Use of Hydration Heat and Solar Energy in Prefabricated Concrete Production Lines

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Abstract

The paper analyses the thermal energy requirements of an industrial production line for prefabricated concrete parts using measurements and tests. The goal is to significantly reduce the energy demand and reduce the temperature level in order to be able to integrate solar thermal process heat, and the first-time use of the hydration heat. The final production line, optimized on the basis of the research results, is presented, as well as a simulation study, which shows, that economically interesting solar thermal process heat production costs can be achieved through an optimized overall concept. Regarding the export of this production technology to countries with hot and dry climates it is also aspired, to cover the additional required cooling load by means of solar thermal driven chillers. This option should also be examined by system simulations. These simulations put also emphasis on the development of cost- effective system concepts, which allow the integration of solar thermal process heat and/ or cold.

Keywords: Solar thermal process heat and/ or cold, prefabricated concrete parts, measurements and tests, heat production costs, optimized overall concept, solar thermal driven chillers, polysun system simulations

1. Introduction

The cooling, respectively heating during the production process of precast concrete parts is extremely important regarding quality. In Middle and Northern Europe concrete heating is more relevant, whereas, in Southern countries such as Turkey, United Arab Emirates a production of high quality concrete would hardly be possible without cooling.

The plants operated by the Austrian company Franz Oberndorfer GmbH & Co KG are producing prestressed hollow core slabs in various construction heights at the locations Wöllersdorf, Herzogenburg, Gunskirchen, Grosswilfersdorf, Radfeld and Völkermarkt. Through the restructuring of the production process in the plant Wöllerdorf the energy consumption shall be reduced by 90% in future. This target is a result of an ongoing company internal development process. The final target will be reached through the worldwide first time usage of the so called hydration heat (heat development through chemical reaction of water and cement) and the integration of solarthermal energy in the whole process. The use of hydration heat decreases the energy demand and necessitates changes in the heat distribution system towards lower temperatures. This modification on the other hand, approves the use of solar thermal energy in the production process.

The use of hydration heat insists a long-term comprehensive evaluation of the production data. In the end the heat shall be discharged by means of a heat transfer medium via the mold surface. Based on the results from the evaluation of the production data as well as a series of laboratory tests, the target is to develop a proven hydraulic concept and a control system for the recovery of hydration heat. Hence the achieved production data will be converted to load profiles. These load profiles serve as a basis for dynamic simulations in order to examine the integration of solar thermal energy in the production process. Regarding the export of this production technology to countries with hot and dry climates it is also aspired, to cover the additional required cooling load by means of solar thermal driven chillers. This option is examined also by system simulations.

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The project puts emphasis on the development of cost- effective system concepts, which allow the integration of solarthermal process heat and/ or cold. The lessons learned during the long-term comprehensive evaluation of the production data and the lab tests will be incorporated also into the redesign of the other production plants. It is planned to hand over the achieved conclusions to further application areas (precast concrete product range worldwide) by licenses to interested competitors.

2. Production data evaluation

The basis for the planned project objectives is a comprehensive, long-term production data analysis at the demonstration and test facility located in in Wöllersdorf, Austria.

Prestressed hollow core slabs are characterized by low overall height and minimum building material consumption. They belong to the group of full-surface ceilings without subdivision with subsequent grouting and are built according to ÖNORM EN 1168 at heights of 16 cm; 20 cm; 26 cm; 32 cm; 40 cm; 45 cm and 50 cm with a length of up to 22 meters [1]. Up to now, the elements have been produced on up to 150 m long lanes, which are heated by means of a thermo- oil heating system. The corresponding pipe system had to be heated to a temperature of approx. 150 ° C.

In Figure 1, the demonstration (right) system is compared to the previous heating system (left). By increasing the number of tubes, embedding them into a storage medium and connecting it to the steel plate, a better heat transfer is achieved. Therefore, the flow temperatures can be lowered, and water can be used as a heat transfer medium. Due to the novel hardening process, the required surface temperature of the floor panel of 35° C. is achieved with a substantially lower energy input. The temperature of the water circuit is now 50-60 °C.

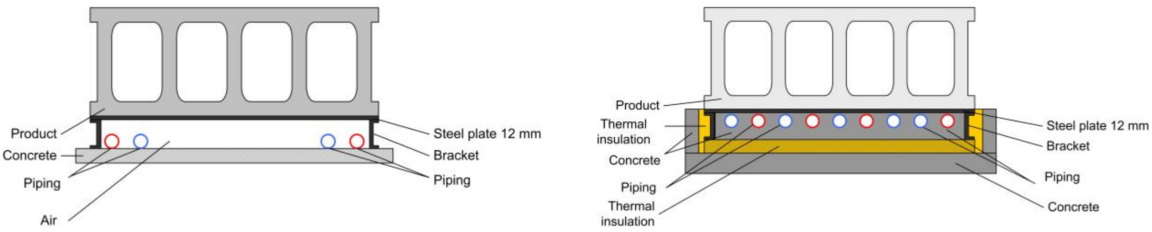

Fig. 1: Comparison old(left) and new (right) product heating system

Three heating circuits are designed hydraulically as parallel circuits with mixing control by three-way valves. A modulating 275 kW gas boiler is the heat source. A control system allows the presetting of a set flow temperature and the definition of heating times per circuit as well as the recording of measured data. The entire production process takes about 24 hours. This production process involves straining the steel ropes, extruding, (applying the concrete on the lane), curing, removing the slab and cleaning the lane.

Irregularities in the internal data collection as well as unexplained temperature gradients along the length of the lane led to the temporary installation of additional data loggers and to the analysis of thermographic images. Control measurements with mobile ultrasonic heat meters confirmed incorrectly closing control valves and showed conversion errors in the internal measurement data acquisition.

The annual energy balance in Figure 2 shows the enormous savings potential that can be achieved by really simple measures. Regarding domestic hot water production and building heating, further measurements are planned.

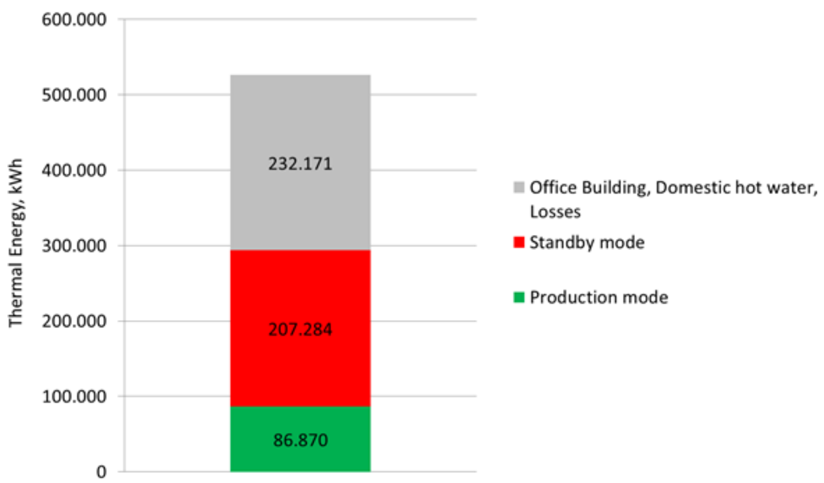

Fig. 2: Annual energy balance of a typical fabrication plant in Austria

3. Use of hydration heat

For the production of concrete, water, binders (e.g. cement), aggregate (e.g. sand/ gravel) and possibly additives (e.g. fluxes) are needed. The chemical- physical reaction of cement with water is called hydration. The heat evolution depends essentially on the amount of cement and the type of cement. The amount of heat developed up to the complete hydration does not differ significantly for the individual types of cement.

Depending on the application, different solutions for the prevention or reduction of hydration heat are sought. On the one hand, attempts are being made to accelerate the curing time of the concrete parts by supplying heat, but on the other hand, the concrete part temperature must not rise too much because of cracking and possible product damaging.

In this project, the heat of hydration is seen as an additional, previously unused energy or heat source, which can help to reduce production costs and increase product quality. The main challenge is posed in the fact that until now there was no way to control the heat of hydration or to offer any technical solutions for removing the heat of hydration. On the basis of temperature measurements and simulations with the software COMSOL® Heat, an attempt was made to document the temperatures occurring during a whole production cycle. Subsequently, a sample was taken to determine tensile and compressive strength. Figure 3 shows one time step of the occurring temperature profile.

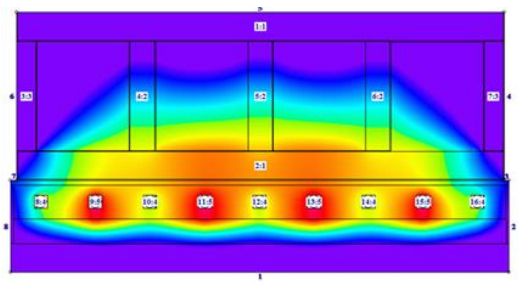

Fig. 3: Temperature profile during production

The high savings potential realized due to the production data analysis relativizes the expected savings of hydration heat recovery. The maximum surface temperature on the bottom side is max 5°C above the current heating return temperature of 45°C. The heat recovery potential is therefore low. For the quality of the products, however, the occurring temperature gradients are important, which should not exceed the maximum 0.3K per hour and 0.7 K/cm slab height.

4. Simulations

4.1 Location Austria, heating energy supply

The data collected during the evaluation over a year were used to create load profiles for the heating of the lanes. From the huge amount of production data and the production plan, the required heating energy quantities were analyzed at different fresh concrete temperatures. The production process consists of 3 parts. The preheating process is used to bring the massive flooring sheet to temperature. A required preheating time of 2 h was selected. The production process is characterized by different thickness of the slabs and therefore different production times. Thus, the thickest slab type is extruded in more than twice the time of the thinnest slab. Finally post heating is used for quality assurance and is necessary to prevent material stresses and to accelerate the hydration. The fresh concrete temperature was approximated with the outside temperature. The resulting energy need equals to 400- 450 kWh for the slight lanes (16-26 cm height) and 600-700 kWh for the massive lanes. (32- 50 cm height). In general, there is only a slight influence caused by the fresh concrete temperature.

The power consumption, the duration and the temperature profile of the production steps results in specific load profiles. These load profiles and the current production plan serves as a basis for the dynamic system simulations using the Vela Solaris software Polysun Designer. This results in a theoretical process heat energy consumption of 248.400 kWh. Figure 4 shows the corresponding plant concept.

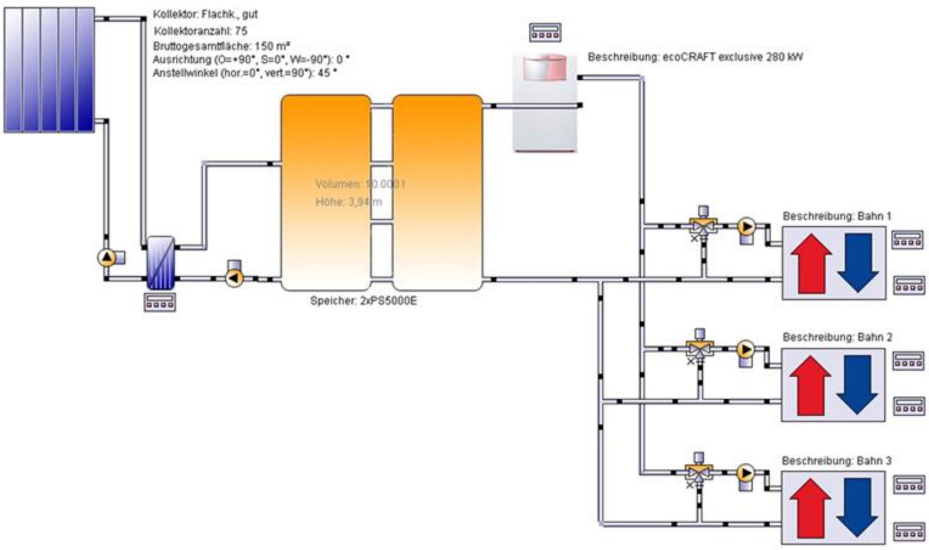

Fig. 4: System concept in the software Polysun Designer

The solar system is designed, that the process heat demand can be covered on a clear summer day. This is to avoid stagnation in summertime. High specific yields are the result, which are important for the profitability of the system. However, the achievable solar fraction is limited. In the industrial sector the aspect of economic efficiency plays an important role [2]. For the design of the hot water storage, it should be noted that the dimensioning depends strongly on the respective load profile. The specific storage volume is calculated by means of the return temperature.

Figure 5 shows the simulation results for flat plate collectors (tilt angle 45°) with optimum azimuth alignment using a 25m³ hot water storage. The plant performance ratio is 29% for a gross collector area of 200m², whereby 25m³ is the minimum storage size. As a result of an increase in the storage volume, the performance ratio increases only slightly.

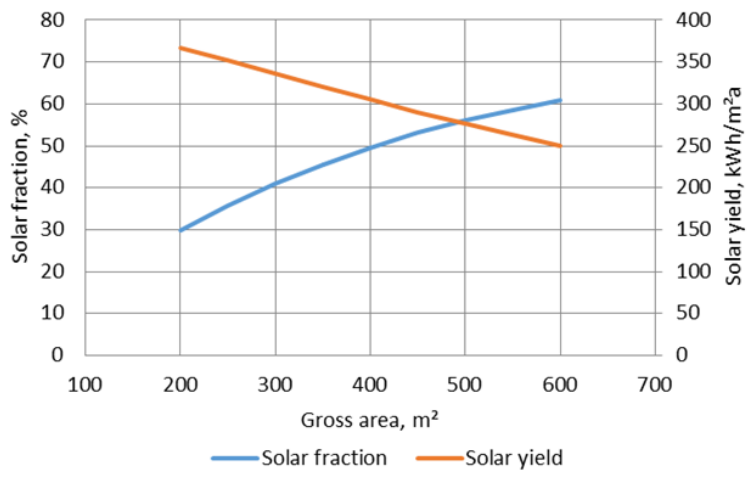

Fig. 5: Solar fraction and solar yield depending on gross area, 25m³ hot water storage

For economic considerations, the costs per kWh heat are used. The investment costs of the plant, an annuity factor, operating costs, consumption costs and the annual solar energy yield influence the costs per kWh heat [2]. For an accurate calculation of the investment costs, functions from a tool developed in IEA SHC Task 48 were used [3]. Since in this case no new additional heat source has to be installed, only the collectors, piping and storage has to be considered. In addition, an Austrian subsidy of 40% of the investment costs was taken into account [4].

At the location Austria,a solar thermal system with a total gross area of 200m² with a 25m² water storage tank for example, can supply 30% of the annual thermal energy demand at a price of 5.6 €cent per kWh heat. This value can be reduced by doubling the storage volume to 4.9 €cent / kWh.

4.2 Location United Arab Emirates, cooling energy supply

Regarding the export of this production technology to countries with hot and dry climates the power consumption load profiles were adapted for the climate in the United Arab Emirates. In these climate the production of high quality concrete is hardly possible without cooling. Therefore a cold supply temperature of 20°C for the lanes was chosen. This results in a theoretical process cold energy consumption of 426.280 kWh.

The system concept includes a single effect absorption chiller with a wet cooling tower, a hot water storage tank which is powered by flat plate solar collectors and a gas backup boiler. A solar thermal driven cooling system with a total gross area of 500m² with a 30m² hot water storage tank, can supply 53% of the annual thermal cooling energy demand. The price per kWh solar generated cold amounts however more than 15 €cent. The investment and operating costs for the backup system are not yet taken into account.

5. Results and conclusion

The detailed investigation of a production line for precast concrete parts in Austria showed that a reduction of the thermal energy requirement to one third is possible. The additional use of the hydration heat (heat development by chemical reaction of water and cement) in order to further reduce the energy requirement has a significant influence on product quality and production time. To ensure a consistent product quality, a massive covering (insulation) of the lanes after the extrusion process, or a heating of the production hall, appears to be more appropriate.

The optimized production line based on these results, was used as a basis to investigate the integration of solar thermal energy generation with simulations. A solar thermal system, located in central Europe, with a total gross area of 200m² with a 25m² water storage tank, can supply 30% of the annual thermal energy demand at a heat price of 5.6 €cent per kWh.

The analysis clearly shows that competitive heat prices can be achieved by the use of solar thermal heat on prefabricated concrete production lines. The precast concrete market or the construction industry represents a promising application for solar thermal process heat integration.

Regarding the export of this production technology to countries with hot and dry climates (e.g. United Arab Emirates), a solar thermal driven cooling system with a total gross area of 500m² with a 30m^3 hot water storage tank, can supply 53% of the annual thermal cooling energy demand. However, costs of 15 €cent/kWh cold must be applied.

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