Journal of Engineering Science *Vol. XXVIII, no. 1 (2021), pp. 117 - 123*
Fascicle *Architecture, Civil and Environmental Engineering* *ISSN 2587-3474*
Topic *Energy Efficiency and New Building Materials* *eISSN 2587-3482*

https://doi.org/10.52326/jes.utm.2021.28(1).12
UDC 691.32:621.311.243

ENERGY-SAVING CHAMBER IN PRODUCTION OF BUILDING MATERIALS AND PRODUCTS

Michael Zavoloka[1], ORCID: 0000-0002-2080-1230,
Elena Shinkevich[2], ORCID: 0000-0002-2842-1785,
Varvara Vinnichenko[3], ORCID: 0000-0003-3700-5414,
Alexander Plit[4*], ORCID: 0000-0003-4745-6358

[1,2,4]*Odesa State Academy of Civil Engineering and Architecture, Odessa, Ukraine*
[3]*Kharkiv National University of Civil Engineering and Architecture, Kharkiv, Ukraine*
*Corresponding author: Alexander Plit, *alex89805@gmail.com*

Received: 12. 11. 2020
Accepted: 01. 15. 2020

Abstract. This paper presents the results of a study of the compressive strength of concrete in a cyclic solar chamber. The analysis of the existing types of industrial solar chambers is carried out and the main structural elements are considered. The method of calculating the solar chamber for the production of concrete products is presented. Experiments were carried out on heavy concrete compositions using MC-Bauchemie superplasticizers additives: MC-PowerFlow 3100 and MC-PowerFlow 2695. The samples were kept in a cyclical solar chamber. The strength of concrete was determined at different periods of concrete hardening. A comparative analysis of the results of the compressive strength of concrete in a solar and normal hardening chamber is carried out.

Key words: *green energy, cyclic solar chamber, heat treatment, superplasticizers, thermophysical processes.*

Introduction.

Analysis of literature data showed that the precast concrete industry is a large consumer of thermal energy. The most energy-intensive process in this area is the technological process of heat treatment of products, which consumes more than 70% of the energy. About 90% of the total volume of reinforced concrete products (concrete goods) is treated with steam. Non-renewable natural energy sources are used to generate steam. Taking into account the growing increase in their cost, heat and humidity treatment should be recognized as energy-inefficient. In this regard, the problem of rational use of traditional fuel and energy resources and the inclusion of unconventional energy sources, such as solar and wind energy, deep earth heat and secondary heat of various production processes, is becoming more acute. Currently, there is a tendency to increase the use of renewable energy sources, primarily solar. The use of solar energy finds its application in various areas of production processes, which is especially important for the southern regions of Ukraine [1, 2].

Solar thermal treatment - heating concrete reinforced concrete products by direct influence of solar radiation through translucent or sun receivers. The simplest way to use solar energy for preheating concrete products is to use helioforms, which consist of two main elements: the mold itself and the lid with a translucent heat-insulating coating or in molds using a moisture-proof sun-perceiving coating in combination with thermos holding. Polymer photovoltaic cells are a promising coating for visible spectrum applications because the absorption spectra of organic semiconductors, including polymers and low molecular weight types, are not continuous as in inorganic semiconductors. As a result, the organic structure is capable of transmitting visible light and absorbing invisible light such as infrared. According to the energy distribution of the solar spectrum, more than half of the sunlight is distributed in the infrared region. Therefore, the theoretical efficiency of polymeric photovoltaic cells with only absorption of infrared radiation can be as high as that of a device with only absorption of visible light. [3 - 5].

The main part of the helioform is solar cells, which are semiconductor photovoltaic cells designed to directly convert solar radiation into electrical energy. They are part of a wider range of photocell devices. Usually solar cells have a large receiving surface area and the most important parameters for them are temperature stability, the coefficient of conversion of light energy into electrical energy, radiation resistance, etc. Most often, solar cells are a structure of semiconductor materials that absorb solar radiation well, metal and dielectric layers ... If the device contains liquid solutions of electrolytes, they are called photo electrochemical converters.

The operation of solid-state solar cells is based on the valve photoelectric effect. Light quanta absorbed by a semiconductor release electrons and holes from intracrystalline bonds and transfer them into a mobile state. After that, oppositely charged free charge carriers are spatially separated and move in opposite directions as a result of diffusion or drift in a force field, which should initially be present in a semiconductor [6].

The most important challenge for solar cells is to improve their efficiency. The efficiency of the photocell increases when concentrated sunlight is used, however, excess heat should be removed from the photocell. To date, scientists from the National Laboratory for the Study of Renewable Energy (USA) have achieved the highest efficiency rate and reached the level of 47% [7], in concentrated sunlight, thus setting a new blight record for solar panels. Among industrial designs, silicon-based cells show the best performance, although low-efficiency cells from cheaper conductors compete economically with mass production of high-efficiency and expensive solar cells. Industrial solar cells work using various solar cells, the main of which are silicon, monocrystalline, polycrystalline, amorphous film, polymer, photosensitized, which differ in efficiency and cost. When developing effective elements, efforts should be directed not only to their efficiency, but also to the compactness of systems. It is worth paying attention to plastic crystals, due to which it is possible to increase the compactness of systems and reduce the cost of their production [8 - 11].

Benefits of solar thermal treatment:

- saving non-renewable fuel and energy resources,
- the use of an environmentally friendly source of thermal energy,
- reducing the cost of concrete products,
- reduction of capital costs for the boiler house, heating main, etc.
- allows you to abandon the traditional heat treatment of precast concrete elements in warm seasons in areas south of 50 ° north latitude.

For heating concrete products, it is necessary to perform a calculation. The calculation method consists of three parts:

- calculation of the thermal balance of the chamber in which heat treatment is carried out. as a result of the calculation, the amount of energy required for heating is determined,

- determine the amount of heat that can be received by the solar collector. Such data for given geographic coordinates are provided by NASA. For the main cities of Ukraine, information is widely distributed on the Internet [12],

- find the area of solar collectors that will provide the required amount of energy. Heat balance equation [13]:

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 + Q_8 + Q_9 + Q_{10} + Q_{11} - Q_{12} \quad (1)$$

where Q_1 is the heat consumption for heating the components of the raw concrete mix, Q_2 is the heat consumption for heating the mixing water, Q_3 is the heat consumption for the evaporation of some of the water, Q_4 is the heat consumption for heating the reinforcement, Q_5 is the heat consumption for heating the molds, Q_6 is the heat, which is accumulated by the walls of the chamber, Q_7 is the heat consumption for heating the chamber lid, Q_8 is the heat consumption for heating the free space in the chamber, Q_9 is the heat loss due to heat leakage through the leaks, Q_{10} is the heat loss to the environment by the chamber walls, Q_{11} is the heat loss into the environment by the chamber lid, Q_{12} - heat of exothermic reactions in concrete, Q - amount of energy required for heating, kJ / cycle.

The amount of heat that can be received by the solar collector [14, 15]:

$$Эк = E \cdot S \cdot \eta \quad (2)$$

where E is the average daily level of solar radiation, kWh / m^2 / day, S is the working area of the solar collector, m^2, η is the efficiency of the solar collector.

The area of solar collectors that will provide the required amount of energy, m^2.

$$S = Q / E\eta \quad (3)$$

The experimental procedure was as follows: a laboratory model of a cyclic solar plant of the "Hot Box" type was installed. The design of the solar plant consisted of a wooden frame, on which a polyethylene film was stretched in two layers, with a gap between the layers of 2 cm. The size was assigned in such a way as to cover all three-piece molds with concrete mixture. The molds with the concrete mixture were placed in a solar plant and kept there until testing. Removal of samples for testing was carried out on 1, 3, 7, 14, 28 days. For the compositions under study, twin control samples were made in parallel, which were stored in a normal hardening chamber with a temperature of 20 ± 3 °C and a humidity of 95 ± 5%. For the manufacture of samples, Portland cement grade 500, quartz sand and polycarboxylate additives from MC-Bauchemie (Germany) were used: a complex additive with a superplasticizer with an accelerated hardening effect MC-PowerFlow 3100 and a superplasticizer MC-PowerFlow 2695. Samples of beams with a size of 40x40x160 mm were made in accordance with the current standard [18]. The tests were carried out on verified equipment. The results were processed in Excel according to calculations in accordance with the current standard, the data are given as the arithmetic mean of all the results of one batch of samples.

Main material

The results of tests of the compressive strength at 28 days for samples with the use of MC-PowerFlow 2695 additive showed an average strength of 26.5 MPa, which corresponds to the grade 250. Results of tests of the compressive strength at 28 days when using the complex additive MC-PowerFlow 3100 with acceleration effect of hardening, the corresponding grade of concrete was obtained on the 3rd day, and on the 28th day the average strength was 49.9 MPa, which corresponds to grade 450. For production, the rate of strength gain is one of the most important indicators, because the faster the product gains the stripping strength of 70-80% (for prefabricated reinforced concrete products) the more products the plant can produce. Samples using MC-PowerFlow 2695 additive gained stripping strength (on average 16.3 MPa) after 14 days of storage in a normal hardening chamber, samples using MC-PowerFlow 3100 additive achieved similar strength in 2-3 days, stripping strength (on average 35.4 MPa), the samples reached within 7 days of storage. When using the same formulations, samples with MC-PowerFlow 3100 additive showed accelerated build-up and a significant increase in strength compared to samples in which MC-PowerFlow 2695 additive was used, which, in turn, reduces cement consumption in the production of products. The results of the strength tests are given in table 1 and fig. 1.

Table 1

Concrete test results when stored in a normal hardening chamber

Name	W/B	Days	Compressive strength, MPa	Name	W/B	Days	Compressive strength, MPa
MC-PowerFlow 3100	0,3	1	12,6	MC-PowerFlow 2695	0,32	1	1,1
		3	27,8			3	5,1
		7	35,4			7	11,8
		14	41,6			14	16,3
		28	49,9			28	26,5

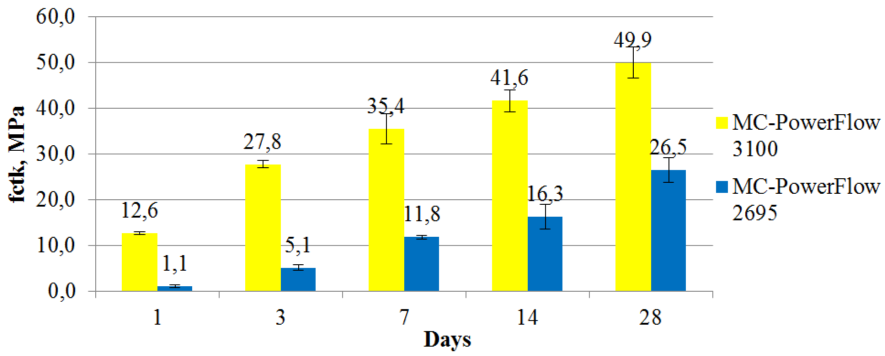

Figure: 1. Comparison of the compressive strength of concrete versus its age, using additives of plasticizers, when storing samples in a normal hardening chamber.

When storing samples in a solar chamber, due to heliothermal heating of samples, it was possible to achieve acceleration of concrete strength gain and to achieve tempering strength of 70 - 80% (on average 35.5 MPa) within 3 days for samples using MC-PowerFlow 3100 additive. time, the samples in the manufacture of which the additive MC-PowerFlow 2695 was used gained tempering strength (on average 19.8 MPa) after 7 days of storage.

Comparison of the strength between the samples from the solar and normal hardening chamber was also carried out. Specimens gaining strength in the solar chamber showed an accelerated strength gain under equal hardening conditions. The results are shown in table. 2 and fig. 2 - 4.

Table 2

Concrete test results when stored in a solar chamber

Name	W/B	Days	Compressive strength, MPa	Compressive strength gain,%
MC-PowerFlow 3100	0,3	1	21,4	169,8
		3	35,5	127,7
		7	43,2	122,0
		14	49,4	118,8
		28	50,7	101,6
MC-PowerFlow 2695	0,32	1	3,9	354,5
		3	12,3	241,2
		7	19,8	167,8
		14	26,5	162,6
		28	28,2	106,4

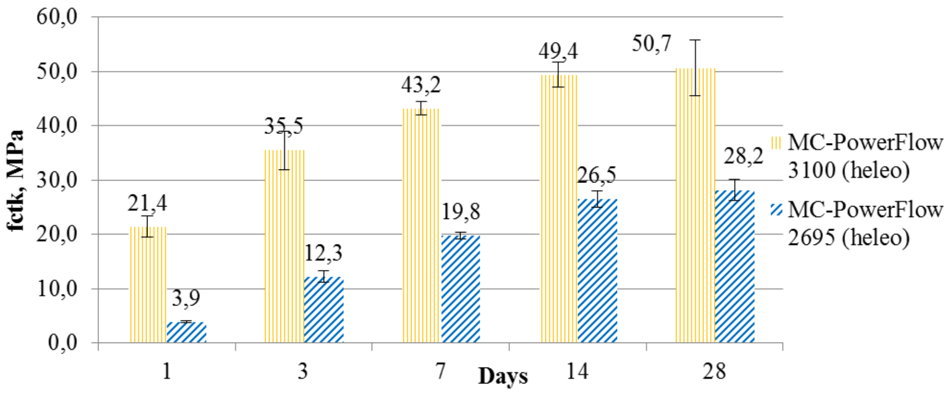

Figure 2. Comparison of the compressive strength of concrete versus its age, using additives of plasticizers, when storing samples in a solar chamber.

During the experiments, the strength characteristics of the concrete mixture were established. Heating in the solar chamber greatly accelerated the strength development of the samples with the use of MC-PowerFlow 2695 additive, so the samples kept in the solar chamber on the first day showed strength 254.5% higher than similar samples from the normal hardening chamber. On the 3rd day of storage, the maximum increase was 141.2%, on the 7th day - 67.8%, on the 14th day - 62.2% and on the 28th day - 6.4%. At the same time, samples with MC-PowerFlow 3100 additive showed less speed gain due to the initial accelerating properties of the concrete mix.

The experiments were carried out in the springtime of the year, which is not the hottest, and the solar chamber works entirely on solar energy and is completely dependent on the ambient temperature.

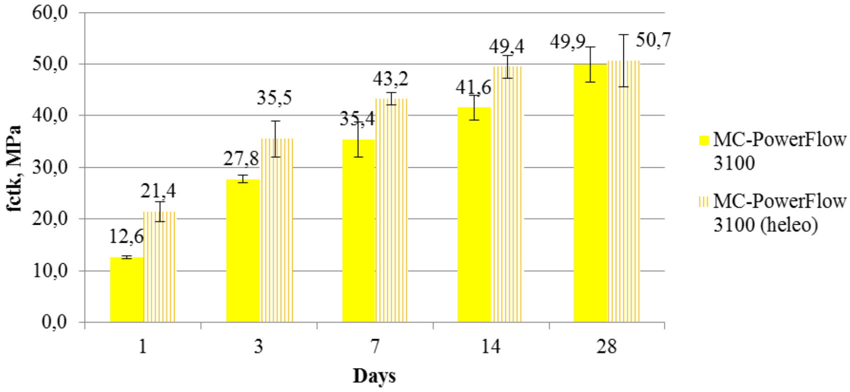

Figure 3. Comparison of concrete compressive strength versus its age depending on storage conditions using MC-PowerFlow 3100 additive.

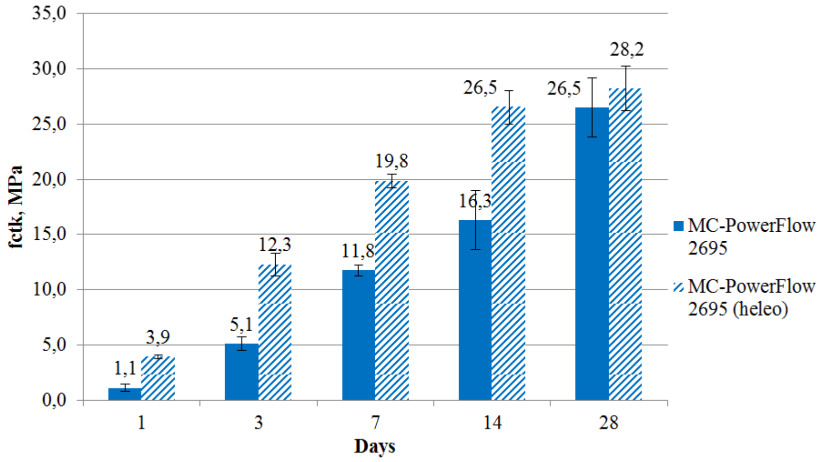

Figure 4. Comparison of concrete compressive strength versus its age depending on storage conditions, using MC-PowerFlow 2695 additive.

To determine the efficiency of the solar chamber, thermometers were installed to measure the temperature of the environment, concrete mixture and the temperature inside the solar chamber. In the course of the experiment, the maximum temperature values were revealed: the environment - 38 °C, the solar chamber - 46 °C and the concrete mix 52 °C.

Main conclusions

Experiments were carried out on two additives of superplasticizers manufactured by MC-Bauchemie showed that the use of a solar chamber significantly improves the initial set of strength, and helps to gain tempering strength in the shortest possible time, which in turn accelerates construction. Also, on the 3rd day of holding, the samples with the addition of MC-PowerFlow 2695 showed 43% strength, and the samples with the addition of MC-PowerFlow 3100 showed 70% strength. The use of a solar chamber does not increase the maximum strength of concrete, but only contributes to a faster gain in strength, and the combination with additives that accelerate the development of strength reduces the advisability of using a solar chamber. The paper presents a variant of calculating the solar chamber, which can be used to further improve existing and create new efficient solar chambers and is one of the directions for the development of precast concrete production in areas with hot climates.

Reference

1. Malyarenco V.A. *Energetika dovkillya. Energosberegennya* - Kharkiv: Rybikon, 2004.
2. Alaa A.F. Husain, Wan Zuha W. Hasan, Suhaidi Shafie, Mohd N. Hamidon, Shyam Sudhir Pandey. A review of transparent solar photovoltaic technologies. In *Renewable and Sustainable Energy Reviews,* October 2018, Volume 94, pp. 779-791; DOI:https://doi.org/10.1016/j.rser.2018.06.031
3. Thibaut Esence, Hadrien Benoit, Damien Poncin, Michael Tessonneaud, Gilles Flamant. A shallow cross-flow fluidized-bed solar reactor for continuous calcination processes. In *Solar Energy,* January 2020, Volume 196, pp. 389-398; DOI:https://doi.org/10.1016/j.solener.2019.12.029
4. Jane M-F Johnson, Don Reicosky, Ray Allmaras, Dave Archer and Wally Wilhelm. A matter of balance: Conservation and renewable energy. In *Journal of Soil and Water Conservation,* July 2006, 61 (4) 120A-125A; https://www.jswconline.org/content/61/4/120A
5. Sheng-Yung Chang, Pei Cheng, Gang Li, Yang Yang. Transparent Polymer Photovoltaics for Solar Energy Harvesting and Beyond. In Joule, 2018, V2, issue 6, pp. 1039-1054 DOI:https://doi.org/10.1016/j.joule.2018.04.005
6. Serdyk V.V. *Fizika colnechnuh elementov*. Odessa: Izdatelstvo "Logos". 1994.
7. John F. Geisz, Ryan M. France, Kevin L. Schulte, Myles A. Steiner, Andrew G. Norman, Harvey L. Guthrey, Matthew R. Young, Tao Song, Thomas Moriarty. Six-junction III–V solar cells with 47.1% conversion efficiency under 143 Suns concentration. In *Nature Energy volume,* 2020, 5, pp. 326 – 335.
8. Angel Serrano, Mikel Durana, Jean-LucDauvergne, Stefania Doppiu, Elena Palomo Del Barrioa. Tailored transition temperature plastic crystals with enhanced thermal energy storage capacity. In *Solar Energy Materials and Solar Cells,* January 2021, Volume 220; DOI:https://doi.org/10.1016/j.solmat.2020.110848
9. Yifeng Zhao, Paul Procel, Can Hana, Luana Mazzarella, Guang tao Yang, Arthur Weeber, Miro Zeman, Olindo Isabella. Design and optimization of hole collectors based on nc-SiOx:H for high-efficiency silicon heterojunction solar cells. In *Solar Energy Materials and Solar Cells*, January 2021, Volume 219; DOI:https://doi.org/10.1016/j.solmat.2020.110779
10. María José Montesa, José Ignacio Linares, Rubén Barbero, Antonio Rovira. Proposal of a new design of source heat exchanger for the technical feasibility of solar thermal plants coupled to supercritical power cycles. In *Solar Energy,* November 2020, Volume 211, pp.1027-1041; DOI:https://doi.org/10.1016/j.solener.2020.10.042
11. Amelia Gulkis. The Energy Pyramid: The best path to lasting energy savings. In *Journal of Soil and Water Conservation,* September 2009, 64 (5) 143A-144A; DOI:https://doi.org/10.2489/jswc.64.5.143A
12. *Karta solnechnoi activnosti v Ukraine*. [online]. [accesat 05.11.2020]. Disponibil: https://www.solar-battery.com.ua/karta-solnechnoy-aktivnosti-v-ukraine/
13. Kucherenko A.A. *Teplovye ustsnovki zavodov sbornogo jelezobetona*. Kuiv: Vyja shkola. Golovnoe izdatelstvo, 1977.
14. Duffie J.A., Beckman W.A. *Solar engineering of thermal process*. – New York: John Wiley and Sons, 1980.
15. K.K. Gopinathan, N.B. Maliehe, M.I. Mpholo. A study on the intercepted insolation as a function of slope and azimuth of the surface. In *Energy*, 2007, 7, pp. 213 – 220.
16. DSTY B V.2.7-214 «Budivelni materialy. Betony. Metody vuznachennya micnosti za kontrolnymy zrazkamy»; DOI:http://online.budstandart.com/ua/catalog/doc-page.html?id_doc=25943