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Research paper

Innovative Technologies for Producing Foam Concrete Products Using Solar Energy

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Abstract

An energy efficient technology and a method for the production of foam concrete products have been developed. They involve the use of solar energy in the process in order to reduce energy consumption for heat treatment, which allows to produce high-quality products with a low production cost with a daily production cycle.
The technical and economic evaluation of the developed solar technology shows that during the hot season up to 95% of the heat energy needed to intensify the hardening of the foam concrete is provided by a renewable energy source. The annual replacement of organic fuels with solar energy, considering the winter period of the year, is up to 65%. The annual economic effect in the oil equivalent of the use of this solar technology in enterprises located in regions with favorable weather and climate conditions, with a productivity of 20 thousand m^3/year is up to 85 tons.
The use of solar technology to ensure accelerated hardening of foam concrete products makes it possible to make production highly efficient, energy-saving and environmentally friendly. It meets modern requirements for saving organic fuels and reducing harmful emissions into the atmosphere.
The energy efficiency of a yearly solar thermal treatment consists of high heat-absorbing and heat-insulating ability of helio-coatings, helio-chambers, and controlling the expenses of the heat source. As a result, energy savings in the winter months are 15-35%, in summer - 70-100%, and the average annual energy savings are in the range from 50 to 75% depending on the class of concrete and the thickness of products.

Keywords: Helio heating, hardening acceleration, plastic strength, helio cover, operational strength control.

1. Introduction

Foam concrete is one of the most effective materials for enclosing constructions of buildings for various purposes. They are characterized by a sufficiently high strength and frost resistance at a relatively low average density. The mass of external walls made of foam concrete is 2.5-3.5 times lighter than walls made of ceramic bricks, and the thickness of walls in terms of thermal protection is 1.5-2.5 times smaller than walls made of expanded clay and silicate bricks.
A significant part of the costs in manufacturing products and structures from foam concrete is accounted for the share of energy carriers used for their heat treatment in order to accelerate hardening. Because of that many manufacturers are forced to exclude the heat treatment from the manufacture process. The result of which is an increased binder consumption, increased costs associated with the use of high grades of cement and special additives of hardening accelerators, an increased need to allocate large areas for ripening foam concrete products and structures, and low turnover of metal forms [1; 4; 5].
Currently there are scientific and production basics for manufacturing foam concrete and rational areas for the use of products from them have been developed. Many years of experience were accumulated in the operation of buildings with foam concrete fencing structures, which showed their high reliability and durability. All these investigations and experience of application concern mainly to foam concrete of autoclave hardening and to concretes subjected to heat and moisture treatment at normal steam pressure (steam heating), which are energy-intensive.
Further development of foam concrete production is planned mainly by reducing the energy intensity and material consumption in the manufacture of products from them, while ensuring high levels of

physical and mechanical properties and expanding the scope of their use.

In this regard, one of the ways to ensure the competitiveness of foam concrete in modern conditions is the creation of an extremely simple energy-saving technology by excluding the most energy-intensive redistribution processes such as autoclave processing and steam heating from the technological process and replacing them with low-energy intensive methods of hardening intensification.

The search for ways to reduce the energy intensity of foam concrete production, while ensuring its high performance of basic properties, confirmed the possibility of effective use for accelerating the hardening of products and solar energy designs. The production of foam concrete products and structures on solar polygons is possible in regions with favorable weather and climatic conditions, which are characterized by hot and warm climate, with more sunny days per year. According to [15], "A significant part of Russia has favorable climatic conditions for the use of solar energy. In southern areas, the duration of solar radiation is from 2000 to 3000 hours per year, and the annual arrival of solar energy on a horizontal surface - from 1280 to 1870 kWh per 1 sq. Km. m."

The southern regions of Kazakhstan are also characterized by long hot summers with a stable outdoor temperature in the range of 35-42 ^{0}C, where the level of solar radiation reaches over 6 kWh/m^2. Such weather and climate conditions create reliable conditions for the organization of solar polygons to produce foam concrete products. Therefore, considering the huge scale of the regions with favorable weather and climate conditions, the attraction of solar energy in the production of foam concrete for the replacement of traditional types of energy has great prospects.

In connection with the state housing program currently being implemented by the Government of Kazakhstan, both full-scale and monolithic construction is rapidly developing in the republic. As previous experiences from around the world have shown, rational development of the construction industry is the development of both directions, which allow us to exclude each other's weaknesses. In European countries, as well as in the United States, the share of full-scale construction is almost half of its total volume, except for some countries (Japan, etc.) located on earthquake-prone zones of the earth [16; 17]. Therefore, increasing the production of prefabricated concrete products and structures using energy-saving technology, especially from such efficient building material as foam concrete, is a nowadays's requirement.

Until now, many scientists have investigated the use of renewable energy sources in the construction industry, including solar, for replacing traditional fuels used in heat treatment of concrete products and structures [11; 12; 13]. However, as the analysis of the scientific literature shows, all known scientific research and developments in this area are devoted to solar thermal treatment of conventional concrete [6; 7; 8], while traditional methods of accelerating hardening are still used to produce such effective building material as foam concrete, requiring significant energy costs. Foam concrete is cardinally different from conventional concrete by manufacturing technology: used raw components, rheological properties, porous structure [2; 3; 9; 10], and other basic characteristics, therefore known solar thermal treatment methods developed for conventional concrete are not suitable for use in production foam concrete.

Investigations studied the possibility of attracting solar energy in the production of foam concrete products, have fulfilled the expectations of introducing the solar thermal treatment method in dry hot climate conditions. To introduce energy-efficient methods of solar thermal treatment of foam concrete products, extensive studies have been carried out to produce new combined heat treatment options based on the results achieved. This will increase the volume of buildings and structures with the use of effective foam concrete products.

The use of solar energy makes it possible to make technological redistribution of hardening products from foam concrete environmentally friendly. And it meets modern requirements and makes solar technology a highly effective and promising method in the production of building materials. Scientific research was conducted in the laboratory of construction materials technology at the L.N. Gumilev Eurasian National University.

2. Methods of Research.

When working out the full technological cycle for the production of foam concrete products on the test site in the production environment, factory compositions of foam concrete wall products D600-800, which complied with the requirements of GOST 25485, were used, using portland cement M400, quartz sand Mkr = 1,2 and frother protein Laston.

The foam concrete mixture was produced on a foam concrete mixer using the classical two-stage technology using a foam generator (Fig. 1).

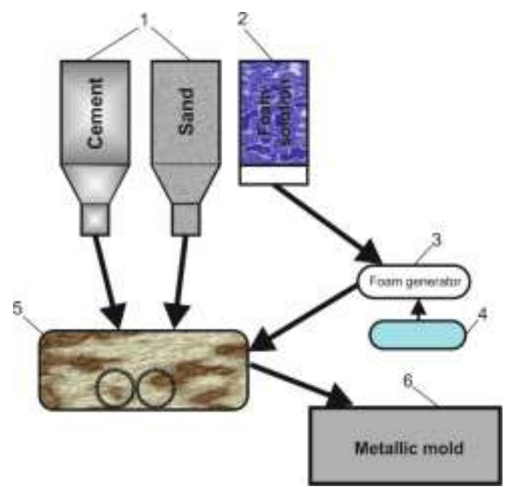

Figure 1:. Scheme of technology for the production of foam concrete: 1- bunker cement and sand; 2 - the ready solution of the foaming agent; 3 - foam generator; 4- the compressor; 5- Foam concrete mixer; 6 - forms.

The detached raw materials were loaded into a rotary mixer in a strictly defined sequence: water, quartz sand, cement, and foaming agent from the foam generator. After mixing all the components, the density and plasticity of the porous mixture were determined. As necessary, the density of the mixture was adjusted by adding a foaming agent to the water or by adjusting the mixing time of the porous mixture. From the foam concrete mixer, the finished mixture was fed through a hose into a prepared and strictly horizontal form.

Further ensuring the quality of products made of foam is carried out by the condition of their aging - eliminating the rapid evaporation of moisture from the surface of products. Therefore, the forms with foam concrete mix were sealed with a helio cover (Fig. 2) and moved to a thermos chamber.

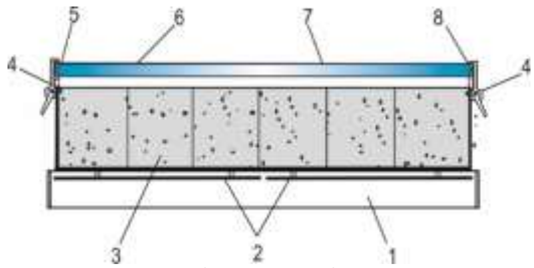

Figure 2:. The cut of the cassette form equipped with a helio cover and installed on a heating pan: 1 - a heating pan; 2 - heating elements; 3 - foam concrete products; 4 - locking devices; 5 - the sealant; 6, 7 - upper and lower layers of transparent coating; 8 - metal frame.

After soaking in a thermosensitive chamber at a temperature of 35 ± 5 ° C for 2.5-3 hours and reaching a plastic strength of 400-600 g/cm^2, the molds with products moved to an open landfill where they were installed on pallets equipped with heat-electric heaters (Fig. 3).

As the results have shown, the electric power consumption is minimal and on the average is from 10 to 20 kW/h per 1 m^3 of foam concrete, which is much less compared to similar expenses with the known methods of electric heating and steam heating.

To ensure a 24-hour cycle of the turnover of forms and to ensure that the products are supplied with the required number of degrees per hour during the day, the heating of the products in the helioforms should begin no later than 10 am. In the production of various types of foam concrete products, the time for the beginning of solar thermal treatment should be determined based on the thickness and massiveness of the products.

Solar thermal treatment lasts 22 hours. Meanwhile, foam concrete products, depending on the class of strength and grade of medium density, acquire strength from 40 to 55% of the brand strength.

After the completion of solar thermal treatment, the products are moved to the storage area for the selection of tempering and vintage strength (Fig. 3, zone F), where they are stacked on pallets.

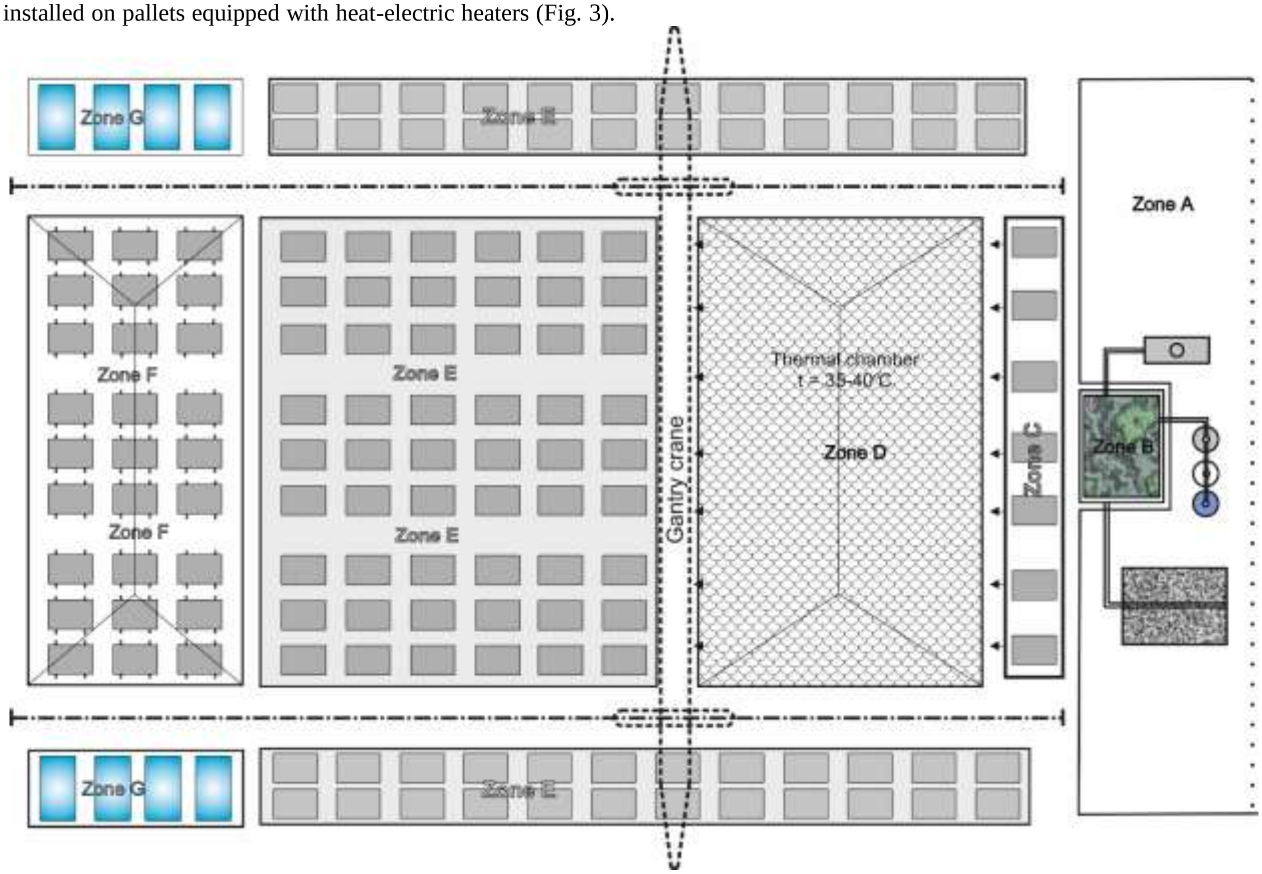

Figure 3:. Technological scheme for the production of foam concrete products with the intensification of their hardening by solar thermal treatment in polygons in combination with the use of electric energy: Zone A-places for the reception and preparation of raw materials; Zone B-zone dosing of components and preparation of porous mass; Zone C-zone molding products; Zone D - the chamber for preliminary aging of foam concrete blocks (a thermosensitive chamber); Zone E - solar thermal treatment of products; Zone G-pad for the preparation of helio-lids; F-zone for storage of finished products.

With a large-scale introduction of the developed solar technology, controlling of the strength of foam concrete products becomes even more important. During helio-thermal processing, with practically identical technological parameters of production, strength parameters of foam concrete products mainly depend on climatic factors. Therefore, if only standard values of strength of concrete are controlled at factories operating in conventional technology, then control of the strength of foam concrete is also necessary for helio polygons to refine the further technological scheme of products: prolongation of solar thermal treatment, regulation of the capacity of additional electric energy, placement products at the post of ripening with subsequent care (during storage before shipment of products) , etc.

As the strength of the foam concrete products is increased, an operational control system has been developed that includes graphs of strength increase depending on the hardening temperature, standard samples, temperature control during hardening and non-destructive testing after the aging of foam concrete products.

As a result of studying the use of solar energy in accelerating the hardening of concrete, summarizing the accumulated experience, as well as our studies, the possibility of effectively accelerating the hardening of products from foam concrete, directly in forms due to solar energy, has been revealed.

Electroheating of the bottom of metal molds works cyclically, periodically switching on and off depending on the temperature set by the temperature sensor. The thermostat controls the on / off times. The cassette molds are sealed with a helio-lid immediately after pouring the foam-concrete mixture and sent to a thermos chamber mounted from sandwich panels, as the thermal insulation in which foam plastic is used with a density of at least 25 kg/m^3, where they are kept for 3-4 hours at a temperature of 30-35°C.
After reaching a plastic strength of 400-600 g/cm^2, sufficient for solar thermal treatment, molds with products were moved to an open landfill designed for heat treatment using solar energy. To ensure a daily cycle of turnover of forms and effective use of solar radiation during the day, warming up of products in helioforms should begin no later than 10 am. In this case, the temperature rise in the solar chamber is carried out at a rate of 7-8 °C/h for 5-6 hours, and isothermal warming for 3-4 hours at a temperature of 62-64 °C, then in the evening and at night there is a slow cooling to a temperature of 33 ± 2 °C.

3. Results of the Research

According to the developed technology, solar thermal treatment is carried out within 20-22 hours and foam concrete products during this time acquire strength from 45 to 55% of the design strength, depending on the brand by medium density.
A comparison of the mechanical characteristics of foam concrete was carried out on samples of similar composition and age, but differing methods and conditions of hardening (Table 1). The kinetics of foam concrete heating during solar thermal treatment was studied with the help of the 4-channel temperature monitor Thermodot-17M5.
Figure 4 shows the kinetics of heating foam blocks (0.2x0.2x0.4 m), depending on the ambient temperature. Analysis of the temperature curves shows that the heating of the products is carried out in soft modes with a rise in temperature in the foam concrete up to 62-64°C for 5-6 hours, with a conditional isothermal holding for 3-4 hours and slow cooling in the evening and night hours at a speed of 4 - 5°C/h to 33-35 ° C.

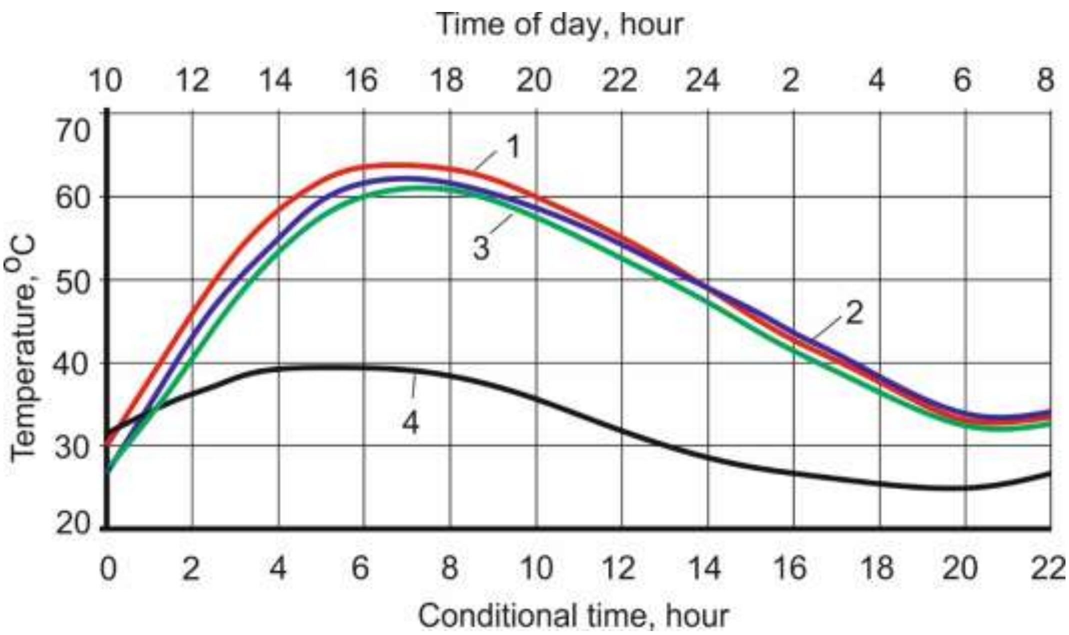

Figure 4.: Kinetics of warming up of products depending on the ambient temperature. 1 - temperature of 20 mm from the top surface of the block; 2 - temperature in 100 mm from the top surface of the block; 3 - temperature of 180 mm from the top surface of the block; 4 - ambient temperature.

At the same time, the products were heated to maximum temperatures in concrete up to 64°C (upper zones), 62°C (middle zones) and 60°C (lower zones). Comparing the heating of concrete in the upper and lower zones, it can be noted that it occurred almost identically, with a difference of 3-4°C. However, the cooling of concrete was slower, especially in the center of the product. So, in the morning the temperature of concrete was 32-33°C, and in the center of products 34-35°C. This is because foam concrete has low thermal conductivity and thus can retain heat for a long time. As can be seen from the experimental results, this regime creates favorable conditions for hardening, which positively influence the formation of the structure and properties of concrete.
Table 1 and Figure 5 show the time variation in the compressive strength of foam concrete with a density of 700, class B2, hardened in various conditions. The degree of maturity of helio-thermobonded foam concrete (3) was 1023 °C/h and the daily strength - 1.6 MPa, i.e. 55% of the branded (B2). At the same time, at the age of one month the strength of helio-thermo-treated foam concrete (3) is higher by about 51% than the strength of normal hardening samples (1). The rest of the strength of foam concrete of normal hardening (1) accumulates within 6 months.

Table 1:. The change in the time of compressive strength of foam concrete D700, B2 solidified under various conditions.

Curing Method	Concrete strength at compression at the age, days.				
	1	3	7	14	28
Normal hardening	0,09/3	0,29/10	0,67/23	1,09/37,5	1,43/49,5
Curing the foam concrete without a care in the natural conditions of a dry and hot climate	0,65/22,5	1,17/40,3	1,54/53	1,67/57,5	1,71/59

Application of solar thermal treatment with helio-lid and heated bottom of the mold	1,60/55	1,89/65	2,09/72	2,38/82	2,91/100,5

Note: Below the durability line in MPa, beyond the line - in% of the brand strength (2.9 MPa) of foam class B2.

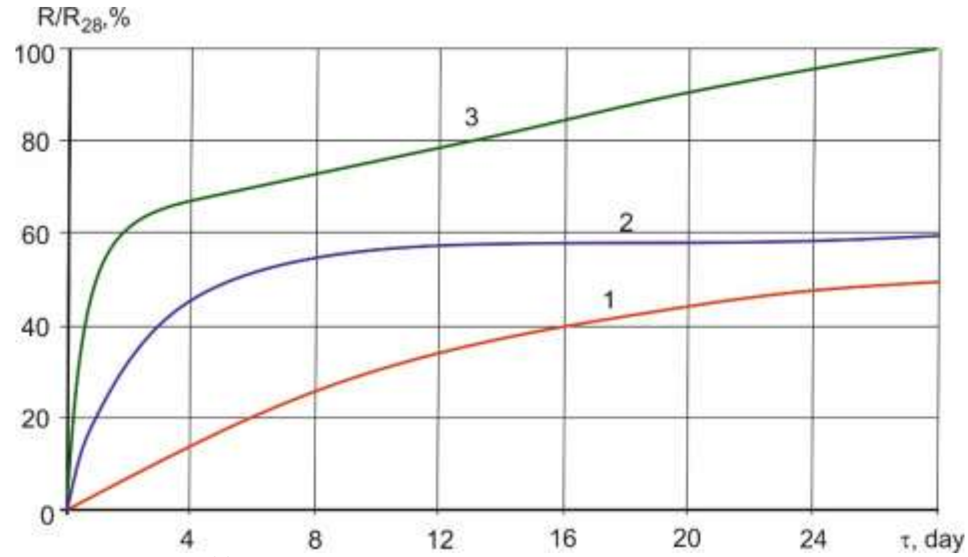

Figure 5:. The time variation in the strength of foam concrete during compression, hardening under various conditions. 1 - normal hardening; 2 - retention of foam concrete without maintenance in the natural conditions of dry hot climate; 3 - helio-thermal processing of foam concrete with the use of helio-covers with electroheating of the mold.

The study of the properties of foam concrete hardened under various conditions indicates a high quality of products subjected to solar thermal treatment. It should be emphasized that solar technology is highly environmentally friendly and safe.
It is established that higher strength parameters can be achieved with the optimal combination of cement exothermy in foam concrete with soft modes of both warming up and cooling of products.
Thus, it can be concluded that the complex heliothermal heating of foam concrete in metallic forms equipped with helio-covers, with the use of additional electric energy, is a new method of accelerating the hardening of foam concrete products, in which the external thermal effect provides a high degree of utilization of the heat of hydration of cement at the most energy-intensive stage of the process – heating of concrete. In addition, the use of hermetic translucent helio-covers prevents the excess heat from the products in the non-perfect time of day.

4. Discussion

The results of studies conducted in production conditions confirmed the reliability of the results obtained in laboratory conditions, which proves the high efficiency of the developed method of complex solar thermal treatment of foam concrete products in the warm and hot months of the year.
A low energy-consuming method for intensifying hardening of foam concrete products at polygons using solar energy in combination with electric energy was created; together they make the optimal temperature regime for the formation of the structure and properties of foam concrete. Meanwhile, when adding the missing amount of heat (for heating concrete), on average, 10 to 20 kW/m^3 of electric power is consumed, which is much lower than for electric heating or steam heating.
In order to effectively implement solar thermal treatment of foam concrete products using the developed method, it is necessary to create a closed air space between the helio-cover and freshly laid concrete with a thickness of 15-20 mm and also to ensure an optimal distance from 3 up to 5 mm between two layers of the translucent material used.
The results of research give the necessary data for the construction of the helio-thermal processing modes in assembling products. During the first 5-6 hours of solar thermal treatment, the rate of heating of the is no more than 6-7^{o}C/h the next 3-4 hours at a temperature of 62-64^{o}C and the isothermal aging stage begins. Then at night, there is a slow cooling of the concrete at a speed of 4-5^{o}C/h to a temperature of 32-34^{o}C.
The degree of maturity of helio-thermo-treated foam concrete was 1023 ^{o}C, and the daily strength - 1.6 MPa or 55% of the branded (B2) strength of concrete. At the age of 28 days the strength of helio-thermo-treated foam concrete is higher than the strength of the samples made from a similar composition and hardened in normal temperature and humidity conditions by an average of 35%.
By calculation, the duration of the seasonal operation period of the helio polygon for the regions of Central Asia, which are below 46 ° northern latitude, which is 8 months a year, from March to October, is established. The established duration of the seasonal operation period of the helio polygon can be extended for another 15-20 days in order to fill the missing amount of heat.
The greatest effect from the use of the developed method of complex solar thermal treatment is achieved during a stable sunny weather with an ambient temperature of at least +20 ° C. It is possible to perform solar treatment of foam concrete products with sufficient efficiency and at lower air values, for example at 15 ° C, by applying additional measures to increase the degree of absorption of solar radiation by foam concrete.
Based on the results of theoretical and experimental studies and their verification in production conditions, the possibility of attracting solar energy to accelerate the hardening of foam concrete products has been proven. This technology allows to obtain an efficient building material during a warm and hot season, from March to October, with considerable savings traditional fuels.

5. Conclusion

The technical and economic evaluation of the developed solar technology shows that in the warm and hot season up to 95% of the heat energy needed to intensify the hardening of the foam concrete is provided by using a renewable energy source. The annual replacement of organic fuels with solar energy, considering the winter period of the year, is up to 65%. The annual economic effect in the oil equivalent of the use of this solar technology in enterprises located in regions with favorable weather and climate conditions, with a productivity of 20 thousand m^3/year is up to 85 tons.

The use of solar technology to accelerate the hardening of foam concrete products makes it possible to make production highly efficient, energy-saving and environmentally friendly, which meets the modern requirements for saving organic fuels and reducing harmful emissions into the atmosphere.

The energy efficiency of yearly solar thermal treatment consists of high heat-absorbing and heat-insulating ability of helio-coatings, helio-cameras, and controlling the costs of traditional heat sources. As a result, energy savings in the winter months are 15-35%, in summer - 70-100%, and the average annual energy savings range from 50 to 75% depending on the class of concrete and the thickness of products.

The conducted research and development of the method of complex solar thermal treatment of foam concrete products confirmed the hypothesis about the possibility of energy efficient, economical and environmentally friendly production of foam concrete products in conditions of dry hot climate.

New approaches to the technology of helio-thermal processing of foam concrete products in conditions of a hot climate in the Republic of Kazakhstan make it possible to abandon traditional methods of heat treatment of concrete within 6-7 months of the year and ensure the production of high-quality material with the required shipping strength or temper strength, with significant savings in fuel and energy resources.

The use of solar energy makes it possible to make the process of hardening products from foam concrete environmentally friendly. It meets modern requirements and puts solar technology in a number of highly effective and promising methods in the production of building materials.

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