using compressed hydrogen and oxygen obtained as a result of water electrolysis as fuel). During the war years, in some countries disconnected from oil supply (for example, Australia), large-scale programs were launched to establish widespread production of hydrogen and its use as motor fuel. With the restoration of cheap oil supplies after the war, these programs were suspended.

Since 1950, interest in hydrogen has been renewed thanks to advances in the development of fuel cells. Although fuel cells were invented as early as the 19th century, the first samples suitable for practical use appeared in the early 1950s. In Great Britain and Germany. Later (in the 70s and 80s), these developments were of great importance for the implementation of the space programs of the USA and the USSR, and later (by the mid-1990s) their development led to a radical revision of the concept of hydrogen energy systems, since the use of fuel cells made it possible to significantly increase the efficiency of electricity generation at the stage of hydrogen use by consumers.

The rapid development of research and development in the field of hydrogen energy and technology in the world occurred in 1974-1983. and was a direct result of the energy crisis that encompassed many industrially developed countries during that period. From the mid-1970s, intensive information exchange and international cooperation began between the activities of hydrogen groups, which until then worked independently of each other. At the end of 1974, the International Hydrogen Energy Association (IAHE) was established, to which a team of scientists, engineers, and managers makes an effective contribution.

The approach of European, and especially Japanese, scientific-technical, business, and government agencies was more realistic. They realized that the widespread introduction of hydrogen technologies here would require long and intensive work, calculated over many decades. Thus, in Japan, in 1974, the long-term project “Sunlight,” implemented until 2000, was launched. This was the largest alternative energy program comparable to the American Apollo space program. In total, approximately $15 billion was spent, of which $3.6 billion was the hydrogen budget. In 1976, the International Energy Agency (IEA), headquartered in Paris, began financing hydrogen work. In 1978, the budget of the IEA road program amounted to about $16 million, which was distributed over several years. At the same time, while general trends in expanding the use of hydrogen in energy and technology have persisted, it has become less dynamic.

An important stage in the development of hydrogen energy and technology was the results of economic research conducted at the end of the 1980s. Energy Research Institute at the Clean Energy Research

Institute of the University of Miami, USA. A detailed justification for calculating the economic damage caused by atmospheric pollution from industrial and transport emissions and a methodology for making appropriate adjustments to economic calculations were proposed. Taking these corrections into account, the environmental friendliness of hydrogen made it potentially useful for use in a number of industries. In general, the period from the mid-1970s to the end of the 1990s was marked by deep research and development, which laid the technical foundations of scientific and modern hydrogen technologies. Significant progress has been made in the field of hydrogen production using renewable energy sources. The main technical solutions for improved characteristics for various types of electrolyzers were improved and brought to pilot industrial samples. In parallel, corresponding developments of fuel cells were developed, which have higher efficiency, longer service life, and reliability than previously existing designs. Radically new technical solutions have emerged for electrochemical systems (new generation electrolyzers and solid polymer fuel cells), or solid oxide electrolytes using hydrogen and other alternative fuels. Fundamentally new environmentally friendly technologies for hydrogen production have also been developed, such as biochemical and photocatalytic. Methods of using hydrogen as fuel for heat engines and power plants have also developed dynamically. In a number of countries (USA, Germany, Japan) in the 1970s-1980s. Demonstrative samples of cars and other vehicles with internal combustion engines running on hydrogen fuel or hydrogen additives were created. In the 90s, the first models of electric motor cars and buses with portable fuel cell power plants appeared. At the same time,

a number of major developments have been carried out on the use of hydrogen as aviation or space fuel. In the United States, large rockets were created (the Space Shuttle program) and (Buran-Energy), the main engines of which used liquid hydrogen as fuel and liquid oxygen as an oxidizer. The first successful hydrogen test of the aircraft (experimental model Tu-155, built in April 1988 on the basis of a serial Tu-154 aircraft, one of the three engines of which runs on liquid hydrogen fuel. A month later, a single-engine light (four-seater) aircraft was tested. Significant progress has also been made in solving the complex - the technological problem of compact hydrogen storage. A new generation of high-pressure composite gas cylinders was developed, which made it possible to significantly increase the weight and bulk density of storage of hydrogen in the form of compressed gas. Technologies for liquefying hydrogen and storing it in a liquid state have also been improved. New developments in physicochemical methods of storing hydrogen in a bound state, including metal hydride technologies, have been rapidly developing. One of the important results achieved in the process of research and development in the latest direction was created in the early 1990s. High-performance nickel-metal hydride batteries, which currently occupy an important segment of the global market for compact chemical energy sources.

Hydrogen is the first element in the periodic table of chemical elements. The formula of H. Hydrogen, derived from the first letter of its Latin name – “Hydrogenum,” is derived from the ancient Greek words δωρ – “water” and γεννάω – “generator.” In translation, it means “water-bearer.”

As a simple substance, hydrogen H_2 is a light, colorless gas. In a mixture with oxygen, it is flammable and explosive. Dissolves in non-toxic ethanol, as well as in a number of metals: iron, nickel, palladium, titanium, and platinum.

Distribution

Hydrogen is the most widespread chemical element throughout the universe. According to scientific estimates, hydrogen atoms make up ≈88% of all atoms in the universe. It is the main component of stars and interstellar gas. Due to the extremely high temperature in stars, the hydrogen in them is in the state of plasma. In interstellar space, hydrogen can exist as individual atoms and ions, forming molecular clouds. Hydrogen constitutes almost half of the Sun's mass, and in percentage terms, it makes up 74.5 percent.

The proportion of hydrogen in the Earth's crust is 1%. Almost all hydrogen on Earth is in a compound state. Its role in all natural processes occurring on Earth is invaluable. Only in the Earth's atmosphere is there a very small amount of hydrogen in the form of a simple substance, which constitutes only 0.00005% of the volume of dry air.

This element is found in tissues of almost all living organisms, as well as in all organic substances. Hydrogen atoms make up 63% of the number of atoms in living tissues.

Physical properties of hydrogen

Hydrogen is the lightest gas. It is 14.4 times lighter than air. Therefore, balloons filled with hydrogen, such as soap bubbles, rise up in the air. The smaller the mass of the molecules, the greater their velocity relative to other molecules at the same temperature. Hydrogen molecules

are the lightest molecules in nature. Therefore, they move faster than the molecules of any other gas and are therefore the fastest in terms of heat transfer (simply put, heat transfer). From this, it can be concluded that among gaseous substances, hydrogen has the highest thermal conductivity. Its thermal conductivity is almost seven times higher than that of air.

The hydrogen molecule is diatomic (H_2) and under normal conditions is a gas without odor, color, and taste. Its density is 0.08987 g/l; boiling point is −252.76 °C; the specific heat released during combustion is 120.9•106 J/kg; it is poorly soluble in water and difficult to dissolve: 18.8 ml/l (at 20°C).

Hydrogen dissolves well in metals (Ni, Pt, Pd, etc.), especially in palladium. 850 volumes of hydrogen can dissolve in 1 volume of palladium. The good solubility of hydrogen in metals is due to its diffusion in metals. However, in carbon compounds (for example, in carbon steel), the decomposition of the compound can also occur due to the diffusion of hydrogen. Because in this case, as a result of the interaction of hydrogen with carbon atoms, the phenomenon of decarbonization usually occurs. Hydrogen is practically insoluble in metallic silver.

Liquid hydrogen exists in very short temperature ranges from −252.76 to −259.2 °C and is a colorless, extremely light liquid with a density of 0.0708 g/sm^3 at −253 °C and a viscosity of 13.8.

The critical parameters of hydrogen are very low:−240.2 °C temperature and 12.8 atm pressure. This explains its difficulty in melting.

Liquid hydrogen, in equilibrium, consists of 99.79% H_2 vapor and 0.21% o-H.

Solid hydrogen exists as a snow-like mass with a melting point of −259.2 °C and a density of 0.0807 g/sm^3 (at −262 °C). Crystals of hexagonal crystal system, spatial group P6/mmc, cell parameters a=0.378 nm and c=0.6167 nm.

In 1935, chemists Winger and Huntington proposed a scientific hypothesis about hydrogen transitioning to metallic state under 250,000 atm pressure. If it were possible to create such conditions and obtain stable metallic hydrogen, it was intended to be promisingly used in many fields as an ultra-light metal. In 2014, it was discovered that hydrogen begins to absorb infrared radiation under 1.5-2 million atm pressure, meaning its molecules' electron shells can be polarized. Perhaps at higher pressures, hydrogen can transition to a metallic state.

Molecular hydrogen occurs in two different spin forms (modifications) in ortho- and para-modifications. In the orthohydrogen molecule, the nuclear spins of o-H_2 (melting point −259.10 °C, boiling point −252.56 °C) are parallel; in parahydrogen, p-H_2 (melting point −259.32 °C, boiling point −252.89 °C) are antiparallel. The equilibrium of a mixture of o-H_2 and p-H_2 at a given temperature is called the equilibrium hydrogen e-H_2.

Physical properties of hydrogen isotopes

Among chemical elements, hydrogen has the greatest physical and chemical differences between the isotopes of the same element. This is explained by the fact that the ratios of atomic problems of hydrogen isotopes are quite large.

Table 3.1

Physical properties of hydrogen isotopes

	Melting point, (K)	**Boiling point (K)**	**Triple point (K/kPa)**	**Critical point (K/kPa)**	**Density liquid/gas; (g/sm^3)**
H_2	13,96	20,39	13,96 / 7,3	32,98 / 1,31	70,811 / 1,316
HD	16,65	22,13	16,6 / 12,8	35,91 / 1,48	114,0 / 1,802
HT		22,92	17,63 / 17,7	37,13 / 1,57	158,62 / 2,31
D_2	18,65	23,67	18,73 / 17,1	38,35 / 1,67	162,50 / 2,23
DT		24.38	19,71 / 19,4	39,42 / 1,77	211,54 / 2,694
T_2	20,63	25,04	20,62 / 21,6	40,44 / 1,85	260,17 / 3,136

Chemical properties

In compounds, hydrogen is always monovalent. It is characterized by a +1 oxidation state. However, in the case of metals, it is equal to 1. Due to the formation of a shared electron pair, in other words, a shared electron cloud, hydrogen is usually diatomic. It is hydrogen in the form of H_2 molecules that is energetically stable compared to individual atoms. Therefore, hydrogen molecules are quite stable, and it requires 436 kJ of energy to separate one mole of hydrogen into atoms.

$$H_2=2H,\ \Delta H^o= 436\ kJ/mol \qquad (3.1)$$

Therefore, under normal conditions, hydrogen reacts only with the most active substances, such as calcium, and forms hydrides:

$$Ca+H_2\rightarrow CaH_2 \qquad (3.2)$$

From metals, it only combines with fluorine under normal temperature conditions to form hydrogen fluoride:

$$F_2+H_2\rightarrow 2FH \qquad (3.3)$$

With most metals and nonmetals, hydrogen reacts at high temperatures or under other influences, such as illumination.

$$O_2+2H_2\rightarrow 2H_2O \quad (3.4)$$

It can bind oxygen from some oxides. For example:

$$CuO+H_2\rightarrow Cu+H_2O \quad (3.5)$$

The above equation is also an example of the reducing property of hydrogen.

$$N_2+3H_2\rightarrow 2NH_3 \quad (3.6)$$

With halogens, it forms hydrogen halides:

$$H_2+F_2\rightarrow 2HF \quad (3.7)$$

the reaction occurs in the dark and at any temperature and is accompanied by an explosion.

$$H_2+Cl_2\rightarrow 2HCl \quad (3.8)$$

the reaction occurs only in light and is accompanied by an explosion.

Exposure to alkalis and alkaline earth metals:

Hydrogen reacts with active metals to form hydrides:

$$2Na+H_2\rightarrow 2NaH \quad (3.9)$$

$$Ca+H_2\rightarrow CaH_2 \quad (3.10)$$

$$Mg+H_2\rightarrow CaH_2 \quad (3.11)$$

In such compounds, metals exhibit a positive oxidation state, while hydrogen exhibits a negative. Hydrides, salt-like white crystalline solids, are easily hydrolyzed and form hydrogen with the corresponding alkali:

$$CaH_2+2H_2O\rightarrow Ca(OH)_2+2H_2 \quad (3.12)$$

Interaction of metals with oxides:

Oxides are reduced to metallic state:

$$CO+H_2\rightarrow CO+H_2O \quad (3.13)$$

$$Fe_2O_3+3H_2 \rightarrow 2Fe+3H_2O \quad (3.14)$$

$$WO_3+3H_2 \rightarrow W+3H_2O \quad (3.15)$$

Hydrogenation of organic compounds

Molecular hydrogen is widely used in organic synthesis and the reduction of organic compounds. Such processes are called hydrogenation reactions. Such reactions, in the presence of catalysts, proceed at high temperature and pressure. The catalyst can be of both homogeneous and heterogeneous types.

When hydrogen burns in oxygen, a large amount of heat is released. The temperature of the hydrogen-oxygen mixture flame reaches up to 3000°C. A mixture of gases, consisting of two volumes of hydrogen and one volume of oxygen, is called thunder gas, and when ignited, it explodes violently. Water is formed both when hydrogen burns in oxygen and when a thunder gas explodes.

Preparation

In industry, hydrogen is obtained by various methods. One of them is the conversion of natural gas with water vapor at a temperature of 1000 °C, the reaction of which proceeds as follows:

$$CH_4+H_2O \rightleftarrows CO+3H_2 \quad (3.16)$$

Also, by passing water vapor over heated coke at a temperature of about 1000 °C:

$$H_2O+C \rightleftarrows CO+H_2 \quad (3.17)$$

By electrolysis of aqueous solutions of salts:

$$2NaCl+2H_2O \rightarrow 2NaOH+Cl_2+H_2 \quad (3.18)$$

By catalytic oxidation with oxygen:

$$2CH_4+O_2 \rightarrow CO+4H_2 \quad (3.19)$$

In laboratories, it is mainly obtained by reacting acidic mixtures with metals. The most common of such reactions is the interaction of zinc with sulfuric acid:

$$Zn+H_2SO_4 \rightarrow ZnSO_4+ H_2 \quad (3.20)$$

or, as a result of the interaction of water with calcium:

$$Ca+2H_2O \rightarrow Ca(OH)_2+ H_2 \quad (3.21)$$

By hydrolysis of hydrides:

$$NaH+H_2O \rightarrow NaOH+H_2 \quad (3.22)$$

By the action of alkalis on zinc or aluminum:

$$2Al+2NaOH+6H_2O \rightarrow 2Na[Al(OH)_2]+3H_2 \quad (3.23)$$

$$Zn+2KOH+2H_2O \rightarrow K_2[Zn(OH)_4]+H_2 \quad (3.24)$$

By electrolysis. When aqueous solutions of alkalis or acids are electrolyzed, hydrogen is released at the cathode, for example:

$$2H_2O+2e \rightarrow H_2O+H_2 \quad (3.25)$$

Application

Hydrogen is widely used in the chemical industry in the production of ammonia, methanol, soap, and plastics. In the food industry, it is used for hydrogenating fats and producing margarine. Registered as a food additive under the E949 (packaging gas) regimen. Due to its extreme lightness, it was previously used to fill balloons in aerostats. However, due to its flammability and rapid explosion, after several major accidents, the filling of balloons with hydrogen was stopped for safety reasons. Nowadays, balloons are mainly filled with helium. Hydrogen is used only in balloons used for metrological purposes. Hydrogen is used as fuel for rockets. Currently, research continues on the use of hydrogen fuel for

passenger cars and other types of vehicles. In the electric power industry, hydrogen is used for cooling powerful and high-power generators. Hydrogen isotopes - Deuterium and Tritium, are used as thermonuclear fuel in nuclear energy.

Table 3.2

Properties of the hydrogen atom

Atomic properties	
Atomic number	1,00784 m.a.b. (g/mol);
Electron configuration	$1s^1$
Atomic radius	53 pm

Table 3.3.

Chemical properties of hydrogen

Chemical properties	
Covalent radius	32 pm
Ionic radius	54 (−1e) pm;
Electronegativity	2,20 (by the floor scale);
Electrode potential	−0.34 V
Oxidation state	1,0, ?1;
Ionization energy (first electron)	1311,3 kJ/mol; (13,595 eV);

Table 3.4.

Thermodynamic properties of hydrogen gas

Thermodynamic properties	
density (m.u.)	0,0000899 g/sm^3;
Melting point	14,01 K;
Boiling point	20,28 K;
Specific heat of fusion	0,117 kJ/mol;
Specific heat of vaporization	0,904 kJ/mol;
Molar heat capacity	28,47 kJ/(K·mol);
Molar volume	14,1 mol/sm^3;
Thermal conductivity	(300 K) 0,1815 Vt/(m·K);
Debye temperature	110 K;
structure lattice shape	Hexagonal;

Grid parameters	a=3,780 c=6,167 Å;
c/a ratio	1,631

HYDROGEN PRODUCTION TECHNOLOGIES

This section discusses hydrogen production technologies, as well as environmentally safe and sustainable methods, and classifies them based on their sources and applications. Some potential sources are electrical, thermal, biochemical, photonic, electrothermal, photothermal, photoelectric, photobiochemical, and thermobiochemical. Such forms of energy can be obtained from renewable sources, atomic energy, and energy recovery processes for hydrogen production. For comparison purposes, these processes were analyzed and evaluated. Various examples are given to emphasize the importance of methods and systems for producing green hydrogen for practical applications. Green hydrogen production technologies currently lack acceptable efficiency and cost. One of the methods of producing green hydrogen is electrolysis, which can be considered as a corresponding notation and can also be carried out with ready-made components, namely PV-electrolysis: it combines a photovoltaic (PV) energy production system with a water electrolyzer. Other authors, such as Mason and Zweibel and Yilanci, analyzed the efficiency and cost of this method for large and small hydrogen production applications. This method is currently expensive (>5$/kg H2) and produces hydrogen with very low efficiency (<5%). Other methods involve the use of one or more green energy sources for direct or indirect hydrogen production. “Green energy sources” are understood as nuclear

energy and renewable energy (for example, exhaust gases, industrial heat recovery, etc.).

Several reviews have been published in the open literature on the production of hydrogen from renewable energy sources and renewable raw materials. One of the earliest works on the analysis of hydrogen production from water using renewable energy sources is associated with Lodhi, who mentions the use of high-temperature water dissociation, thermochemical separation of water, water electrolysis, and water photolysis. In the next article, Lodhi lists green energy sources for hydrogen production: sunlight, sea and ocean energy, flowing waters, winds, and decomposable materials. Materials from which hydrogen can be obtained by green methods are identified as water, salt water (sea water), hydrogen sulfide, and biomass. Miltner et al. classified methods for producing green hydrogen based on the material from which hydrogen is obtained.

Table 3.5 shows the existing methods of producing green hydrogen according to the energy used to control the process. Two types of energy (electrical+thermal,electrical+photonic,biochemical+thermal,photonic+biochemical), except for methods that use a single energy (electrical, thermal, photonic, or biochemical) hybrid methods are indicated. The table also shows the resources of materials from which hydrogen is obtained for each of the methods. The hydrogen-containing materials under consideration are: water, biomass, hydrogen sulfide, and extracted hydrocarbons. If coal or fossil hydrocarbons are used in the conversion process, carbon dioxide is released in the hydrogen production process.

Table 3.5
Methods of production and conversion to energy for the production of "green hydrogen"

Methods		Source		Brief overview
		Primary energy	Materials	
1	Electrolysis	Elecktric	Water	Direct current is used to separate water into O_2 and H_2. (electrochemical reaction)
2	Plasma arc decay		Fossil fuel	The purified natural gas passes through the plasma arc to form H_2 and carbon black
3	Thermolysis	Heat	Water	Thermal decomposition of water (vapor) at temperatures above 2500 K
4	Thermochemical process		Water	Cyclic chemical reactions (resulting reaction: decomposition of water into H_2)
5			Biomass	Thermal catalytic conversion
6				Biomass conversion to synase
7				Conversion of liquid biomass (biofuel) to H_2
8	Photoelectric electrolysis	Photon	Water	FES panels are used for the production of electricity
9	Photocatalysis			With the help of an electron hole, water is split into H_2, vapor formed as a result of photocatalysis
10	Photoelectrochemical method			When a hybrid cell absorbs light, it creates both current and voltage
11	Dark fermentation	Biochemist	Biomassa	Biological systems are used to produce H_2 in the absence of light
12	Electrolysis at high temperatures	Electricity + Heat	Water	Electrical and thermal energy are used together to control water separation at high temperatures
13	Hybrid thermochemical cycles			Electrical and thermal energy are used together to control cyclic chemical reactions
14	Coal gasification			Conversion of coal into synthesis gas
15	Fossil fuel reform			The fossil fuel is converted into H_2 and CO_2

16	Biophotolysis	Photon + Biochemical	Biomass + water	Biological systems (microbes, bacteria, etc.) Used to produce H_2
17	Photofermentation			The fermentation process is activated by the action of light
18	Artificial photosynthesis			Chemical engineering systems simulate photosynthesis to produce H_2
19	Photoelectrolysis	Electric + Photon	Water	Photoelectrodes and external electric current are used for water electrolysis

Photoelectrolysis and photoelectrochemical hydrogen production

Photoelectrolysis involves the use of heterogeneous photocatalysts on a single electrode exposed to sunlight. Additionally, the electrolysis cell is powered by an electric current supplied to the electrodes. Under the influence of photonic radiation, the required electrical energy is reduced. A photoelectrochemical cell (PEC) is a modern implementation of photoelectrolysis that uses photosensitive semiconductors immersed in an electrolyte along with counter electrodes. Figure 3.3 shows a possible configuration of the PEC

A semiconductor works similarly to PEC cells, that is, it uses photons with higher energy than the semiconductor's branch gap to create electron hole pairs separated by the electric field that crosses the electrolyte.

The remarkable advantage of a photoelectrochemical cell is that it truly combines solar energy absorption and water electrolysis into a single unit. Thus, the device does not require a separate solar energy generator (for example, PEC cells) and an electrolyzer, making it more compact. The technology is under development, and an efficiency of nearly 18%

has been achieved in laboratory settings. Experiments have shown that the operational lifespan of PEC (photoelectrochemical cell) is currently low, as water causes corrosion of the electrolytes. Many types of photosensitive semiconductor electrodes have been studied, with titanium dioxide (TiO_2) being one of the most promising; other types include strontium titanate, carbon oxide, NaOH oxide, tantalum oxynitride, other niobates and titanates, cadmium sulfides can be listed.

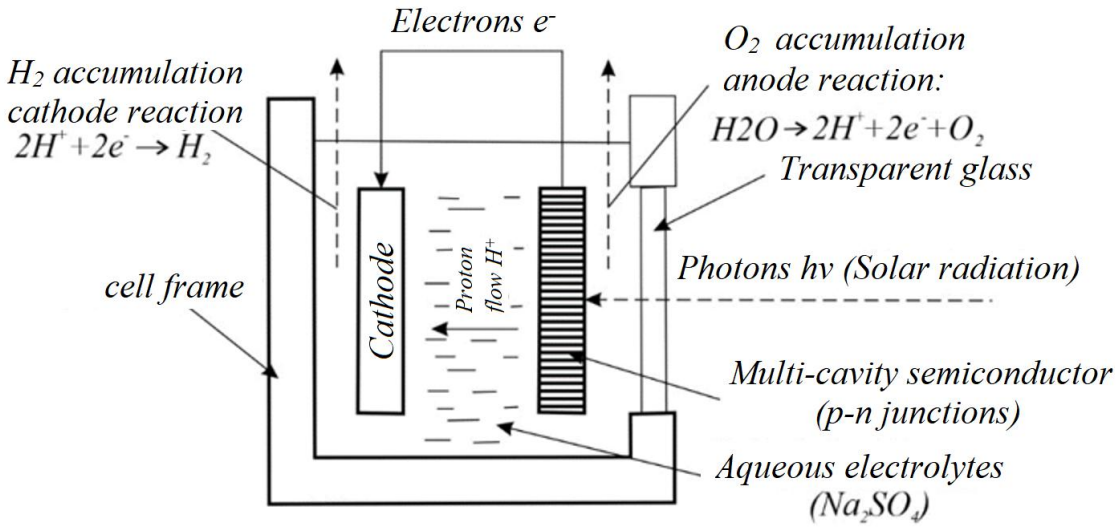


Figure 3.3. Reflecting the operating principle of a photoelectrochemical cell.

Artificial photosynthesis for hydrogen production

The key stages in the natural photosynthesis processes of plants and bacteria serve as models and inspiration for a completely biomimetic, industrial-scale technological approach to achieve the following specific objectives:

- production of electricity using photovoltaic systems. The generated energy can be transferred directly to the national grid.

-“Dry agriculture” utilizes enzyme-layered reactor systems powered by bioelectric transducers, which are fueled by hydrogen and electricity from the national grid, to capture carbon dioxide from the air or other convenient sources. These systems produce carbohydrates (food), liquid fuels, chemical raw materials, and polymers for fiber production. Water consumption in this process is at or near the absolute chemical minimum, making it thousands of times lower than in traditional agriculture.

Production of hydrogen from seawater or other suitable water sources. Electrode systems using modeled catalytic surfaces at the corresponding high-efficiency active sites of photosynthetic organisms achieve electrolytic decomposition of water (to hydrogen and oxygen).

Artificial photosynthesis, as illustrated in Figure 3.4, is a means of achieving the aforementioned goals of clean energy production and dry food production. The figure presents a schematic diagram of artificial photosynthesis. It is divided by a straight line, with the upper half depicting the light reaction and the lower half showing the dark reaction of photosynthesis.

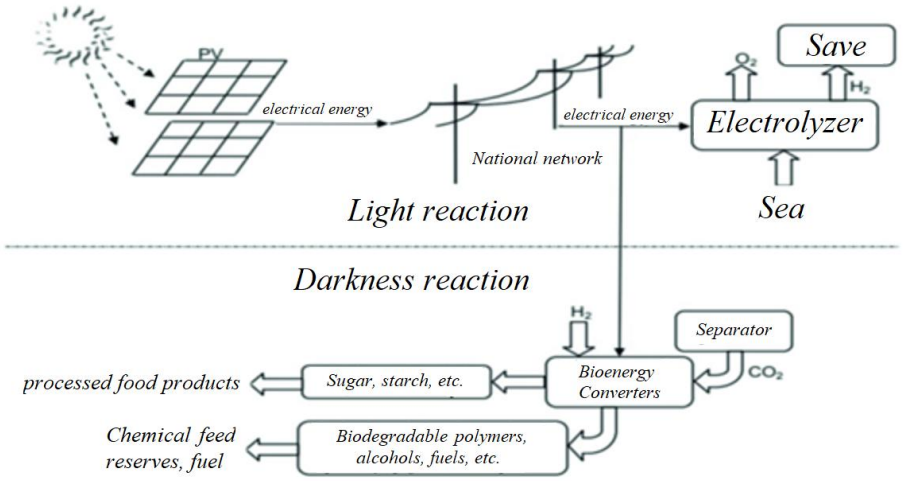


Figure 3.4. The concept of artificial photosynthesis.

It is known that hydrogen can be obtained from fossil fuels using technologies such as coal gasification, steam reforming of natural gas, water electrolysis, and thermochemical decomposition of water. Currently, hydrogen is primarily produced from natural gas, as this resource is available at a relatively low cost and has an established supply and distribution infrastructure. For similar reasons, despite emissions of CO_2, NO_x, and other gases, natural gas may remain a source of hydrogen in the near future.

The production of green hydrogen requires sustainable use of energy sources and water instead of fossil fuels. Sustainable energy sources can include renewable and nuclear energy. Thus, hydrogen facilitates the use of sustainable energy sources (solar, wind, hydro, geothermal, biomass, and others). Additionally, as mentioned above, there are promising biological methods for producing green hydrogen. The main concern is the quantities produced by such methods. Considering the methods mentioned above, apart from biological methods, there are three main products for controlling hydrogen production processes: electricity, heat, and light. Therefore, the key question here is how to make these processes green (environmentally friendly). This can only be achieved if these main drivers are supplied with green resources. In this regard, renewable sources become an excellent source for the production of these commodities. Consequently, it will be necessary to link hydrogen production processes with renewable sources.

To determine whether the hydrogen economy will become a reality, Figure 3.4 presents a clear illustration of the types of fuels humanity has used and depended on throughout the centuries. It shows that the journey

began with wood (which has a high carbon-to-hydrogen ratio), and then transitioned to coal, oil, and natural gas. As clearly seen in the figure, the carbon-to-hydrogen ratio in fuels has significantly decreased over time. It is now evident that a carbon-free society one with a carbon-to-hydrogen ratio approaching zero is not possible without hydrogen. This serves as a strong justification for why a hydrogen economy is necessary. Such a solution will help combat global warming and contribute to the development of green alternatives.

This system was installed in February 2007 at the Clean Energy Center (CEC) on the campus of Pamukkale University in Denizli, Turkey. The system is equipped with PV panels with a capacity of 5 kW. To monitor performance, half of the photovoltaic modules are mounted at a fixed tilt angle, while the other half are installed on solar trackers. The fixed-angle (45° south-facing) photovoltaic modules are located on the roof of the building. Each tracker consists of ten modules, with a nominal power of 1.25 kW.

A linear feedwater deionizer was selected to ensure the required water quality for the electrolyzer. A primary particulate water filter was also used before the deionizer. The system uses a PEM-type electrolyzer. A metal hydride (MH) storage tank was used for hydrogen storage. However, a drawback is that the hydrogen produced for MH storage must be of very high purity. Six OVONIC 85G250B storage tanks were selected. The system also includes a fuel cell for converting the produced hydrogen into electrical energy and is connected to the grid. Table 3.6 presents the efficiency of the individual system components. The system’s average hydrogen production over the course of one week is 4.43 kg.

Table 3.6
Efficiency of the Solar-to-Hydrogen Generator – Pamukkale University Components

Components	Energy efficiency (%)	Exergy efficiency (%)
PEC	11,2-12,4	8,9-11,5
Charge regulators	85-90	85-90
1-Inverter	80-85	80-85
Electrolyzer	56	52
Hydrogen Tanks	100	100
Fuel cells	30-44	24,5-38
2-Inverter	85-90	85-90

Energy efficiency is more useful than the energy consumed by each component; Exergy efficiency is more useful than the exergy consumed by each component.

Control questions.

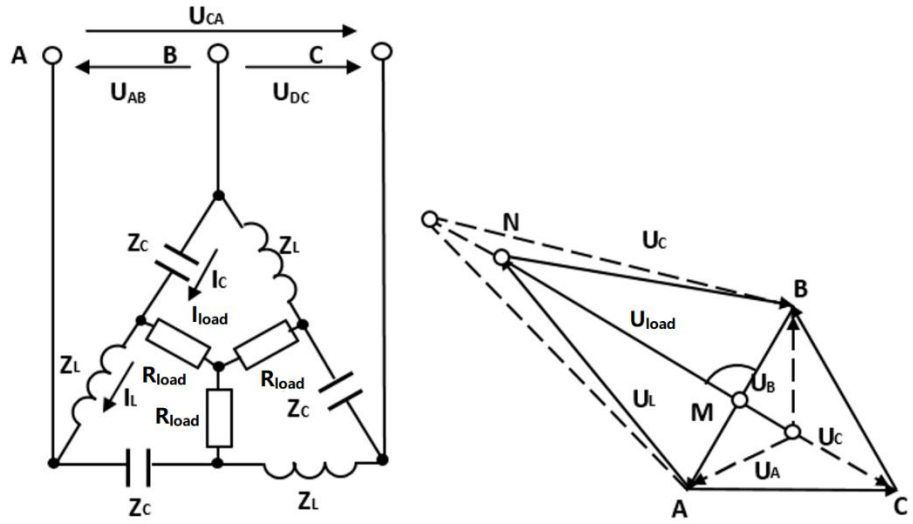
1. Define the concepts of photoelectrolysis and photoelectrochemical hydrogen production.
2. What do you know about hydrogen production technologies?
3. Define the concept of artificial photosynthesis for hydrogen production.

3.3. Inductive energy harvesting systems

If thyristor-controlled rectifiers are used as a voltage source, the voltage value remains almost unchanged even when the current value of the load changes, and its variation depends solely on the control voltage value. However, based on specific circuits, such as a current-controlled critical positive feedback circuit, the current value of the load remains

constant while the voltage value changes, and the rectifier performs as a current source. In industry, current source rectifiers are widely used in applications such as maintaining a constant arc current in electric arc furnaces, generating consistent mechanical tension in motors for cable and wire winding devices, and creating constant torque in load devices for experimental test benches.

The disadvantage arises when a DC motor is connected as a load to current sources (CS) through a rectifier, as the condition for maintaining the constant value of the DC current is violated. One of the drawbacks of a single-phase current source is the existence of an intermittent current regime and its significant effect on the load. To eliminate this disadvantage, multi-phase circuits for current sources are used (Figure 3.5a).



a) **b)**

Figure 3.5 – Schematic of a three-phase inductive-capacitive current source (CS) (a) and its voltage diagram (b)

The ease of use of asynchronous motors compared to DC motors, along with their lower mass-weight ratio and higher reliability, makes

them stand out. For this reason, it is advisable to create “current source – motor” electric drive systems based on asynchronous motors. The core of such a system is formed by an inductive-capacitive parametric converter, which serves to stabilize the current in the phase of the rotor of the asynchronous motor. The torque generated by the asynchronous motor is directly proportional to the actual value of the rotor current under the constant magnetic flux of the stator winding, and by adjusting the stabilized rotor current, a set of characteristics with *M=const* can be formed. If negative feedback with respect to speed is applied in the electric drive system, a set of characteristics with constant values can be generated.

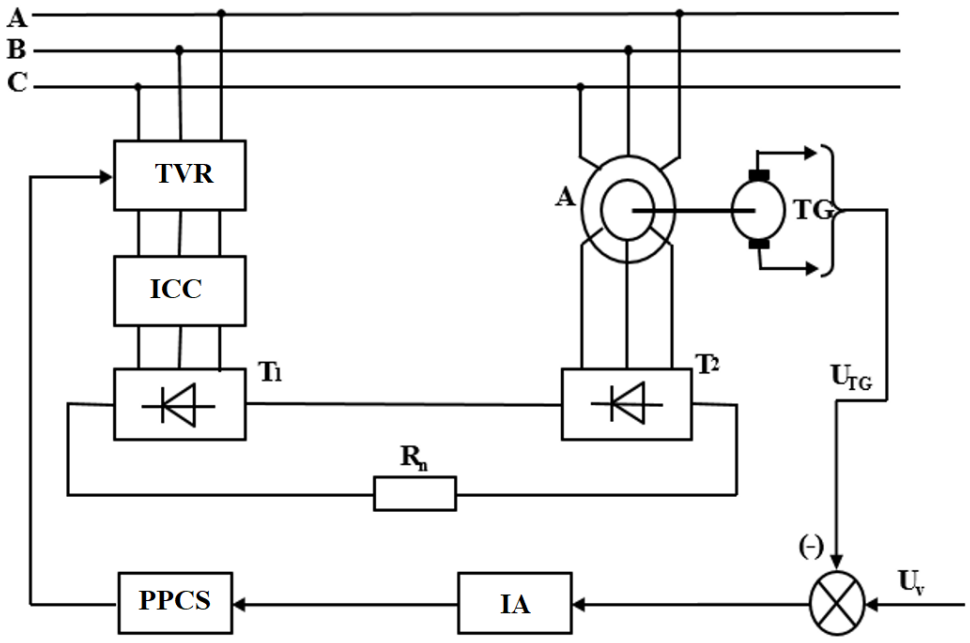


Figure 3.6. Functional diagram of the “current source - asynchronous motor” electric drive system

The functional schematic of the “current source – asynchronous motor” electric drive system is shown in **Figure 3.6**, where ICC –

Inductive-Capacitive Converter, TVR – Thyristor Voltage Regulator, T1 and T2 – rectifiers, A – asynchronous motor, TG – tachogenerator, PPCS – Pulse-Phase Control System, R_N – active resistance in the rotor circuit, A – intermediate amplifier. The resistance R_N in the rotor circuit ensures the operation of the rectifiers T_1 and T_2 connected in series.

The Impact of Converter Devices on Power Supply

The rapid development of semiconductor power converters and their use in DC and AC thyristor electric drives, as well as the use of ventel converters for power supply, leads to a decrease in the quality indicators of electrical energy as defined by the State Standard (SS), which in turn results in a decrease in the actual power factor of the power supply. Despite their technological efficiency and potential for further development, thyristor converters are causing issues with electromagnetic compatibility.

The change in the operating modes of converter devices directly affects the power supply sent to the electrical grid. Specifically, this occurs in the form of frequency and voltage fluctuations (up to 20% in a 10kV network). This happens during significant changes in active and reactive power. The increased use of ventil converters and their power output impacts the voltage quality of the supply source in many cases. Considering this, converters, especially those with adjustable settings, consume a significant amount of reactive power due to the shift in the first harmonic with respect to the voltage, leading to uneven operating patterns and high harmonic currents, which cause severe voltage distortion in the grid.

Such situations lead to losses in the power supply network. Therefore, the issue of increasing the power factor in modern electrical power systems and converter technology is currently of significant relevance. The controller-based ventil rectifiers are notable for their wide capabilities (compared to the simplicity of using basic controllers, with lower power losses), but they also have several drawbacks, the main one being the low power factor in wide voltage control.

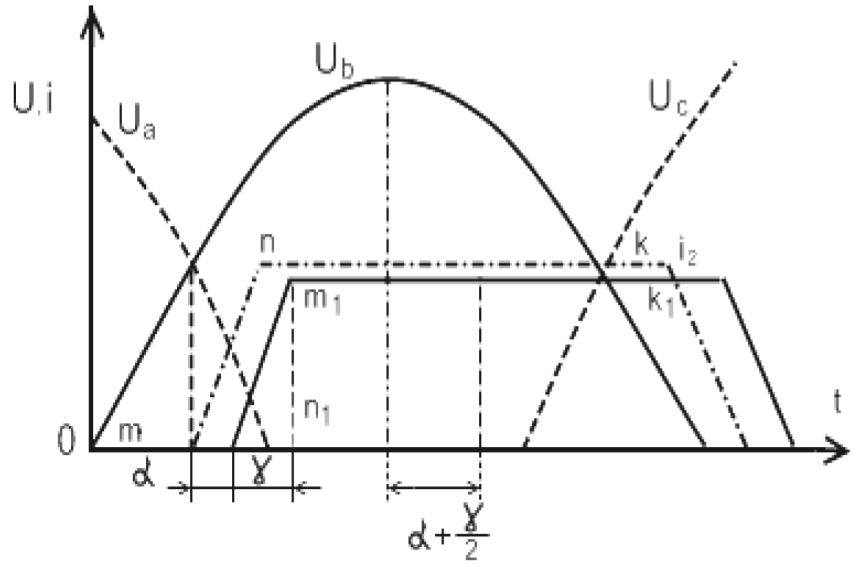


Figure 3.7. Displacement of phase voltage and current in a valve converter.

The consumption of reactive power by converter devices can be attributed to two main reasons. In the actual commutation process and the control of the rectifier voltage, the delay in the opening of the artificial ventil is the cause. These situations lead to a phase shift between voltage and current in the ventil circuit, which results in a decrease in the power factor and an increase in reactive power consumption.

In the operating mode of a three-phase converter device, when the current transitions from phase A to phase V, the voltages are not in

equality at the moment of switching but are delayed by several commutation times.

The amplitude voltage is equal to the phase current i_2 and the displacement angle U_2 :

$$\varphi_2 = \alpha + \frac{\gamma}{2}$$

Similarly, the primary current I_1 of the transformer is related to the voltage U_1 by the displacement angle.

The converter device in rectifier mode consumes active and reactive power from the alternating current network. In inverter mode, it supplies active power to the grid while consuming reactive power. If α =90˚ the converter in ventil mode consumes only reactive power from the alternating current network.

Reducing the rectified voltage increases the reactive power of the rectifier, loading the electrical network with reactive current, leading to increased active energy and voltage losses. The rectifier has two ways to reduce these losses: external and internal compensation.

External compensation consists of several compensation devices - capacitor banks generating reactive power to the network, synchronous compensators, and regulated and unregulated reactive power sources.

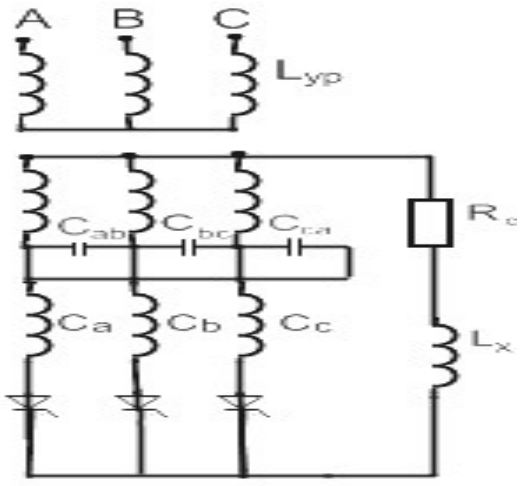


Figure 3.8. Principal diagram of the compensating converter unit.

This diagram forms a phase shift of the phase currents according to the interphase voltage ratio of the group of 3 phase capacitors. The problem of non-sinusoidality and higher harmonics has emerged with the use of powerful electrical receivers such as electric welders, arc furnaces for steelmaking, and both uncontrolled and controlled rectifiers.

The current problem of higher harmonics is a part of the electromagnetic compatibility issue of electricity consumers in power networks. For thyristor converters, higher harmonics are determined by the following expression: n=mk±1,where: *m*–number of phases in the rectifier, *k* – order of natural numbers.

For example, in the case of a 6-phase converter circuit. n=5, 7, 11, 13, 17, 19, 23, 25 and etc.

If in the 12-phase circuit n=11, 13 ,23, 25, 35, 37 and etc. If the 24-phase conversion circuit n=23,25,47,49,71,73, and etc.

In supply networks with rectifier converters, the consumed current is distorted due to the phase shift of the fundamental harmonic current relative to the supply voltage.

This indicates that higher harmonics are generated in the supply network, which leads to the consumption of reactive power from the grid. As a result, this increases energy losses and deteriorates the quality of electric power consumed by other users.

The higher harmonics of current and voltage cause errors in electrical measuring instruments.

In practice, this has significant importance, as induction-type active and reactive energy meters tend to show increased measurement errors due to these harmonics.

In many cases, the large size of these measuring instruments leads to an error increase of up to 10%.

Such errors negatively affect the accuracy of electricity billing. The non-sinusoidal waveform of voltage adversely impacts the operation of rectifier converters, causing distortion in the rectified current.

The operation of the power supply network at a frequency of 1000 Hz can cause a high-frequency resonance phenomenon, leading to an increase in the voltage amplitude at the resonant harmonic frequency.

As a result, the disturbance of harmonic norms in power networks leads to the following adverse effects in railway power supply systems.

1) causes additional losses of active power and electrical energy in network elements.

2) decrease in the power factor.

3) limits the use of capacitor banks. Because in this case, the resonance phenomenon or modes very close to high harmonic frequencies arise.

4) accelerates the wear and tear of the insulation of electrical devices.

5) generate high harmonic currents in the rectified voltage network.

6) leads to an increase in the error of active and reactive energy meters.

7) negative switching conditions in three-phase manifold engines.

8) improper operation of several relay protections leads to disruption of the state, quality, and control.

The appearance of a high harmonic reduces the operating norm of power supply networks. Currently, measures to reduce higher harmonics in the electrical network are as follows.

- Rational construction of power supply schemes.
- Application of multiphase rectifier circuits.
- Application of resonance filters.

The reduction of higher harmonic levels is achieved by increasing the number of rectified phases. However, the use of anode transformers for multiphase rectification introduces complexity, high cost, and reduced reliability.

As a result, in high-power converters, rectification schemes are generally limited to no more than 12-phase operation.

In other applications, it is recommended to suppress higher harmonic resonance using filters integrated with voltage and current limiting components.The filter typically consists of a series-connected inductance and capacitance circuit, tuned to the specific harmonic frequency.

The structural resistance of a high harmonic current filter is determined by the resistance of the reactors and capacitor banks operating at industrial frequency.

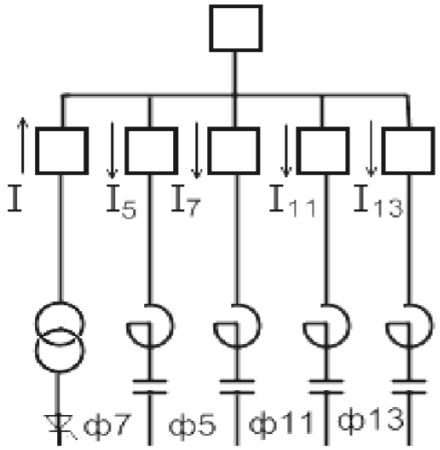
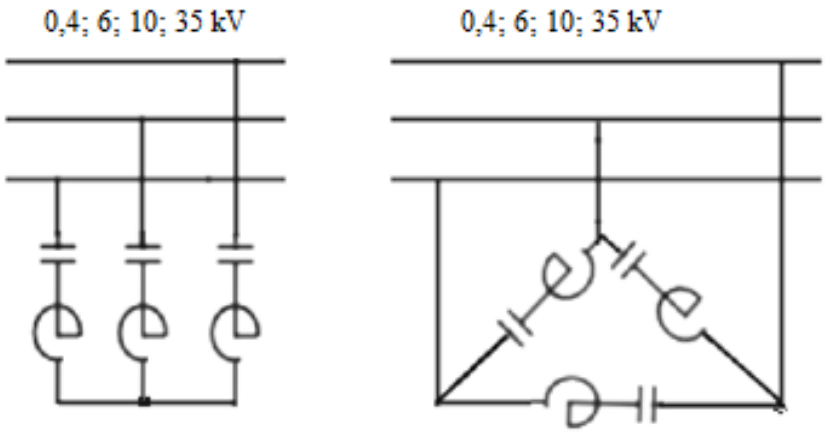


Figure 3.9. Connection diagram of harmonic filters 5, 7, 11, and 13.

Figure 3.10 shows a schematic diagram for connecting filters to a three-phase network.



a b

Figure 3.10 – Diagram of high harmonic power resonance filters: a–in star connection; b – in delta connection.

Energy sector - the field of national economy, science, and technology that encompasses the generation of various types of energy,

their conversion from one form to another, transmission over certain distances, delivery to users, and the utilization of energy in all sectors, as well as the theoretical and practical issues related to these processes.

Throughout human development, the growing need for different energy sources compelled people to utilize natural resources—such as firewood, coal, peat, and other fuels—as well as renewable sources like wind and water flow energy (windmills and watermills).

Later, with the advancement of science and technology—especially following the scientific and technological revolution in the second half of the 20th century—the demand for electrical energy increased sharply. These factors necessitated the rapid development of the energy sector.

Scientific and technological progress is reflected in the development of new methods for generating and converting energy, the creation of efficient equipment and technologies, the centralization of energy distribution, and more.

The science of alternative fuels deals with solving scientific and technical problems related to the potential energy of natural resources and its efficient use.

The development of energy is closely linked to the availability of a country’s energy resources. Coal, oil, natural gas, peat, firewood, shale, water, electricity, nuclear energy, wind, and solar energy are considered energy resources. Energy resources are divided into fossil fuels (coal, oil, gas, nuclear, peat, shale, firewood) and non-fossil fuel sources (water, wind, solar energy, and others). Fossil fuel-related energy resources are non-renewable, while those not related to fossil fuels are considered renewable resources.

To compare the amount of various fuel energy resources on a global scale, a conditional fuel unit (1 kg of fuel releasing 7000 kcal of heat when burned) has been adopted. The total potential reserves of all fuel resources worldwide (excluding nuclear energy) are equivalent to 25,000 billion tons of conditional fuel. Of this, 95% corresponds to solid types of fuel. The reserves of uranium and thorium, which are the primary sources of nuclear energy, along with the reserves in the world's oceans, amount to 69,000 billion tons of conditional fuel. The most commonly used natural energy resources (coal, oil, gas) are unevenly distributed among countries worldwide. In this regard, considering the energy resources of Uzbekistan, the country's energy sector is a key part of its national economy. Uzbekistan's energy system fully meets the fuel (coal, gas, oil) and electricity needs of the economy and population, and it also exports energy.

Energy, as an important sector of the national economy, is divided into hydroelectric and thermal energy. (Hydroelectric power – a branch that focuses on utilizing water resources for energy production. To harness the energy of water resources, the flow of water is converted into electrical energy using specialized infrastructure and equipment, namely hydroelectric power stations (HPS))

Control questions.

1. What do you know about inductive energy storage systems?
2. Explain the influence of converter devices on the power supply.
3. Tell us about the methods of energy accumulation.

3.4 A house with almost zero energy consumption, equipped with alternative energy resources

What kind of house is an energy-efficient house? Imagine a rural or urban residential building that consumes a very small amount of energy, produces energy for its own consumption, is provided with hot water, and does not lose heat. For the first time in Uzbekistan, such a model house was built in Nurafshan at the expense of UNDP and GEF funds.

Figure 3.11. Overview of an energy-efficient house.

What does a house that consumes almost zero energy look like, and what is it equipped with? The first such model house in Uzbekistan was built in the “Yoshlik” mahalla of the city of Nurafshan, Tashkent region.

The house was built with funds from the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF). Construction work continued until May 2022 and was completed on May 1. Below we will consider the details of the energy-saving house in Figures 3.12-3.15.

According to Article 2 of the EU Building Energy Efficiency Directive, almost zero or a very small amount of necessary energy must be supplied from renewable sources, including energy generated by renewable energy technologies installed directly in or near the house.

The thermal insulation of the exterior walls, floors, and roof of this type of building provides high thermal insulation, which significantly reduces energy consumption compared to energy consumption in uninsulated houses of the traditional type.

Home comfort is ensured by “green” materials, equipment and technical solutions, maintaining the optimal temperature in winter and summer. The home’s environmental sustainability is that it reduces the carbon footprint by reducing greenhouse gas emissions.

- **The house has the following features:**
- low energy consumption;
- high-performance construction shell;
- adequately designed ventilation, heating, and air conditioning systems, as well as power systems;
- the possibility of energy production on the territory of the building.

Figure 3.12. Location of the energy-saving house and storage systems.

Optimized building location

The building is designed to maximize heat gain from solar radiation during the winter season and to minimize this heat gain during the summer.

Heat pump

«Air-to-water» heat pumps are a cost-effective and energy-efficient solution for heating both modern and older homes. This type of heating system provides a clean and sustainable form of heat and helps reduce energy costs.

Batteries for solar panels installed directly near the house Figure 3.13.

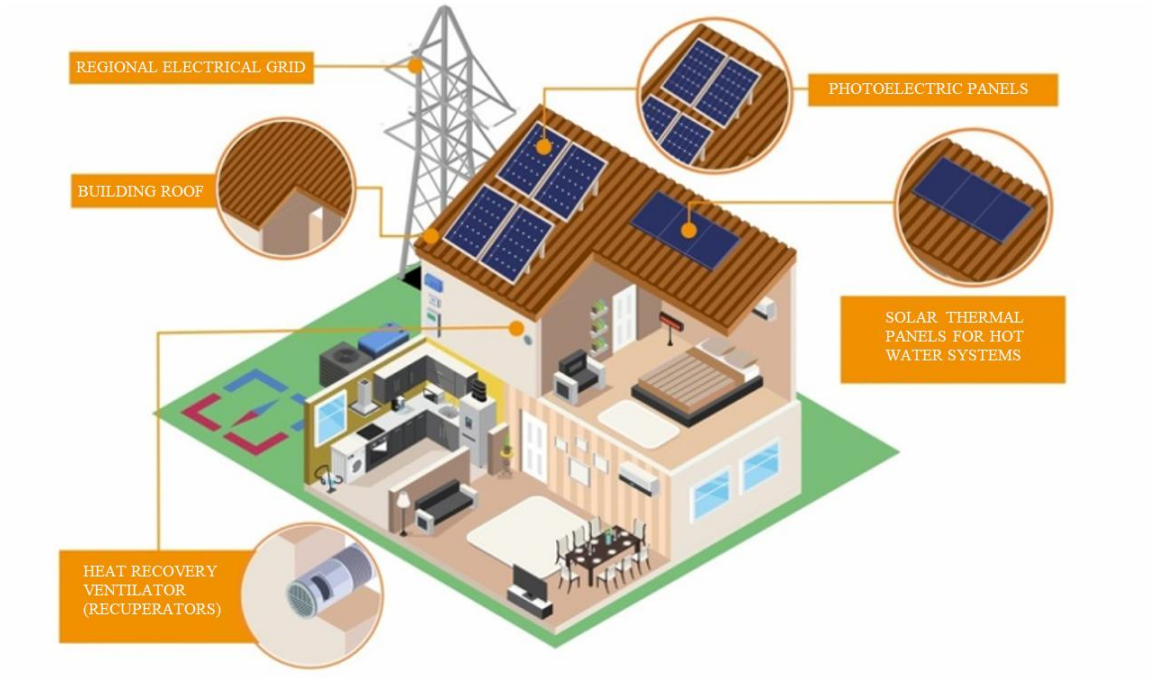


Figure 3.13. Constructive layout systems of an energy-efficient house.

Part of the roof Hydrophobic waterproofing material with a layer of protective foil 3 mm thick:

• 150 mm thick insulating glass wool;

• High-density vapor barrier membrane with a thickness of 2 mm.

Solar collectors and photovoltaic panels for hot water and electricity supply are installed on the roof.

Photoelectric panels

The photovoltaic panels installed on the roof produce 15 kW/hour of energy, which is sufficient to meet all the needs of the house.

Local electrical grid

Excess energy generated by solar panels is sold to the local electrical grid.

Figure 3.14. A heat recovery ventilator (recuperator) is installed on the wall of the building.

Figure 3.14. Energy-saving house insulation materials.

Energy-saving windows

The use of three-layer glass with the correct size, placement, and low thermal conductivity reduces heat loss and increases the absorption of sunlight.

Wall insulation:

• External wall made of M-75 type baked brick;

• Stone fiberboard with a thickness of 100 mm and heat and sound insulation;

• wind and waterproofing membrane with a thickness of 2 mm;

• ventilation gap 6 mm wide;

• Fiber cement slabs 6 mm thick.

Floors:

• 75 mm thick extruded polystyrene foam;

- 5 mm thick double-layer waterproofing for hydro-isolation.

The general view of a house with nearly zero energy consumption is shown in Figure 5

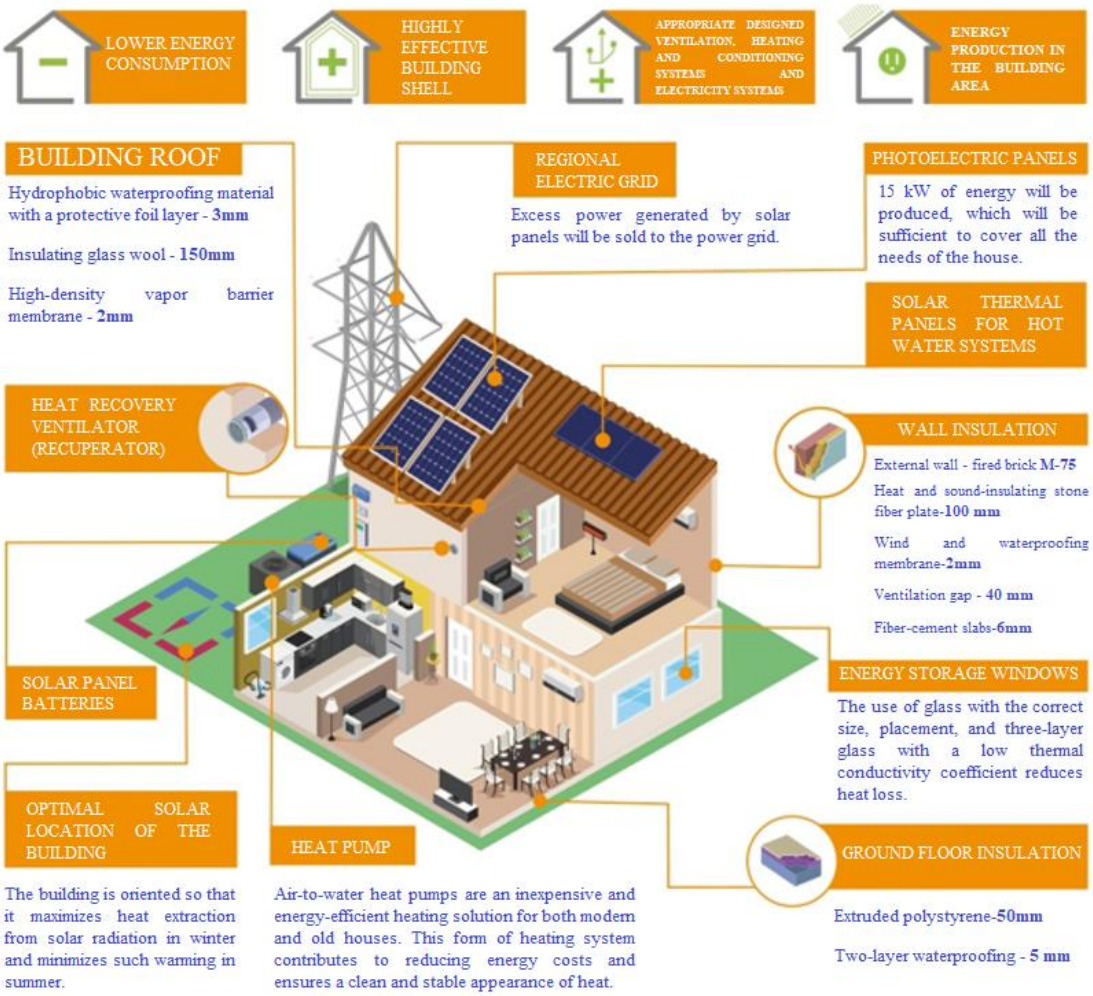


Figure 3.15. General view of a house with nearly zero energy consumption.

Chapter IV

ENERGY TRANSFER METHODS

4.1. Electricity transmission.

Transmission of electric current — The transmission of electrical energy from a power station over a certain distance is carried out using electrical equipment and devices. The components of the electrical transmission system include step-up and step-down transformers, overhead transmission lines suspended on poles, underground cable lines, and protective automation devices designed to prevent failures and ensure safety. When energy is transmitted through the line, a certain amount is lost due to the resistance of the wires. The amount of energy loss is proportional to the square of the current and the resistance of the wire. To reduce the wire resistance, its diameter must be increased. However, to save on conductor material, step-up transformers are installed at the beginning of the transmission line and step-down transformers at the end. As a result, the transmitted power (energy) remains unchanged. The higher the voltage, the lower the current flowing through the line. The power transmission capacity of the line is directly proportional to the square of the voltage, while energy loss in the line is inversely proportional to the square of the voltage. The voltage level of transmission lines depends on the transmission distance and the amount of electrical power being transmitted.

Transmission lines can be constructed either as underground or underwater cables, or as overhead lines. In cable-based transmission lines, the power transmission capacity is limited by the line’s active resistance, while in overhead lines, it is limited by inductive resistance. In practice,

the inductive resistance of overhead lines is several times greater than their active resistance.Therefore, in order to transmit very large amounts of power over long distances using alternating current (AC) through overhead lines, measures are taken to reduce the effects of inductive resistance. These measures include the use of synchronous or capacitor-based compensators, inductive reactance devices (chokes) connected in parallel with the line, and capacitive reactance devices (capacitor banks) connected in series with the line. Alternating current transmission lines are always three-phase. Electrical energy can be transmitted not only via alternating current, but also through direct current (DC). The amount of power transmitted through a line depends on the voltage of the current and the length of the transmission line.

Power transmission lines consist of positive and negative polar wires. To achieve high voltage in the line, transformers at the beginning of the line convert the amplified alternating voltage into direct current using rectifiers. At the end of the line, inverters convert the direct current back to alternating current, which is then transformed to low voltage using transformers and distributed to consumers.

Overhead power transmission line — This is a structure used for the transmission and distribution of electrical energy over long distances. It consists of one or more uninsulated electrical conductors (typically multiplied by three for three-phase power), suspended by towers or poles.

Since most of the insulation is provided by the surrounding air, overhead power transmission lines are generally considered the most cost-effective method for transmitting large amounts of electrical energy.

Towers for building transmission networks are made from laminated wood, steel or aluminum (in the form of lattice structures or tubular poles), concrete, and occasionally reinforced plastics. The uninsulated wire conductors used in the network are usually made of aluminum (either solid, steel-reinforced, or reinforced with composite materials such as carbon or glass fibers). However, copper wires are sometimes used in medium-voltage distribution systems and for low-voltage connections to consumer buildings. The primary goal in designing overhead power transmission lines is to prevent dangerous contact with the line and to provide reliable support for the conductors, maintaining adequate clearance between live conductors and the ground. This ensures resilience against storms, ice loads, earthquakes, and other potential hazards. Today, overhead lines commonly operate at voltages exceeding 765,000 Volts between conductors.

Depending on the operating voltage

Overhead power transmission networks are classified in the electrical power industry based on their voltage range:

- **Low Voltage** (LV), less than 1000 Volts, used for connections between residential or small commercial customers and utility services.
- **Medium Voltage** (MV; distribution), ranging from 1000 Volts (1 kV) to 69 kV, used for distribution in urban and rural areas.
- **High Voltage** (HV; subtransmission under 100 kV; 115 kV and 138 kV are typical for subtransmission or transmission), used for

transmitting large amounts of electrical energy and for connecting very large consumers.

- **Extra High Voltage (EHV; transmission)** — from 345 kV, up to approximately 800 kV, used for transmitting very high power over long distances.
- **Ultra High Voltage (UHV)**, often associated with ±800 kV DC and ≤1000 kV AC.

Based on network length.

Overhead transmission networks are typically classified into three categories based on network length:

- Lines shorter than 50 km are usually referred to as short-range power transmission networks.
- Lines between 50 km and 150 km are generally called medium-range power transmission networks.
- Lines longer than 150 km are considered long-range power transmission networks.

This classification is mainly done for the convenience of energy professionals in analyzing the operation of power transmission networks.

For overhead networks, structures take various forms depending on the type of network. The structures can be as simple as wooden poles directly installed on the ground, which are built by attaching one or more cross poles to support the conductors. Tubular steel poles are typically used in urban areas. High-voltage networks are often implemented with lattice-type steel towers or poles. For long-distance areas, aluminum towers can be installed using helicopters. Concrete poles are also used.

There are also poles made from strong plastics, but their high cost limits their use.

Each structure must be designed to support the loads imposed by the conductors. It must also withstand the dynamic loads caused by the weight of the conductors, as well as the effects of wind, ice accumulation, and vibration. When the conductors are aligned in a straight line, the towers are primarily designed to resist only the weight, as the tension in the conductors approximately balances out with no resulting force on the structure. At their ends, the supported flexible conductors take on a catenary shape, and much of the analysis for building overhead power transmission lines relies on the characteristics of this shape.

In the design of large power transmission networks, there may be several types of towers. These include “tangent" (or “suspended” or “line” towers, as referred to in the UK) designed for most positions, and heavier, more robust towers used to bend the line at an angle, typically located at dead-end (termination) points or at major river or road crossings. Depending on the design criteria for a specific line, semi-flexible type structures may rely on the weight of conductors balanced on both sides of each tower. More rigid structures can remain upright even if one or more conductors are broken. Such structures can be installed at intervals in power transmission networks to limit the scale of cascading tower failures.

The foundation of the tower structure can be large and expensive, especially if the soil conditions are poor, such as in marshy areas. Each structure can be significantly stabilized using its guy wires to resist some of the forces applied by the conductors.

Power networks and supporting structures can be a form of visual pollution. In some cases, to prevent this, networks are buried underground; however, these "underground" networks are more expensive and therefore not widespread.

For a single wooden pole construction, the pole is placed in the ground, and the insulators are attached to the crossarms. For an H-type wooden pole construction, two poles are placed in the ground, and then a crossarm is extended on both sides of the poles. The insulators are attached between the ends and the middle of the crossarm. Lattice tower constructions have two common forms. One has a pyramidal base, followed by a vertical section with three cross arms at the top. Deformation insulators are attached to the crossarms. The other has a pyramidal base, which extends to four support points. On top of this, a structure similar to a horizontal truss is placed.

Control questions.

1. What do you know about inductive systems for energy harvesting?
2. What are the types of insulated conductors and cables?
3. Tell me about the methods of energy harvesting.

4.2. The importance of energy use in the development of society.

The progress of human society and its achievements is directly linked to the level of production and the creation of essential material conditions for people’s lives. Scientific-technical and social progress typically occurs alongside an increase in energy consumption and the adoption of new, more efficient forms of energy.

The energy consumed by modern machines amounts to a vast quantity. This can be expressed through the following comparison: even if the entire global working population labored for a full year, eight hours a day, with maximum physical effort, they would not be able to produce even one-hundredth of the energy generated by modern thermal and hydroelectric power stations. Energy consumption will continue to rise in the future, provided it supports the growth of production levels.

Economic progress can only be accelerated by increasing energy consumption and production levels through the use of advanced, automatically controlled machines that perform physical and non-intellectual tasks.

The demand for energy has been continuously increasing. This, in turn, has created the need to search for new energy resources and develop new methods for converting energy from one form to another. In the present era, the use of various energy sources—solar energy, the chemical energy of organic fuels, the mechanical energy of rivers, seas, and oceans, wind energy, and nuclear energy derived from the fission of heavy nuclei—is considered conventional. Figure 4.1 illustrates the dynamics of energy resource utilization in various aspects of human activity worldwide over the last 20 years of the 19th century and throughout the 20th century. It shows that the use of all types of energy resources has intensified significantly. While the relative increase in coal usage has been relatively steady year by year, accounting for approximately 30% of total energy resources used by the end of the 20th century, the relative growth in the use of gas and oil has risen sharply. The primary reason for this is the lower costs associated with their transportation and utilization.

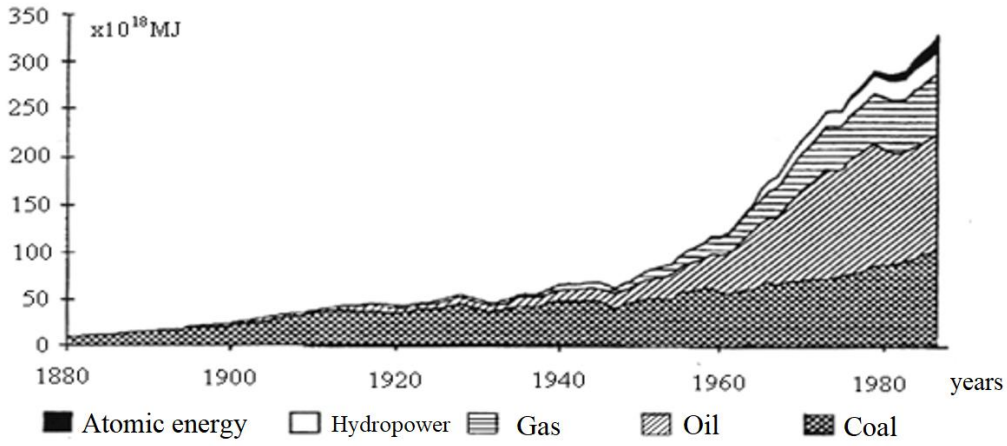


Figure 4.1: Dynamics of Global Energy Resource Utilization

Over the past two centuries, the global population and the demand for energy have increased dramatically. During this period, the Earth's population grew sixfold, while the demand for energy per capita increased fivefold. Figure 4.2 illustrates the changes in global primary energy consumption and its per capita share from the late 19th century through the 20th century.Translated and Refined Caption for Figure 4.2.

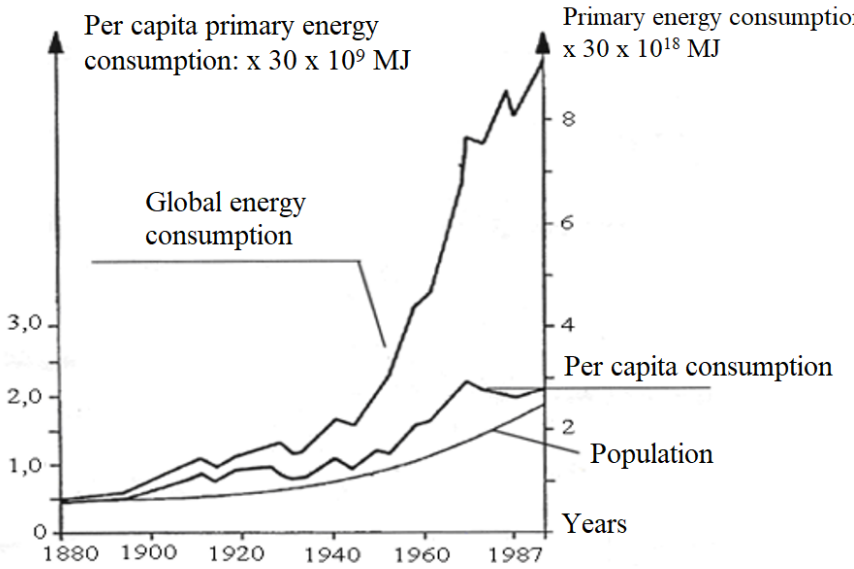


Figure 4.2. Changes in global primary energy consumption and its per capita amount.

The intensive growth in energy demand necessitates tasks such as discovering new reserves of energy resources, utilizing them efficiently, and identifying alternative energy sources.

In the present era, the potential of all energy resources available on Earth has been estimated in the following quantities in terms of conditional fuel units (tons of conditional fuel, t.c.f.):

- Chemical energy of fossil fuels – 1.77×10^{13}
- Nuclear energy – 0.67×10^{14}
- Thermonuclear energy – 1.22×10^{17}
- Geothermal energy – 1.0×10^{14}
- Solar energy reaching the Earth's surface – 0.82×10^{14}
- River energy (annual) – 0.4×10^{10}
- Wind energy (annual) – 2.1×10^{11}
- Bioenergy from forests (annual) – 0.5×10^{10}
- Streamflow energy (annual) – 0.86×10^{14}

The energy system that produces electricity and thermal energy, during its development process, is influenced by a number of other systems and, in turn, also affects them (Figure 4.3).

The construction of the energy system and its operating conditions are directly related to natural factors (such as the presence of water bodies, the geographical location of energy resources, and the location of consumers). The state of the biosphere and the level of pollution caused by the operation of energy facilities impose certain limitations on the technical characteristics and operating conditions of the energy system.

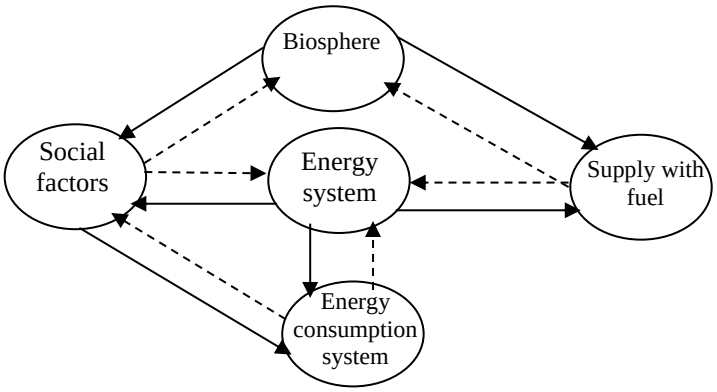


Figure 4.3: Diagram of the Energy System's Interconnections with Other Systems

The management of the energy system takes into account not only its impact on the biosphere but also the social functions of the fuel supply system, as well as the influence of industry, transport, and other factors.

Energy is considered one of the sources that negatively affect the environment and human health. Therefore, the development and implementation of technologies to reduce its impact is currently one of the most urgent tasks facing scientists and specialists in this field.

Use of Energy Resources in the World and in Our Republic

Energy is the fundamental basis of natural phenomena, culture, and human life. At the same time, energy is a quantitative indicator of various forms of matter movement. Depending on its type, energy is classified into chemical, mechanical, electrical, nuclear, and other forms. The types of energy that can be utilized by humans exist in material objects known as energy resources.

Among all types of energy resources, those that are widely used for practical needs are referred to as primary energy resources. These include fossil fuels such as coal, oil, and gas, as well as natural sources like rivers,

seas and oceans, solar energy, wind, and the thermal energy of the Earth's interior (geothermal energy).

Energy resources are divided into renewable and non-renewable types. Renewable energy resources are those that are naturally replenished on a continuous basis by nature, such as water, wind, and others. Non-renewable energy resources refer to those that were accumulated in nature over long geological periods but are no longer being formed under current geological conditions—such as coal.

Energy that is obtained directly from nature (such as fuel, water, wind, geothermal heat, nuclear energy, etc.) is called primary energy. When this energy is transformed by humans through special devices into another form, it becomes known as secondary energy.

The designation of power plants reflects the type of primary energy used. For example, a thermal power plant (TPP) converts thermal energy (primary energy) into electrical energy (secondary energy). Similarly, a hydroelectric power plant (HPP) converts water energy into electrical energy, and a nuclear power plant (NPP) converts nuclear energy into electrical energy.

The process of obtaining the required type of energy and supplying it to consumers is carried out in the energy production process. This process can be divided into five stages.

1. Extraction and concentration of energy resources: Mining and preparing fuel, creating pressure through hydraulic structures, etc.
2. Transfer of energy resources to conversion devices: This is done through land or water transport or by pumping water, gas, etc., through pipelines.

3. Conversion of primary energy into a form of energy suitable for distribution and consumption under existing conditions (usually electrical and thermal energy).
4. Transmission and distribution of converted energy.
5. Consumption of energy in its transmitted and converted forms.

If we consider the energy of the primary energy resources used as 100%, the energy that performs useful work accounts for only 35-40%, while the remaining portion is lost. The majority of this loss corresponds to thermal energy.

Energy loss is determined by the technical characteristics of the energy machines currently in use. Energy resources are unevenly distributed across the regions and countries of the world. The areas where these resources are abundant often do not align with the areas of high consumption. More than half of the world's oil reserves are located in the Near and Middle East, where consumption is 4-5 times lower than the global average.

Approximately 60% of the territory of the Republic of Uzbekistan is considered prospective for oil and gas reserves and their utilization. Based on extensive exploration and geological-geophysical studies conducted over many years, the republic's territory has been divided into five oil and gas regions (Ustyurt, Bukhara-Khiva, Southwestern Hissar, Surkhandarya, and Fergana). The total resources of oil and condensate in these regions amount to 5,780 million tons.

Uzbekistan is the only country among the Commonwealth of Independent States that has not reduced the rate of extraction of hydrocarbon fuel products but has instead increased their production

volume during the years of independence. Up until 1991, 75% of the Republic's demand for oil products was met through imports. By 1995, the annual extraction of oil and condensate had increased from 1.5 million tons to 7.6 million tons.

Approximately 90% of the oil extracted in the Republic comes from the Bukhara-Khiva region.

Table 4.1

Natural gas production and reserves in some countries of the world

Country	Mining, billion m^3	Reserves, billion m^3
Russia	560,90	48140
USA	539,07	4711
Canada	167,83	1840
Indonesia	74,23	2045
Uzbekistan	54	5000
Malaysia	38,52	2258
Mexico	33,06	1808
Australia	29,54	550
China	20,11	1160
Thailand	16,33	198
Vetnam	10,313	170
New Zealand	5,65	68
Japan	2,28	39

Global natural gas consumption reached nearly 3 trillion cubic meters annually by 2005. Natural gas accounts for 22% of the world's fuel and energy complex. Uzbekistan's natural gas reserves are approximately

5 trillion cubic meters, constituting about 1.3% of global reserves (see Table 4.1). According to data, 187 hydrocarbon deposits were identified and explored in Uzbekistan by 2004, of which 91 are gas and gas condensate deposits. Currently, the country operates 25 compressor stations. One of the major stations, “Kokdumoloq” produces 4.2 million cubic meters of gas per day.

The high level of technical progress and the achievements it has attained today would not have been possible without the use of a qualitatively new type of energy, particularly electrical energy. Electrical energy is widely used in modern human life. It powers various mechanisms in industry and agriculture, is directly involved in technological processes, and is extensively applied in transportation and cultural-domestic life. The operation of modern communication tools such as telephones, telegraphs, radios, and televisions is also based on the use of electrical energy. Without electrical energy, the development of cybernetics, computing technology, and space technology would not have been feasible. The primary advantage of electrical energy lies in its ability to be easily transmitted over long distances and converted into other forms of energy relatively simply and with minimal loss. Electrical energy is currently the most widely used form of energy by humanity.

Due to the aforementioned reasons, significant attention has been devoted to the development of the electric power industry worldwide, including in our country.

History of the Development of Uzbekistan’s Energy Sector. In 1914, the capacity of Turkestan’s energy sector exceeded 20,000

horsepower, with the total number of electric motors in the 51 existing power plants not surpassing 500.

By 1917, the total capacity of power plants in the territory of what is now the Republic of Uzbekistan was 3,000 kW, producing 3.3 million kWh of electrical energy annually.

A significant milestone in the development of Uzbekistan's energy sector was the formulation of a plan to electrify the Turkestan region. In 1923, construction began on a hydroelectric power plant (HPP) on the Bozsu canal near Tashkent. In 1926, the first phase of the Bozsu HPP, which had a capacity of 2,000 kW and was the largest in Central Asia at the time, was commissioned.

When Uzbekistan's energy system was established (in 1934), the growth in electrical energy capacity was primarily driven by a series of hydroelectric power plants built along the Chirchiq-Bozsu direction, with a total capacity of 180,000 kW.

In 1939, the Quvasoy State District Power Station (DRES) with a 12 MW capacity condenser turbine unit and the Tashkent Textile Combine's thermal power plant with two 6 MW turbines were launched based on the Qizilqiya coal basin.

The construction of power plants and the development of industrial enterprises led to the necessity of building main electrical transmission lines. Along with the launch of the Qodir HPP, the first two-circuit 35 kV transmission line was put into operation to deliver electricity from there to Tashkent.

In 1939-1940, 110 kV overhead lines connected the Quvasoy DRES to Andijan city, and the Tavoqsoy HPP to Chirchiq city.

During the years of World War II, a 35 kV circular overhead line was completed, connecting the areas around Tashkent city, and a large-capacity “Severnaya” substation was built to supply electricity to the northern industrial zone.

In 1943, the construction of the Farhod Hydroelectric Power Plant with a capacity of 125 MW began on the Syr Darya River, enabling the development of the chemical industry and the supply of water for irrigated land. Water reservoirs were built, which made it possible to develop over 700,000 hectares of land in Uzbekistan and neighboring republics. The development of the Angren coal basin led to the construction of two thermal power plants: the Angren TPP with a capacity of 600 MW and the Olmaliq Thermal Power Center (Thermal Power Center).

In 1972, the Syr Darya Thermal Power Plant (TPP) launched the first large critical-parameter (steam pressure 240 atm., temperature 545°C) 300 MW power block in Central Asia. Currently, there are 10 such power blocks in operation at the Syr Darya TPP.

Development and Prospects of the Electric Power Industry in the Republic of Uzbekistan.

Today, the energy sector is the foundation of progress for any country. Opportunities for economic development, a comfortable life for the population, education, medical services, social welfare, and the stable operation of communal services are all created precisely within this field.

However, without transitioning the sector to a market economy, it is difficult not only to maintain the vast energy infrastructure in working condition but also to increase electricity generation volumes.

Achieving the set goals is possible only by applying the most advanced achievements in the construction and operation of power plants, electrical networks, and alternative energy infrastructures.

Developing the energy sector based on market principles creates conditions for competition, which makes it possible to attract not only resources but also highly qualified engineers who possess modern knowledge, experience, and technologies for project implementation.

In this way, it becomes possible to introduce into Uzbekistan’s energy system the equipment and methodologies that will remain relevant and effective for many decades to come.

The Ministry of Energy was established a little over two years ago.

The main reason for the reform was the inefficiency and lack of adaptability of the previous structures.

Some of them failed to meet modern objectives such as ensuring a coordinated approach to the development of the fuel and energy complex, introducing innovative management principles, and creating a healthy competitive environment and favorable investment climate in our country.

At present, the Ministry of Energy coordinates the development of the entire fuel and energy complex of Uzbekistan.

Together with its subordinate organizations, the Ministry manages, at the state level, the processes of production, delivery, distribution, and consumption of electric and thermal energy, as well as the extraction, processing, transportation, distribution, sale, and use of oil, gas, and coal products.

The ongoing changes in the fuel and energy complex have required a fundamental reform of the entire basic structure.

In particular, at the beginning of 2019, the joint-stock company “Uzbekenergo” was completely reorganized, and based on it, three new joint-stock companies were established: “Thermal Power Plants,” “National Electric Grids of Uzbekistan,” and “Regional Electric Grids.”

The purpose of this reorganization was to introduce modern methods for the production, transmission, distribution, and sale of electrical energy.

At the same time, the process of reforming the oil and gas sector began, marking the completion of the transition from one management model to another.

A new organizational structure of “Uzbekneftgaz” JSC was created, with redundant intermediate management levels eliminated.

From the structure of “Uzbekneftgaz” JSC, “Uztransgaz” JSC was separated and designated as the sole operator responsible for purchasing natural gas from production companies for further transportation, including export and import operations, as well as for selling gas to consumers connected to main gas pipelines.

On the basis of the regional gas supply divisions of “Uztransgaz” JSC, a new joint-stock company, “Hududgazta’minot” JSC, was established.

It is responsible for operating gas distribution networks and supplying natural and liquefied gas to the population and social sector facilities.

Since the establishment of the Ministry of Energy, a number of fundamental changes have taken place.

Particular attention has been given to the development of energy production based on renewable energy sources (RES).

The adoption of the Law of the Republic of Uzbekistan “On the Use of Renewable Energy Sources” in May 2019, as well as the development by the Ministry of Energy of the “Concept for the Development of Renewable Energy Sources in the Republic of Uzbekistan for 2019–2023,” confirm this priority.

At the end of April 2020, the Government of Uzbekistan approved the “Concept for the Supply of Electric Power in the Republic of Uzbekistan for 2020–2030.”

This document was developed by the Ministry of Energy in cooperation with related ministries, agencies, and international consultants.

The main goal behind these efforts is to ensure the country’s energy security — that is, to create conditions in which both the population and the entire economy are continuously supplied with electricity and fuel.

This implies increasing energy generation capacities, modernizing power grids, and improving the systems of energy consumption accounting and control. These are complex but entirely achievable objectives.

Public–Private Partnership (PPP).

One of the successful steps toward transitioning to market relations in the energy sector is the implementation of energy projects, including

renewable energy (RES) generation, based on a completely new model for Uzbekistan — the public–private partnership (PPP).

Today, this model has become the foundation for all newly built and planned power plants. Thus, the launch of new power plants — including thermal (TPP), solar photovoltaic (SPP), and wind (WPP) power stations — serves as a clear example of the ongoing market transformations in the country's energy sector.

PPP-based projects are implemented through tenders, i.e., on a competitive market basis.

In this regard, the International Finance Corporation (IFC) of the World Bank Group, the Asian Development Bank (ADB), and the European Bank for Reconstruction and Development (EBRD) are providing technical assistance to adopt best international practices and to conduct transparent tenders.

It is important to note that the tender winner is responsible for the design, construction, and operation of the new power plant.

A long-term agreement, usually for 20 to 25 years, is concluded with the investor for the purchase of the electricity produced.

The most advantageous electricity tariff offered becomes the main criterion for winning the tender.

However, before submitting their bids, tender participants must undergo a pre-qualification process, during which they must demonstrate their high level of experience, sufficient financial capacity, and ability to implement and sustain such projects.

Thus, the market principles that have been actively introduced in Uzbekistan's energy sector over the past three years have made it possible to create a healthy competitive environment.

The growing interest and participation of independent power producers clearly confirm the success of these reforms.

Current Situation.

As of today, a total of 17 power purchase agreements (PPAs) have been signed, marking an important stage in the creation of a competitive environment in the energy sector.

Among the independent power producers are such major companies as Total Eren SA (France), Abu Dhabi Future Energy Company – Masdar (UAE), Aksa Enerji Üretim A.Ş. (Turkey), and ACWA Power (Saudi Arabia).

Regardless of the reforms taking place in the energy sector, the main outcome must remain the same — ensuring a stable supply of energy resources for the population and the economy of Uzbekistan.

Considering analytical forecasts that predict a twofold increase in electricity demand within the next decade, one of the key tasks of the Ministry of Energy and the fuel and energy complex is to construct new power plants, including thermal power plants (TPPs), to develop renewable energy sources (RES), to identify and implement new projects based on renewable technologies, and to expand the use of hydropower plants (HPPs), including small-scale hydropower facilities.

By the end of 2021, it was planned to increase power generation capacity from 14,000 MW to 15,800 MW, i.e., to launch an additional 1,800 MW of new capacity.

As a result, electricity generation capacity would grow by 50 percent compared to 2016.

Under the public–private partnership (PPP) model, three thermal power plants with a total capacity of 710 MW were to be commissioned in the Tashkent region, two thermal power plants with a combined capacity of 444 MW in the Bukhara and Khorezm regions, and two solar photovoltaic power plants with a total capacity of 200 MW in the Navoi and Samarkand regions.

By commissioning new modern thermal power plants, it will be possible to save about 1.5 billion cubic meters of natural gas annually, creating additional opportunities for electricity generation to meet the needs of the population.

By 2025, the total capacity of the national energy system is expected to reach 25.6 GW, including:

18.8 GW from thermal power plants,

2.5 GW from hydroelectric power plants, and

4.3 GW from solar and wind power plants.

Physically outdated and inefficient equipment will gradually be decommissioned.

By 2030, the total installed capacity is projected to reach 29,200 MW, which is twice as much as the current level.

As a result, by 2030 the total electricity generation will amount to 120.1 billion kWh, compared to 66.4 billion kWh produced in 2020.

Modernization.

No matter how many new power plants are built today, the complete modernization of existing thermal and hydroelectric power plants remains

a key priority — specifically, the introduction of equipment and technologies based on the latest achievements in energy efficiency.

A vivid example of this is the installation of combined-cycle gas turbine (CCGT) units, produced by leading foreign companies, at existing thermal power plants across the country.

Each modernization project embodies the work of hundreds of national and international specialists.

Without their professional expertise, it would be impossible to carry out precisely calculated projects that consider all existing conditions — from the operational lifespan and capacity of a particular thermal power plant to both standard and site-specific factors.

Given the complexity of such technical facilities as power stations, this process simply cannot be otherwise.

The figures clearly reflect the real situation. If in 2000, Uzbekistan’s energy system had an installed capacity of 7,750 MW, and in 2016 — 10,830 MW, this means that within those sixteen years, approximately 3,000 MW of new capacity was commissioned.

At present, the total installed capacity of the national energy system amounts to 14,131 MW — that is, more than 3,000 MW of new capacity has been brought online in just the past three years.

During 2017–2021, such a sharp increase in power generation capacity was achieved mainly through the commissioning of new combined-cycle gas turbine (CCGT) units at the Navoi, Tolimarjon, and Tashkent thermal power plants.

In addition, in 2019, the new Turakurgan Thermal Power Plant with a capacity of 900 MW was launched.

As a result of introducing modern, energy-efficient equipment and technologies, the specific fuel consumption at thermal power plants decreased by 11%, from 375.8 g/kWh in 2016 to 333.9 g/kWh in 2020 (a reduction of 41.9 g/kWh).

Furthermore, the Syrdarya Thermal Power Plant is currently undergoing modernization, which will increase its capacity by 150 MW.

The Farhad Hydropower Plant is also being modernized, and this work will add an additional 13 MW to its installed capacity.

As a result of ongoing modernization efforts, the total capacity of Uzbekistan’s energy system is planned to reach 25,600 MW by 2025 and 29,200 MW by 2030.

Alongside the increase in power generation, it is also necessary to modernize and renew the electricity transmission infrastructure.

Only by combining these two directions — expanding generation and upgrading transmission — can the country successfully achieve the vital goal of ensuring national energy security.

In recent years, significant work has also been carried out to strengthen the electric power transmission networks across the country.

Over the past four years, low-voltage power transmission networks have been modernized, with 25,000 kilometers of new lines constructed and replaced.

It should be noted that during 1991–2016, only 9,300 km of low-voltage power transmission lines were modernized and built — approximately 2.7 times less than in the most recent period.

In recent years, 9,575 transformer substations have been modernized and upgraded, accounting for 60% of all transformer substations across the country.

Already this year, compared to the previous year, it is planned to repair 13% more — or an additional 26,300 km of low-voltage power lines — as well as 16% more, i.e., over 9,000 transformer substations.

During 2021–2030, reconstruction and modernization work on 0.4–110 kV transmission networks will continue intensively.

According to the plan, a total of 130,000 kilometers of power transmission lines and more than 40,000 transformer substations will be gradually modernized and renewed.

Renewable Energy Sources (RES).

Uzbekistan is a sun-rich country, which is a key factor in the development of renewable energy production, particularly in the construction of solar photovoltaic power plants (SPPs).

In cooperation with the Asian Development Bank (ADB) and the World Bank, the Ministry of Energy has developed a ten-year plan for electricity supply in Uzbekistan.

By 2030, the implementation of this plan will result in the creation of additional generation capacities, including 5 GW of solar energy, 1.9 GW of hydropower, and up to 3 GW of wind energy.

The Government of Uzbekistan has set a goal to increase the share of renewable energy sources in total electricity generation to 25% by 2030.

Currently, this figure stands at approximately 10%.

In the autumn of the current year, the first industrial-scale solar power plant with a capacity of 100 MW was commissioned in the Karmana district of Navoi region, constructed by the Masdar Company (UAE).

Additionally, another 100 MW solar power plant is planned to be launched in the Samarkand region in the coming months.

It should be noted that the Scaling Solar program plays an important role in the implementation of renewable energy projects in Uzbekistan.

Within the framework of this program, in 2020, tenders were announced for the construction of two solar photovoltaic power plants (SPPs) — each with a capacity of at least 200 MW — in the Samarkand and Jizzakh regions.

A total of 83 companies submitted applications to participate in the tender, which demonstrates the growing interest of investors in implementing renewable energy projects in Uzbekistan.

At the beginning of this year, the second phase of the tender was held, and in May, the tender commission selected the Masdar Company (UAE) as the winner.

One of the key advantages of the Masdar Company lies in its highly competitive electricity delivery proposal.

According to the terms of the agreement, energy from these solar power plants will be supplied for 25 years at record-low tariffs.

In particular, the Jizzakh SPP will deliver electricity to the unified energy grid at a tariff of 1.823 US cents per kilowatt-hour, while the Samarkand SPP will do so at 1.791 US cents per kilowatt-hour.

There are many similar examples.

In particular, significant progress is also being made in the development of wind power plants (WPPs), which will begin supplying electricity to the national grid in the near future.

A large-scale project is currently being implemented by the Masdar Company in the Tomdi district of Navoi region, involving the construction of a 500 MW wind power plant.

The first phase of this wind power facility is scheduled to be commissioned in 2024.

It is worth emphasizing the initial tenders for the construction of a wind power plant (WPP) in the Republic of Karakalpakstan.

In Uzbekistan, a new wind power plant based on renewable energy sources with a capacity of 100 MW is planned to be commissioned within two years from the date of signing the project agreements.

Based on the evaluation of submitted proposals, the ACWA Power Company was selected as the winner of the tender for the construction of the wind power plant, offering a tariff of 2.5695 US cents per kilowatt-hour.

The renewable energy projects currently being implemented in Uzbekistan are making a significant contribution to achieving the strategic goals set for the national energy sector.

In addition, these projects will help reduce annual greenhouse gas emissions by approximately 500,000 tons of CO_2 equivalent.

Thus, relying on facts and figures, it can be confidently stated that in recent years Uzbekistan has made significant progress in developing its energy sector based on best international practices and in ensuring the sector’s transition to market-based operation.

All these efforts will undoubtedly contribute to meeting the growing demand for energy and to ensuring the country's energy security both now and in the future.

Classification of Countries by Electricity Generation Methods. Countries around the world are divided into the following groups based on their methods of electricity generation:

- **First Group**: Countries that primarily generate electricity through thermal power plants, including the Russian Federation, the United States, and Western European nations. These countries mainly use natural gas, fuel oil, and coal for electricity production.
- **Second Group**: Countries such as China, Australia, Mexico, Romania, the Netherlands, and Poland, which predominantly rely on natural gas for electricity generation.
- **Third Group**: Countries including Honduras, Colombia, Kenya, Brazil, New Zealand, Austria, and Paraguay, which primarily produce electricity through hydroelectric power plants (GES).
- **Fourth Group**: Countries like Japan, France, and Belgium, which generate electricity mainly through nuclear power.

Currently, China, the United States, the Russian Federation, and Brazil are leading countries in global electricity production. Amid the industrialization process and increasing global energy demand, sustainable development cannot be achieved without renewable energy sources. According to the U.S. Department of Energy, global energy consumption reached 13.8 billion tons of oil equivalent (t.o.e.) in 2012. This figure is projected to grow at an average annual rate of 1.4% from 2012 to 2040, reaching 20.5 billion t.o.e. by 2040.

Table 4.2 presents the electricity production indicators of countries around the world for the period 2000–2020. Among the top electricity-producing countries, China generated 1,356 TWh of electricity in 2000. By 2020, this figure had increased by 5.7 times, reaching 6,442 TWh. Compared to 2000, India's electricity production had increased by 2.8 times by 2020. The United States saw a 5.1% increase, Russia – a 24.8% increase, Japan – a 5.3% decrease, Canada – a 6.9% increase, Brazil – a 75.9% increase, Germany – a 0.9% decrease, South Korea – a 96.9% increase, and France – a 1.3% decrease.

Looking at the countries with the lowest electricity production, compared to 2010, by 2020, Nigeria's production had increased by 2.7 times, New Zealand – by 12.8%, Portugal – by 20.4%, Romania – by 7.7%, Uzbekistan – by 38.3%, Kuwait – by 2.3 times, Colombia – by 76.7%, the Czech Republic – by 24.6%, Chile – by 2.1 times, and Algeria – by 3.1 times.

4.2-table.

Electricity Production by Country Worldwide (TWh)

№	Countries' names	The year 2000	The year 2010	The year 2015	The year 2020	The difference between 2020 and 2000 is 20 years.
Countries that produce the most electricity						
1	China	1,356	4,208	5,860	7,798	6,442
2	USA	4,053	4,378	4,317	4,262	0,209
3	India	0,562	0,975	1,358	1,557	0,995
4	Russia	0,878	1,038	1,068	1,096	0,218
5	Japan	1,068	1,171	1,059	1,011	-0,057

6	Canada	0,606	0,603	0,658	0,648	0,042
7	Brazil	0,349	0,516	0,582	0,614	0,265
8	Germany	0,577	0,633	0,648	0,572	-0,005
9	South Korea	0,290	0,500	0,553	0,571	0,281
10	France	0,540	0,569	0,580	0,533	-0,007
Countries with the lowest electricity generation						
1	Nigeria	0,015	0,026	0,032	0,040	0,025
2	New Zealand	0,039	0,045	0,044	0,044	0,005
3	Portugal	0,044	0,054	0,052	0,053	0,009
4	Romania	0,052	0,061	0,066	0,056	0,004
5	Uzbekistan	0,047	0,052	0,059	0,065	0,018
6	Kuwait	0,032	0,057	0,068	0,075	0,043
7	Colombia	0,043	0,061	0,079	0,076	0,033
8	Czech Republic	0,065	0,086	0,084	0,081	0,016
9	Chile	0,040	0,060	0,067	0,084	0,044
10	Algeria	0,028	0,048	0,052	0,088	0,06

Note: 1 terawatt (TW) = 1,000,000,000 kilowatts (kW).

It can be concluded that the greater the increase in electricity production capacity, the more closely the economies of these countries have grown in tandem. Among the Central Asian countries, the Republic of Kazakhstan ranks first in terms of electricity production capacity and installed power, while the Republic of Uzbekistan is in second place. In terms of establishing an electricity market in the Central Asian region, the Republic of Kazakhstan may have a unilaterally higher potential due to its significant electricity production capacity. However, the Republic of Uzbekistan is considered to have broader opportunities in this regard. The energy resource potential of Central Asian countries is presented in Table 4.3.

Table 4.3.

Energy resource potential of the countries of Central Asia

Countries / year		Coal* billion tons	Oil* mln.t	Gas* billion. m^3	Uranium ** thousand tons.	Hydro *** billion. kWh/year		RES*** billion kWh/year
Kazakhstan	2000	34,1	2760	1841	601	27		66
	2020	34,1	2760	1841	601	27		66
Kyrgyzstan	2000	1,34	11,5	6,54	-	52		-
	2020	1,27	1,2	6,2	-	99		-
Tajikistan	2000	0,67	5,4	9,2	-	317		18,4
	2020	1,0	10	10	-	317		18,4
Turkmenistan	2000	-	75	2860	-	2		-
	2020	-	75	2860	-	2		-
Uzbekistan	2000	2	350	2000	83,7	15		-
	2020	2	350	2000	83,7	15		-
Central Asia	2000	38,11	3261,9	6716,7	684,7	413		84,4
	2020	38,37	3205,2	6716,2	684,7	460		84,4

Note: The volume of confirmed renewable reserves for coal, oil, and natural gas is provided. Proven uranium reserves, with production costs up to $30/kg, as assessed by the World Energy Council (WEC). Hydropotential – economically viable. Uzbekistan – technical hydropotential. RES – Renewable Energy Sources.

Analysis of Data shows, the energy resource potential of Central Asian countries can be summarized as follows:

1. Coal Reserves:

- Kazakhstan leads with the largest coal reserves, amounting to 34.1 billion tons.

2. Oil Reserves:

- Kazakhstan holds the highest oil reserves at 2.76 billion tons.

- Uzbekistan ranks second with 350 million tons.

3. Natural Gas Reserves:

- Turkmenistan is in first place with 2.86 trillion cubic meters.

- Uzbekistan follows in second place with 2 trillion cubic meters.

- Kazakhstan is third with 1.841 trillion cubic meters.

4. Uranium Reserves:

- Kazakhstan leads with 601,000 tons of proven uranium reserves (with production costs up to $30/kg, as assessed by the World Energy Council).

- Uzbekistan is second with 83,700 tons.

- Other Central Asian republics have no reported uranium reserves.

5. Hydropower (Electricity from Water Resources):

- Tajikistan ranks first, producing 317 billion kWh of electricity from hydroelectric power plants.

- Kyrgyzstan is second, generating 99 billion kWh of electricity in 2020 from hydroelectric sources.

6. Renewable Energy Sources (RES):

- Kazakhstan holds the leading position in renewable energy sources, though specific data on its renewable energy production or potential is not fully detailed in the provided text.

If you have additional data (e.g., specific figures for renewable energy in Kazakhstan or other details from Table 4.4), please provide them, and I can refine the analysis or translation further. Let me know how you’d like to proceed!

In the Republic of Kazakhstan, 66 billion kWh of electricity is produced annually, making it the leader in renewable energy sources

among Central Asian countries. In second place is the Republic of Tajikistan, producing 18.4 billion kWh of electricity annually. The dynamics of electricity production in Central Asian countries, expressed in percentages, are presented in Figure 4.4.

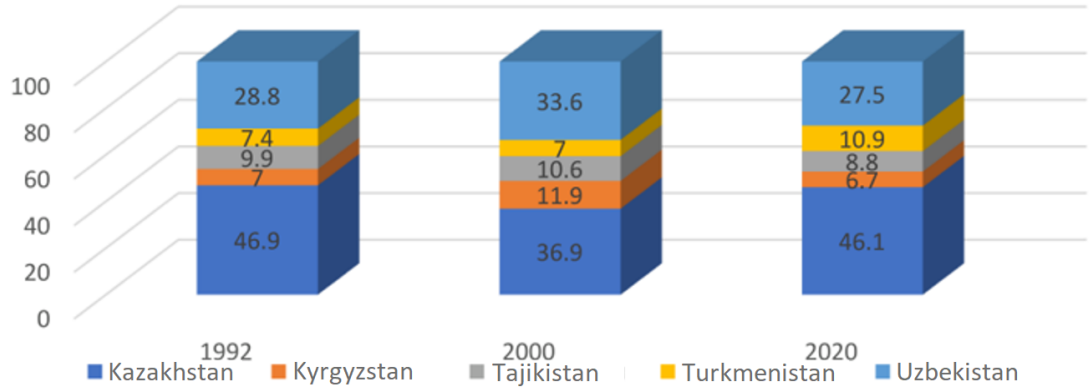


Figure 4.4: Electricity Production Status in Central Asian Countries, in Percentages

If we pay attention to the data presented in Figure 4.5, we can see that in the years 1992, 2000, and 2020, the Republic of Kazakhstan held a leading position among Central Asian countries in terms of electricity production. In 2020, of the total electricity produced in Central Asia, 46.1% was generated in the Republic of Kazakhstan, 27.5% in the Republic of Uzbekistan, 10.9% in the Republic of Turkmenistan, 8.8% in the Republic of Tajikistan, and 6.7% in the Kyrgyz Republic.

The accumulation of existing problems in the energy sector may jeopardize the development of the industry and its financial stability. To prevent this, it is necessary to focus on the proper development of the electric power sector by expanding the use of renewable energy sources, efficiently utilizing low-cost technologies, ensuring advance payments for consumed electricity, and increasing the inflow of foreign capital to foster a competitive environment.

Control questions.

1. What is the role of energy in the development of society?
2. Explain the concept of energy resources.
3. Explain why the demand for electricity increases?

4.3. Photovoltaic solar energy converters.

Many view photovoltaics as an achievement of the last few decades. However, the initial ideas related to photovoltaics emerged nearly two centuries ago. In 1839, French scientist Edmond Becquerel began experimenting with an electrolytic cell that generated electricity under the influence of sunlight. At the age of just 19, Becquerel created an element that produced an electric current under sunlight using a solution of silver chloride and acid.

In 1876, London professor William Grylls Adams and his student Richard Evans Day observed the photovoltaic effect in selenium. Although they could not generate electricity sufficient to power any device, they demonstrated the possibility of producing electricity from solid materials under the influence of sunlight. Thus, the concept of a photovoltaic cell was born.

In 1883, American inventor Charles Fritts created the first photovoltaic cell based on selenium, coating a selenium base with a thin layer of gold. This first functional solar cell had an efficiency of only 1%. The world’s first solar panels, based on these cells, were installed in 1884 on the roof of a building in New York. However, the high cost of these photovoltaic cells hindered their widespread adoption.

In 1905, Albert Einstein provided a theoretical foundation for the photoelectric effect. He introduced the concept of “light quanta” to science, which we now call photons. Einstein’s theory helped explain how photons generate electricity. In 1921, Einstein was awarded the Nobel Prize “for his contributions to theoretical physics, and especially for his discovery of the law of the photoelectric effect.”

In 1918, the Polish scientist Jan Czochralski developed a method for growing silicon monocrystals. Today, all types of diodes, transistors, microchips, and the most widely used solar cells are produced using silicon obtained through the Czochralski method.

In 1938, at the Leningrad Physics and Technology Institute of the Academy of Sciences of the former Soviet Union, under the leadership of academician A.F. Ioffe, two of his postgraduate students (Yu. Maslokovets and B. Kolomiets) created the first photoelectric cell. These cells, based on thallium sulfide, had a quantum efficiency (QE) of no more than 1%.

In 1941, American scientist Russell Ohl received a U.S. patent for the photoelectric effect in a silicon crystal with a p-n junction. In the early solar cells, the p-n junction was oriented perpendicular to the working surface and was formed during the process of growing the monocrystal. When illuminated by an incandescent lamp with a filament temperature of 2900 K, the cell exhibited a sensitivity of 10 mA/lm.

In 1952, the first prototype of a solar cell with a p-n junction perpendicular to the working surface was developed. The p-n junction was formed in a germanium monocrystal and mounted in a hermetically sealed casing made of transparent plastic, measuring 6×4.5×2.25 mm (Figure

4.6, a). When illuminated by an incandescent lamp with a color temperature of 2400 K, the solar cell generated a photocurrent of 30 mA/lm.

The rapid development of the photoelectric energy conversion method was closely linked to the creation of a solar cell design with a p-n junction parallel to the working surface (Figure 4.5, b).

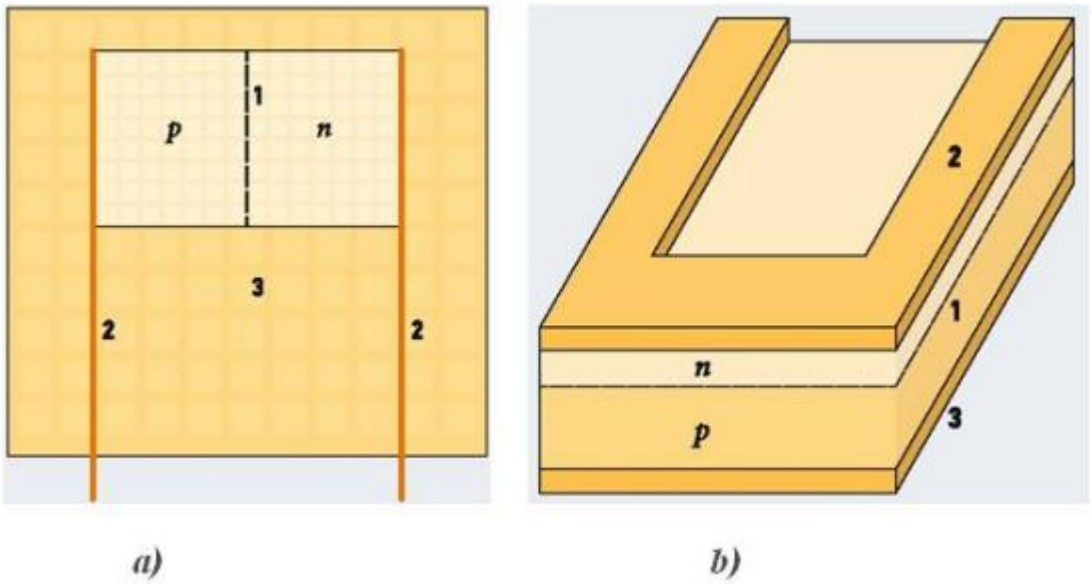


Figure 4.5. a) The first prototype of a solar cell with a p-n junction perpendicular to the working surface:
1 – p-n junction; 2 – conductors connected to the p and n regions;
3 – transparent dielectric.
b) The first prototype of a solar cell with a p-n junction parallel to the working surface:
1 – p-n junction; 2 – contact to the doped layer; 3 – contact to the base layer.

Interest in this design increased significantly after researchers at Bell Laboratories in the United States, led by J. Pearson and his colleagues, demonstrated in 1954 that silicon solar cells with a p-n junction parallel to the working surface had a quantum efficiency (QE) approximately 5–6

times (around 5–6%) higher than those with a p-n junction perpendicular to the working surface.

Indeed, the discovery made in 1954 by J. Pearson, D. Chapin, and C. Fuller made a groundbreaking contribution to the emergence of pure photovoltaic solar energy. The silicon cell they developed had an efficiency of 6%, which was a record in the field at that time.

Thus, 115 years after the discovery of the photoelectric effect, the modern solar cell was born. These types of cells were soon successfully used to supply electricity from solar energy to artificial satellites orbiting the Earth.

In 1955, the Solar Energy Association was founded in Phoenix, Arizona (USA), and simultaneously, an international symposium and the first exhibition dedicated to solar energy were organized. Thousands of scientists from 36 countries participated in this event, and 80 inventions were showcased.

In 1958, artificial satellites equipped with solar panels (Sputnik-3 in the USSR and Vanguard in the USA) became the first artificial satellites powered by solar energy.

The first Soviet solar panel installed on an artificial satellite launched on May 15, 1958, had a capacity of 2.0 watts, and the cost of the 1 watt-hour of energy it produced was 500 US dollars.

In 1964, a 0.25 kW concentrator-type solar battery was tested in the Karakum Desert of Turkmenistan for the purpose of extracting underground water.

In 1970 and 1972, gallium arsenide solar batteries supplied electric power to the lunar exploration vehicles “Lunokhod-1” and “Lunokhod-

2.” By this time, the cost of producing 1 watt-hour of energy had decreased to 100 US dollars.

In 1980, the technology for multi-junction solar cells based on GaAlAs-GaAs was developed.

In 1984, a photovoltaic system with a plastic parabolic concentrator and a capacity of 10 kW was installed in Ashgabat.

In 1985, Soviet scientists achieved a quantum efficiency (QE) of 36% in converting laser radiation into electrical energy using solar cells. By 1995, the cost of producing one watt-hour of solar energy had dropped to 15 US dollars. In particular, developed countries sharply increased their focus on solar energy, and governments began taking all possible measures to further reduce the cost of solar energy production to match that of traditional methods.

In 1998, inventor and scientist Subhendu Guha (USA) successfully created the first flexible thin-film photovoltaic module. In 1999, a low-temperature, chlorine-free technology for silicon production was developed.

In the 21st century, bold steps have been taken to advance the development of photovoltaics, making solar energy use one of the most promising fields, and these efforts are beginning to show significant results.

In the 21st century, bold steps are being taken to develop photovoltaics, one of the most promising fields for utilizing solar energy, and these efforts are beginning to yield results. Photoconverters play a key role in converting solar energy into electrical energy. The operating principle of photoconverters is based on the internal photoelectric effect

(Figure 4.6). When two semiconductor or metal-semiconductor contacts are illuminated, the process of generating a photovoltage (electromotive force) is called the photovoltaic effect. This phenomenon allows solar energy to be directly converted into electrical energy.

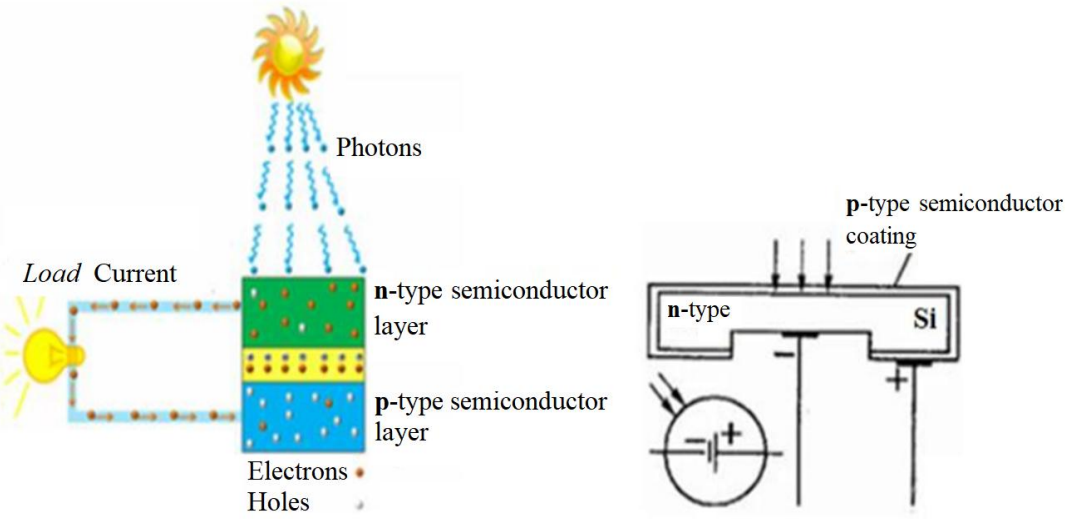


Figure 4.6. Operating diagram of the photoelectric converter.

Electricity generation through photoelectric processes occurs due to the spatial separation of positive and negative charge carriers resulting from the absorption of electromagnetic radiation in a semiconductor. In the presence of an electric source, these charges create an electric current in an external circuit. The presence of junctions in the material or its non-uniformity generates an internal electrostatic field. When the solar radiation flux density is 1 kW/m², a semiconductor-semiconductor or metal-semiconductor structure produces an internal field with a potential difference of approximately 0.5 V and a current density of around 200 A/m².

Manufacturing devices based on monocrystalline silicon is technically complex and expensive. For this reason, in recent years,

scientists have turned their attention to amorphous silicon (a–Si:N), gallium arsenide, and polycrystalline semiconductor materials. Amorphous silicon has proven itself as an effective alternative to monocrystalline silicon. Photovoltaic cells based on it were first developed in 1975. The optical absorption capacity of amorphous silicon is 20 times higher than that of monocrystalline silicon. As a result, a thin amorphous silicon layer of 0.5–1.0 μm is sufficient to absorb visible light, compared to a costly 300 μm thick layer of monocrystalline silicon. Additionally, producing large-area thin films of amorphous silicon does not require labor-intensive processes such as cutting, grinding, and polishing, which are necessary for monocrystalline silicon. Unlike the production of photovoltaic cell components from polycrystalline silicon, high temperatures are not required. Manufacturing products from a–Si:N is carried out at a temperature of 3000°C. When using inexpensive glass substrates as a base, costs can be reduced by a factor of 20. Currently, the maximum efficiency (power conversion efficiency, or PCE) of experimental cells based on a–Si:N is around 12%, which is slightly lower than that of monocrystalline silicon-based photovoltaic cells (15%). However, advancements in manufacturing technology could potentially increase the PCE to 16%.

One of the promising materials for creating solar cells is gallium arsenide: it has a bandgap width of 1.43 eV, which is ideal for single-junction solar cells; it possesses high solar radiation absorption capacity; the cell thickness does not exceed a few microns; its high radiation resistance makes it effective for use in spacecraft; no significant performance degradation is observed even when heated; and doping with

elements such as aluminum, phosphorus, or indium increases the efficiency of solar cells.

One of the main advantages of gallium arsenide is the ability to create devices with various designs from it. GaAs-based photovoltaic cells can consist of multiple layers with different compositions. This allows precise control over charge transport and collection in the cells. Such elements can also be used as window glass (AlGaAs). The primary disadvantage of gallium arsenide is its high cost.

Polycrystalline thin films are considered promising for solar energy applications. Their ability to absorb sunlight is exceptionally high (up to 99%). They are widely used in the production of solar cell window glass. For such purposes, the use of copper indium diselenide ($CuInSe_2$) is particularly suitable.

Currently, the efficiency of converting solar energy into electrical energy ranges from 13–16%, while in laboratory conditions, this figure has reached up to 40% for some semiconductors. Over the past 40 years, the cost of silicon-based photovoltaic converters has decreased by more than 40 times, and the cost of generating 1 kW of power in photovoltaic solar power plants has fallen below $2,000. The use of photovoltaic solar power plants, initially considered a secondary cost, originated in space technology.

The wing of the Mir space station consists of hundreds of square meters of photovoltaic cells. A lunar rover on the Moon, powered by solar batteries, operated for over a year. The American space station Skylab is powered by a 130 m^2 solar battery with a capacity of 10.5 kW. Currently, photovoltaic solar power plants are serving large-scale energy needs in

various countries around the world. In conclusion, from an energy perspective, the most efficient devices for converting solar energy into electrical energy are semiconductor photovoltaic converters. These devices directly convert solar energy into electricity. The efficiency of industrially produced photovoltaic cells averages around 16%, with the best models reaching 25%. In laboratory conditions, this figure has reached 43%.

Control questions.

1. Explain the phenomenon of the photoelectric effect.
2. What was the efficiency of these elements, created on the basis of thallium sulfide?
3. What are the main advantages of gallium arsenide?

4.4. Transfer of thermal energy.

Thermal Power Engineering is a branch of thermal engineering focused on converting heat, primarily into mechanical and electrical energy. Thermal devices, which mainly consist of heat engines, are used to convert heat into mechanical energy. The mechanical energy generated in these devices powers various working machines (such as metal-cutting lathes, conveyors, etc.) or electromechanical generators that produce electrical energy. Heat can also be converted into electrical energy without electromechanical generators, using direct energy conversion devices such as magnetohydrodynamic generators, thermoelectric generators, and others.

The foundation of modern thermal power engineering lies in stationary steam turbine thermal power plants, which produce the

majority of the total electrical energy. Gas turbine power plants are used to supply energy to main gas pipelines and to cover peak loads. In addition to primary power supply sources like condensing power plants, there are also thermal power centers and nuclear power plants. Combined-cycle gas-steam turbine systems, which reduce the relative heat consumption for electricity production by approximately 5%, are widely used.For high-capacity power plants, systems incorporating magnetohydrodynamic generators, operating in conjunction with conventional gas-steam turbine plants, are being developed. Diesel power plants are utilized in areas located far from power transmission lines.

In addition to stationary systems, thermal devices are also installed in transportation vehicles (e.g., locomotives, automobiles), such as reciprocating internal combustion engines. Aircraft are equipped with piston aviation engines, jet engines, and similar systems.

Thermal power engineering emerged primarily in the early 17th century. The invention of steam engines, heat engines, and diesel engines laid the foundation for its rapid development. Currently, thermal power plants account for 62% of the total global electricity-generating capacity.

In the early 20th century, two power plants were built in Tashkent, Uzbekistan. The first, equipped with five diesel generators and a capacity of 1,450 kW, was used to supply electricity to the tram system. The second, the Pavlov power plant with a direct current and a capacity of 125 kW, was used for city lighting. By 1913, there were six small power plants in Uzbekistan with a total capacity of approximately 3 MW, producing 3.3 million kWh of electricity annually. In 1923, construction began on a hydroelectric power station (HPP) on the Bozsu Canal near Tashkent. Its

first phase, consisting of two hydro-units with a capacity of 1 MW each, was commissioned in May 1926. At that time, this HPP was connected to the tram diesel power plant in Tashkent, and a 6 kV alternating current cable network with 30 transformer substations was established. This integration laid the foundation for the development of Uzbekistan's energy system.

Thermal power engineering in Uzbekistan began to develop in the 1920s with the construction of diesel and small steam turbine power plants. Diesel power plants were built for general purposes as well as to support cotton factories, pumping stations, canals, and other enterprises requiring thermal energy. The Tashkent diesel power plant, along with those in Samarkand, Andijan, Kokand, and other cities of the republic, was expanded. Large diesel power plants were constructed in Bukhara and Samarkand (5,000 horsepower), and in Nukus, Urgench, and Namangan (1,600 horsepower). The first steam turbine power plants in the republic were commissioned at oil factories in Fergana and Kattakurgan. The "Sharq Tongi" thermal power center at the Fergana oil factory was the first thermal power center (TPC) designed for general-purpose electricity generation.

In the 1930s, a thermal power center with a capacity of 12 MW was built at the Tashkent textile complex. In the second half of the 1930s, construction began on the Kuvasay State District Thermal Power Plant (DTPP) with a capacity of 48 MW, based on the Kyzylkiya coal mine, with its first unit commissioned by the end of 1939. In 1936, construction of the Tashkent TPC began, and its first unit was launched in 1939. In the early 1950s, based on the Angren coal mine, design and construction

started for a 24 MW TPC at the Altyntopgan complex in Almalyk and a 200 MW DTPP in Angren. The Angren DTPP was the first power plant in the region designed for high-pressure steam parameters and equipped with large (50 MW) turbines. During this period, coal-based thermal power plants, such as the Kuvasay DTPP, Tashkent TPC, and Fergana TPC, were also constructed.

Currently, Uzbekistan's energy system, including thermal power, supplies electricity to the republic's industrial, agricultural, and communal enterprises, as well as its population. In 1996, the government of Uzbekistan signed the Energy Charter Treaty, confirming the country's participation and opening the way for its energy sector to integrate into the global economy. The discovery and development of the Bukhara and Shurtan natural gas fields played a significant role in the rapid advancement of Uzbekistan's thermal power engineering, enabling the commissioning of the Tashkent, Navoi, Takhiatash, and Syrdarya DTPPs.

Large thermal power plants in Uzbekistan account for 85% of the country's total electricity production. In accordance with the "Program for the Development and Reconstruction of Power Generation Capacities in the Republic of Uzbekistan for 2001–2010," approved by the Cabinet of Ministers on December 27, 2000, the construction of the Talimarjan DTPP, the largest in Central Asia, was planned to be completed, alongside the technical refurbishment and addition of new capacities at other thermal power plants in the republic.

Uzbekistan possesses significant reserves of organic fuels. In the republic's fuel balance, natural gas is the primary fuel type for most thermal power plants, thermal power centers, and district boiler houses.

The development of the coal industry is focused on increasing the production of brown coal at the Angren mine.

The “Program for the Development and Reconstruction of Uzbekistan’s Power Generation Capacities for 2001–2010” includes provisions for attracting foreign investments and the participation of foreign companies. Currently, Germany’s Siemens, with funding from the European Bank for Reconstruction and Development, has begun a project to reconstruct two turbine units at the Syrdarya DTPP. Additionally, foreign investments are being attracted for the reconstruction of the Tashkent DTPP and Navoi DTPP, as well as for projects to modernize Tashkent’s electrical grid infrastructure and cable networks.

Heat energy is transferred from one body to another through air, water, or water vapor. The medium of the body involved in heat transfer is distinguished by its ability to transfer heat from the body’s surface to the thermal environment and vice versa.

Conduction occurs when rapidly moving or vibrating atoms or molecules interact with neighboring particles, transferring kinetic energy. The first two forms—conduction and convection—can be observed as energy transfer from one body to another through a medium.

Conduction is the process of transferring energy from one body to another through a medium, such as a liquid or solid, and introducing it into the space between molecules.

The process of heat transfer depends on the material used, its length, and the temperature of the materials involved. The rate of heat transfer through pipes is proportional to the speed at which energy is transferred from one body to another through a medium like a liquid.

A temperature gradient is a physical quantity that describes the direction and rate of temperature change in a specific location. Since cold is merely the absence of heat energy, temperature flows from one place to another at a uniform rate.

Thermal radiation occurs in air and space when two bodies at different temperatures interact, leading to heat transfer through conduction. This transfer continues until a state called thermal equilibrium is reached.

Bodies with high temperatures have a high concentration of heat energy resulting from rapid collisions between particles and materials. Thermal conductivity occurs when moving particles interact with slower, hotter, or less pure materials. The faster the particles move, the higher the material's temperature, and the more rapidly they move. Transferring particles to hotter or more confined areas increases the material's thermal conductivity, allowing heat energy to be transferred directly from one particle to another.

Radiation is a method of heat transfer in which particles do not need to carry heat energy. In other words, heat can be transferred directly from one particle to another without radiation.

Heat waves travel at the speed of light and are scattered by the objects they strike. Heat waves can radiate in various directions, even when they encounter an object while passing through space.

When adjacent atoms vibrate against each other, heat is transferred as electrons move from one atom to another. Conduction is the process of transferring energy from the surface of an atom to neighboring atoms through the vibration of the atom's electrons. This is highly effective

because fixed spatial connections between atoms, such as the distance between them, facilitate energy transfer through vibration.

Fewer collisions between atoms result in lower conductivity, meaning less energy is transferred from one atom to another due to reduced atomic interactions.

Heat is transferred from one atom to another through thermal conductivity between the two atoms, enabling heat transfer in the form of energy exchange.

Typically, heat transfer involves transferring thermal energy from one object to another through conduction. This occurs when heat conductors, such as wires, are in direct contact, and the temperature of one object is higher than that of the others. In conduction, thermal energy is transferred through the conductivity of an object, such as a wire or cable.

Thermal radiation is another mechanism of heat transfer, involving the transfer of wave energy from one object to another in the form of heat radiation. Thermal radiation requires an intermediate medium, such as a gas, liquid, or other substance, to deliver energy waves to the target.

The heat transfer process depends on the material used, its length, and the temperature of the materials involved. A temperature gradient is a physical quantity that describes the direction and rate of temperature change in a specific location. The term denoted by “E” represents the material’s emissivity coefficient, which can range from 0 to 1 depending on the reflection, absorption, or transmission of radiation.

If a system is cold, it indicates a lack of thermal energy, and the temperature flows in the direction opposite to the gradient.

The transfer between bodies continues until a state called thermal equilibrium is reached, where the body’s temperature rises, and thermal conductivity decreases.

Radiative heat transfer involves transferring heat from one body to another in the form of electromagnetic waves and is implemented in modern technical objects. This process can easily occur in a vacuum and requires a material or medium. Due to the high energy density of the material and the absence of thermal equilibrium, radiative heat transfer dominates in heat transfer processes.

Control questions.

1. What are the types of heat energy transfer?
2. What are the shortcomings of heat transfer?
3. What materials are used in the heat transfer process?

Glossary

Accumulator – A device that stores energy for later use. It comes in various types, including electrical, thermal, hydraulic, and inertial accumulators. It is a galvanic system that converts chemical energy into electrical energy under the influence of electric current.

Alternative Energy – A collection of promising methods for obtaining energy, considered significant due to their minimal environmental impact compared to methods used up to the present day.

Absorption – The process of gases dissolving in a liquid or being absorbed by a liquid.

Lead-Acid Accumulators – Used in automotive transport, aviation, and telecommunications.

Alkaline Accumulators – Depending on the type of electrodes, they can be cadmium-nickel, iron-nickel, silver-zinc, or silver-cadmium.

Cadmium-Nickel Accumulator – The positive electrode is made of nickel oxide mixed with graphite, while the negative electrode is made of iron mixed with cadmium.

Nickel-Cadmium Accumulators – In these accumulators, the active materials are nickel hydroxide and cadmium, respectively, with a potassium hydroxide solution serving as the electrolyte, which is why they are also referred to as alkaline batteries.

Sealed Batteries – These batteries are distinguished by their high discharge rate and ability to operate at low temperatures, but they are more expensive and susceptible to the memory effect.

Nickel-Metal Hydride Accumulators – The active material of the electrode is an intermetallic compound that adsorbs hydrogen, meaning the electrode is essentially hydrogen in a reduced, absorbed state.

Nickel-Zinc Accumulators – These are hydroxide batteries with zinc electrodes. Their specific energy is approximately twice that of nickel-cadmium accumulators.

Silver-Zinc and Silver-Cadmium Accumulators – These use silver oxide, zinc, and cadmium as active materials, with alkalis serving as electrolytes. They are distinguished by high energy and power density, as well as low self-discharge rates.

Electromotive Force – The voltage displayed at the terminals at a specific moment in time.

Primary Energy – Natural energy carriers such as oil, natural gas, solar energy, and uranium serve as primary energy sources.

Resistance Level – This property depends on temperature, charge size, and the condition of plates and fasteners. For automotive applications, these technical characteristics are not particularly significant.

Polarity – Vehicles are equipped with batteries that have reverse polarity (European models) or direct polarity (Russian models).

Battery – A single cell that, when combined with similar cells, forms a battery.

Chemical Accumulation – During biomass processing, liquid (ethanol), gaseous (biogas), and other secondary fuels are obtained.

NCRES – Non-conventional and renewable energy sources.

TAM – Thermal accumulation material, where accumulation is achieved by altering physical properties and utilizing the bonding energy of atoms and molecules in the material.

LTA – Liquid thermal accumulators are among the simplest and most reliable thermal accumulation devices, as the liquid serves both as the thermal accumulation material and the heat carrier.

HPS – Hydroelectric power station, a complex of hydraulic engineering structures and energy equipment that converts the energy of water flow into electrical energy using hydraulic turbines.

HAPS – Hydro-accumulating power station.

Dehydrogenation – The process of extracting hydrogen from organic compounds, used industrially to produce olefins and diene hydrocarbons.

Distillation – (From Latin, meaning “to drip”) The process of evaporation or separation of liquid mixtures into fractions. The process is based on the difference in boiling points of the mixture’s components. Various distillation methods are applied depending on the physical properties of the components being separated from liquid mixtures.

Energy Carrier – A physical medium that forms a technical system for transporting electrical, thermal, or other types of energy (e.g., heat carriers, compressed air, solar radiation used in heliodevices, etc.).

Energy Reserve – A physical medium or body that stores a type of primary natural energy in an explicit or latent form (e.g., energy carriers, coal, oil, ocean waves, geothermal heat, etc.).

Energy – The amount of energy or fuel consumed in the main and auxiliary technological processes for product manufacturing.

Energy Supply – Substances accumulated in various states of matter (solid, gas, liquid) or in different forms of matter (plasma, radiation) and used to provide energy.

Renewable Energy Types – Solar energy, wind energy, energy from geothermal hot water, and energy derived from the temperature gradient in nature.

Compressed Natural Gas – Natural gas, typically consisting of methane, compressed or pressurized for convenient storage or transportation.

Thermal Power Engineering – A branch of thermal engineering focused on converting heat, primarily into mechanical and electrical energy.

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