（様式６号）「課程博士用」

学 位 論 文 の 要 旨

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学位論文題目

Energy-saving method for changing periodic air temperature field in greenhouse crop cultivation

（英訳又は和訳　　温度周期性のある温室栽培での省エネルギー制御））

In control agricultural section, the greenhouse and plant factories are increasingly popular. The greenhouse cultivation is an enclosed environment that creates suitable conditions for the high-quality crops production. In contrast to traditional open-field cultivation, greenhouses allow for higher production levels, better crop quality, and out-of-season production. Regarding energy consumption, greenhouse cultivation is a major energy consumer where the entire facility environment is controlled. High energy consumption of creating an appropriate climate for crop growth becomes the main limiting issue in greenhouse cultivation. In particular, some crops like strawberry require periodic temperature field in day and nighttimes. To address this issue, this study proposed periodic local climate control using a simple serpentine copper tube heat exchanger near the crop areas in greenhouse cultivation. Since the environment far away from the crops is not very essential, the environment only near the crops is controlled to provide a suitable climate for crops. In this way, the energy consumption of climate control can be reduced due to a smaller volume compared to climate control for the whole volume of greenhouse cultivation.

The first objective of this thesis was to investigate the local air temperature profiles as well as the performance of the serpentine heat exchanger such as the heat flux and pressure drop in them. Copper tubes were arranged in the shape of serpentine and used as a heat exchanger. In contrast to fin-and-tube heat exchangers, the serpentine heat exchanger has a simple design, provides minimal shade for plants, and is easy to maintain for agriculture. To employ this system for practical use, its scale can be expanded by connecting heat exchangers in series and parallel. The experimental system was constructed under with the assumption that a part of actual plant cultivation was being left out. This study was conducted in a laboratory. Experiments were performed by varying inlet fluid temperature and fluid flow rates. Inlet fluid temperature varies from −5 to 10 ºC for cooling, and 30 to 50 ºC for heating. The fluid flow rate is changed from 0.3 to 3.0 L/min (Reynolds number = 50 – 3,480) for cooling and heating. The local air temperatures, tube surface temperatures, air temperature inside and outside of the experimental area, inlet and outlet fluid temperatures, and pressure drop were measured. The relative humidity was monitored for reference. In terms of cooling, the local air temperature can be reduced by 4–10 °C from the initial air temperature of 22 °C in the area below the heat exchanger at a distance of 150 mm. In terms of heating, the local air temperature can be increased by 6–13 °C from the initial air temperature of 22 °C in the area above the heat exchanger at a distance of 150 mm. For cooling, the average heat flux values in the heat exchanger at inlet fluid temperatures of 5, 0, and −5 °C are enhanced by 55%, 120%, and 170% for all flow rates compared with that at inlet fluid temperature of 10 °C. The average heat flux values in the heat exchanger at inlet fluid temperatures of 40 and 50 °C are increased by 100% and 197% at all flow rates compared with that at inlet fluid temperature of 30 °C. Considering both cooling and heating operations, the pressure drop in the heat exchanger reaches a minimum of 0.3 kPa and a maximum of approximately 5.0 kPa for flow rate of 0.3 to 3.0 L/min. Based on the results, inlet fluid temperature markedly affects the heat flux in the heat exchanger, subsequently influencing the local air temperature. Particularly, the local air temperature control and heat flux in the heat exchanger are more

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strongly affected by inlet fluid temperature than by the flow rate.

The second objective of this thesis was to evaluate the change in the periodic air temperature field characteristics of the serpentine copper tube heat exchanger. For this, the air temperature difference between the area below and the area above of the heat exchanger as well as the transition time were examined. The periodic air temperature change was evaluated at the inlet fluid temperatures of −5 and 50 ºC for all flow rates. The results showed that the air temperature difference between the areas below and above the heat exchanger of the cooling and heating processes is approximately 15 ºC. Increasing flow rate does not notably change the air temperature at the areas below of cooling and above of heating the heat exchanger. Larger flow rate of 0.9 L/min, the local air temperatures and air temperatures in the experimental system were not substantially changed. When the flow rate increases from 0.3 to 1.3 L/min, the quick change state and moderate change state from cooling to heating (heating transition) took approximately twenty minutes and two hours, respectively. On one hand, for heating to cooling process (cooling transition), the quick change state took around forty-nine minutes and the moderate change state took about one hour and forty minutes. When the flow rates were 1.5 to 3.0 L/min, the quick change state and moderate change state of heating transition took about eighteen minutes and one hour, respectively. On the other hand, quick change state and moderate change state of the cooling transition took approximately forty minutes and one hour, correspondingly. Regarding the transition time, the cooling transition seems to be more gradual compared to the heating transition, indicating that while the system heats up quickly, it cools down more slowly. The transition time reduces with flow rate increases. When the flow rate increases, the tube surface temperature becomes close to the value of inlet fluid temperature enhancing the heat exchange between the tube wall and surroundings.

The last objective was to estimate the energy requirements theoretically between the whole area and the local area control of practical greenhouse crop cultivation. Here the volume of the cultivation area per unit length was approximated from a practical greenhouse. The maximum system capacity requirement of the whole area control is around 62 W/m whereas that of the local area control is approximately 10 W/m which is more than 80% reduction compared to the whole area control. The total energy requirement of the whole area control was about 152 kJ/m. On the other hand, the total energy requirement of the local area control was approximately 37 kJ/m. The total energy requirement of the local area control was more than 70% reduced compared to that of the whole area control of practical greenhouse crop cultivation. This theoretical calculation is a simple and taking into some assumptions to show the advantage of the local climate control heat exchanger system.

This energy-saving method for periodic air temperature change with local climate control could be applied for crop cultivation in greenhouses.

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