Application of multisectional rock bed heat accumulator in high tunnel horticultural crop production and potential effects of its use

Paweł Konopacki, Ryszard Hołownicki, Robert Sabat, Waldemar Treder and Jacek Nowak, Research Institute of Horticulture, ul. Pomologiczna 18, 96-100 Skierniewice, Poland

Sławomir Kurpaska and Hubert Latała, Institute of Agricultural Engineering and Computer Science, University of Agriculture in Krakow, Balicka 116 B, 30-149 Krakow, Poland

Abstract

The protected crop cultivation in the moderate climate requires heating almost every day during the season, either for raising the temperature, or for reduction of air humidity. The required amount of heat might be partially met by accumulation of excessive heat from conversion of solar energy entering the plastic tunnel or greenhouse. The typical plastic tunnel used in Poland has width between 7.9 m and 9.6 m, and length about 30 m. The rock bed heat storage system has been designed for a half of such tunnel and located underground. The full scale facility has been built in Skierniewice, central Poland, and used for tomato and cucumber crops. When the heat storage systems is used in a real microclimate created by growing plants, the maximal temperature of the air entering the rock bed is limited due to necessity of tunnel/greenhouse ventilation to maintain the temperature within the range optimal for plants. Yet, even in such conditions unfavorable for efficient heat storage, the amount of heat stored daily in a single accumulator unit (located under each of 135 m² tunnel compartments) reached 270 MJ, while when all sections are used the daily amount of heat gained from the accumulator regularly exceeds 400 MJ.

The rock bed heat accumulator has been designed as a multi-sectional facility, to enhance its efficacy when the solar radiation is limited and the use of full volume of rock bed is not recommended. In such conditions the air flow has to be reduced to keep the high temperature of air entering the rock bed and maintain the rate of heat exchange. The limited solar radiation occurs mostly at spring and autumn time, therefore a special system of dampers has been designed to let each section of rock bed to be used individually or in combinations with other sections.

During the mid-summer hot period the plants in greenhouses mostly do not need overnight heating, but the daily temperatures exceed the optimal range by far. For that reason, the air circulation system has been design to allow also the plant cooling during such hot days.

The list of operation modes covers, among the others: charging of accumulator during the day, charging of accumulator with simultaneous cooling of plants during the day, heating the plants during the night (or a cold day), cooling of accumulator overnight, cooling of accumulator overnight with simultaneous heating of plants, and cooling of plants during the day.

Apart of change of temperature inside the tunnel/greenhouse the use of rock bed heat accumulator causes the significant reduction of air relative humidity (and increase of vapour pressure deficit). The higher VPD means healthier conditions for plant growth and reduction of required number of plant protection treatments. The highest recorded difference (among tomato plants) between tunnel with accumulator and tunnel without it reached 975 Pa at the end of July 2013.
Keywords: protected crops, plastic tunnel, horticulture, heat accumulation, rock bed

1. Introduction

The protected crop cultivation in the moderate climate requires heating almost every day during the season, either for raising the temperature, or for reduction of air humidity. The total area of protected crop production in Poland is around 6600 ha. In Europe it exceeds 125000 ha of which over 30000 ha is located in temperate climate zone (Eurostat, 2013). The yearly cost of heating of modern greenhouses may exceed € 100000 per ha. However, different countries are characterized by different intensity of production, and respectively, different heating requirements. For example, in Poland majority of protected area are single-cover tunnels, which are used only for few months per season and the average cost of heating probably exceeds € 20000 per ha. On the other hand protected crop production in Netherlands and Germany is plausibly much more intensive, and the average annual heating cost is much higher there. The Mediterranean countries require much less of greenhouse heating and the yearly cost in Turkey is only about 20 € / ha (Canakci et al., 2013). Nevertheless, the annual heating cost in Europe is between 600 mln € and 3 bln €, of which overwhelming majority is incurred in temperate climate countries.

The required amount of heat might be partially met by accumulation of excessive heat from conversion of solar energy entering the plastic tunnel or greenhouse, which is nowadays wasted due to need for prevention of plant overheating.

2. Heat accumulator

The typical plastic tunnel used in Poland has width between 7.9 m and 9.6 m, and length about 30 m. The rock bed heat storage system has been designed for a half of such tunnel and located underground. The full scale facility has been built in Skierniewice, central Poland, and used for tomato and cucumber crops (Holownicki et al., 2014). The rock bed heat accumulator has been designed as a multi-sectional facility, to enhance its efficacy when the solar radiation is limited and the use of full volume of rock bed is not recommended. In such conditions the air flow has to be reduced to keep the high temperature of air entering the rock bed and maintain the rate of heat exchange. The limited solar radiation occurs mostly at spring and autumn time, therefore a special system of dampers has been designed to let each section of rock bed to be used individually or in combinations with other sections. The estimated heat capacity of the whole accumulator is 561.7 kJ K^{-1} m^{-2} (Konopacki et al., 2012). Moreover, the air flow may be directed sequentially through a part or all sections, to extend the path of air flow and increase the heat exchange. During the mid-summer hot period the plants in greenhouses mostly do not need overnight heating, but the daily temperatures exceed the optimal range by far. For that reason, the air circulation system has been design to allow also the plant cooling during such hot days. The list of operation modes covers, among the others: charging of accumulator during the day (Fig.1), charging of accumulator with simultaneous cooling of plants during the day, heating the plants during the night (or a cold day) (Fig. 2), cooling of accumulator overnight, cooling of accumulator overnight with simultaneous heating of plants, and cooling of plants during the day.

3. Results

When the heat storage systems is used in a real microclimate created by growing plants, the maximal temperature of the air entering the rock bed is limited due to necessity of tunnel/greenhouse ventilation to maintain the temperature within the range optimal for plants. Yet, even in such conditions unfavorable for efficient heat storage, the amount of heat stored daily in a single accumulator unit (located under each of 135 m² tunnel compartments) reached 270 MJ (in 2012 year). When the whole accumulator (all sections) is used, the early spring conditions allow daily supply of more than 400 MJ from accumulator to the plants (and sometimes exceeding 650
MJ) (mid-April 2013). The amount of energy stored in an accumulator was sufficient to cover heat requirements of cucumber production from mid-May on.

In 2012 the heat stored in the accumulator was sufficient to warm the air among the plants by 9.9 °C above the temperature outside the tunnel (which on that night dropped to 2.9 °C). In 2013 the maximal temperature difference reached 9.4 °C (when temperature outside was 2.1 °C).

The minimal heat requirements of cucumber production, necessary for proper nutrient uptake (temperature above 12 °C), were covered during almost the whole growing season (since mid-April until beginning of October 2013). The total amount of energy obtained from the accumulator during the season 2013 exceeded 41 GJ.

Apart of change of temperature inside the tunnel/greenhouse the use of rock bed heat accumulator causes the significant reduction of air relative humidity (and increase of vapour pressure deficit). The higher VPD means healthier conditions for plant growth and reduction of required number of plant protection treatments. The night VPD difference among tomato plants between tunnel with accumulator and tunnel without it regularly exceeded 300 Pa since mid-April until beginning of September in 2013 year, and reached 975 Pa at the end of July.

4. Conclusions

The fully charged accumulator with the thermal capacity of about 561.7 kJ K⁻¹ m⁻² is capable to increase the temperature inside the tunnel for several consecutive days, even when the additional charging is not possible. The requirement of maintaining the minimal temperature above 12 °C was met from mid-April until beginning of October 2013.

The recorded temperature differences above 9 °C between inside and outside the tunnel on the cold nights suggest, that even in case of night ground frost the rock-bed accumulator may avoid plant frost damage.

The increase of minimal vapour pressure deficit among the plants reduces the risk of plant disease development.

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6. References


Figure 1: Circulation of air during accumulator charging.

Figure 2: Circulation of air during plant heating.