

# **Energy Saving Technology Development for Agricultural Machinery and the Greenhouse in Korea**

**Kyu-Hong CHOI\***

\* Director/Senior Researcher, Agricultural Safety Engineering Division, Department of Agricultural Engineering, National Academy of Agricultural Science, Rural Development Administration, 150 Suin-Ro, Gwonseon-Gu, Suwon, Kyeonggi-Do, 441-857, Republic of Korea, E-mail: niaechoi@korea.kr

## **1. Introduction**

A recent rapid increase in the price of crude oil is deepening the instability of the energy market, and the needs to develop new energy saving technologies and secure new renewable energy sources that can substitute for fossil fuels are very urgent. Domestically, the new and renewable energy accounts for 2.24% of the total primary energy in 2006, and the waste-to-energy accounts for 76% of the new renewable energy which indicates that the waste-to-energy technology is the most effective method for the supply and expansion of new renewable energy.

The regulations on materials causing global warming have been strengthened by UNFCCC's Bali Roadmap, which may cause the ever-increasing pressure to Korea to commit the greenhouse gas reduction target after 2012. Energy recovery from wastes is being internationally recognized as a reliable method to reduce greenhouse gases to countermeasure the effects of climate change. New and renewable energy supporting by 2013 is estimated to increase by 3.8%, of which 84% will occupied by waste and biomass energy. In order to cope with the price rise of oil, it is necessary to establish the 3Es paradigm that controls the environment, economy and energy in the integrated manner. This will surpass the recycling-level of the 2Es era that integrates the environment and economy, and changes the policies.

The greenhouse crop production in Korea has greatly threatened by not only its existence but also making ends meet since 1990s due to the ever-increase of because of the ever-increases of oil price for combustion. In fact, the greenhouse heating is mostly accomplished by fuel combustion, which heats air and water. Light oil is the most common fuel type in both heating system.

The fuel cost occupies about 30 to 40% of the total crop production cost depending upon the

crop type, which is higher than the ones in The Netherlands (15%), Israel (10%) and Japan (20%). The light oil price per liter, tax free price, was maintained within the range of 519 to 1,166 won, equivalent to approximately 0.5 to 1.1 dollars. More precisely, the price was 661 won in August, 2007 and then increased up to 1,328 won in July, 2008. This was 100% increase compared with the previous year. The quantity of light oil for greenhouse crop production (1,586 thousands kl) was about 64% of the total tax free fuel in agricultural production (2,478 thousands kl). This explains that the greenhouse crop production was considerably relied on the tax free oil and the tax free oil price was also influenced by the existence of greenhouse farming. Overall, the fuel price is the most important factor in determining the greenhouse farming industry profitable.

To transform this greenhouse farming industry extremely sensitive into less sensitive to the fuel price, the policies have focused on how to reduce the greenhouse heating cost through the technology development of energy saving and alternative heating systems. RDA has provided innovative solutions to release the economical burden of the employers in the greenhouse farming groups. Some of our outstanding research achievements for the past few years will be followed.

## **2. Energy Saving Technologies**

### **2-1. Exhaust heat recovery system for hot air heater**

Hot air heater with light oil combustion is used as the most common heater for greenhouse heating in the winter season. However, exhaust gas heat discharged to atmosphere through chimney reaches up to 10~20% of total heat capacity of the oil burned. In order to recover the heat of this exhaust gas and to use for greenhouse heating, the heat pipe type exhaust heat recovery system was manufactured and tested in this experiment. The system consisted of a heat exchanger made of heat pipes, Ø 15.88x600mm located rectangular box, an air suction fan and air ducts. The number of heat pipe was 60, calculated considering the heat exchange amount between exhaust gas and air and heat transfer capacity of a heat pipe (Figure 1).

The working fluid of heat pipe was acetone because acetone is known for its excellent heat transfer capacity. The system was attached to the exhaust gas path. According to the performance test it could recover 53,809 to 74,613kJ/h depending on the inlet air temperature of 15 to -12°C at air flow rate of 1,100 m<sup>3</sup>/h. The temperature of the exhaust gas left the heat exchanger dropped to 100°C from 270°C after the heat exchange between the suction air and the exhaust gas.

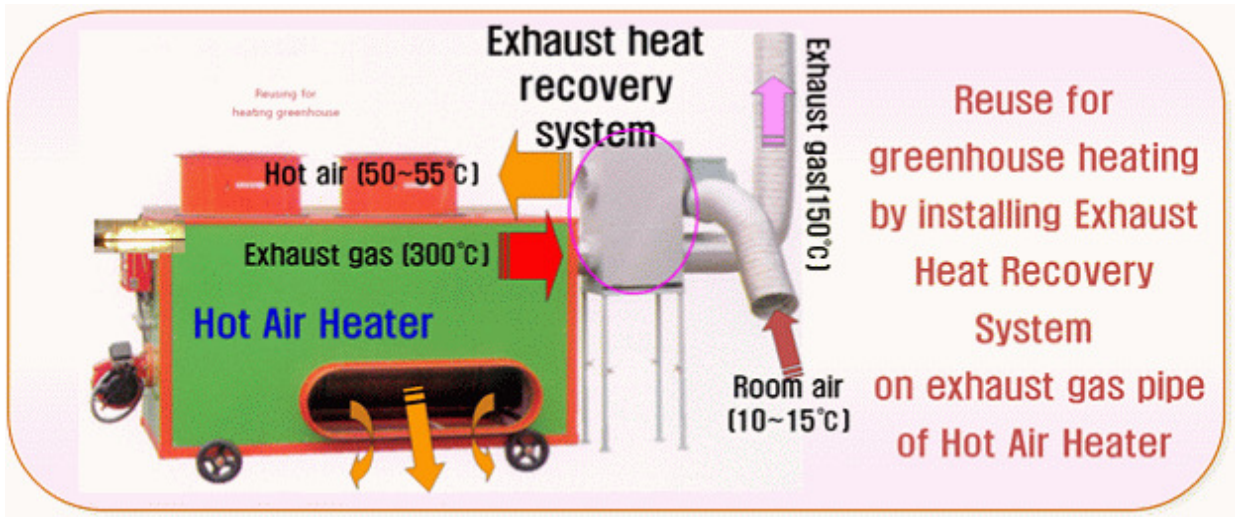
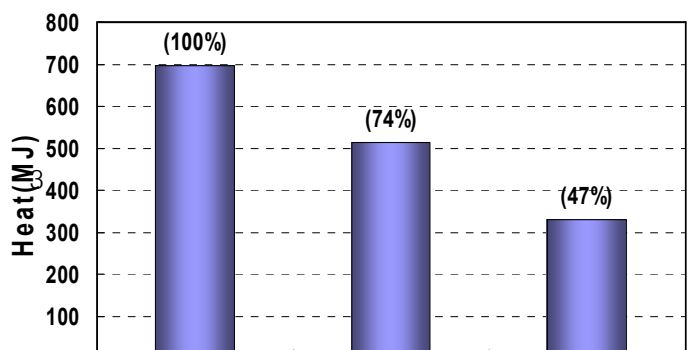


Fig. 1 Exhaust heat recovery system with heat pipe unit attached to the hot air heater

## 2-2. Waste heat recovery system for an agricultural product dryer

The heat recovery system was initiated to recover discharged waste heat from a drying chamber in an agricultural product dryer and recycle it as heat source to save the drying cost. It consists of five components, which are drying chamber, fan, burner, circulation pump and heat exchanger made of fins and tubes. For the performance test, the heat balance analysis on the dryer and drying experiments using fresh peppers were conducted (Figure1). The amounts of fuel consumed by a conventional dryer and the heat recovery system attached to a conventional dryer were compared.

According to the heat balance analysis on a conventional dryer, heat of exhaust gas, heat of discharged drying air from a drying chamber, and convection heat loss were about 14%, 77% and 9%, respectively. In the case of the heat exchanger attached to a dryer, air temperature at an inlet and outlet of the discharged section were 55~60°C and 41~43°C, respectively. Air temperature at an inlet and outlet of the suction section was 25~28°C and 41~43°C, which could supply 41~43°C air to the drying chamber. When red pepper was dried, the heat exchanger could recover the amount of heat (2,200~3,000kcal/h) from waste air heat of 4,700~6,000kcal/h. The recycled heat amount was 47% of total heat input of the dryer and 64% of waste heat discharged to atmosphere. In comparison to the conventional dryer, the drying time of red pepper was significantly reduced, and the drying cost and fuel consumption were reduced by 21% and 43%, respectively (Figure 3).



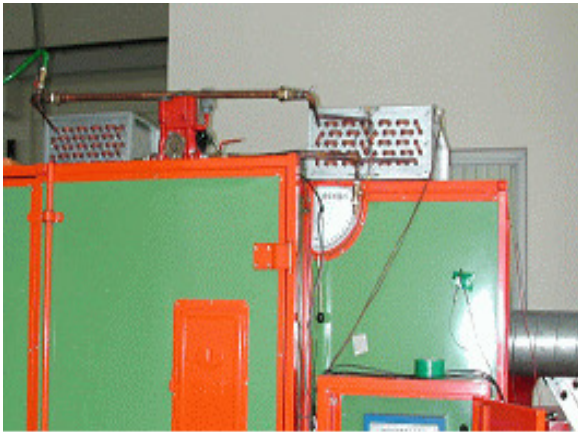


Fig. 2 Heat recovery for agricultural dryer

Fig. 3 Heat balance of heat recovery system

### 2-3. Automatic rolling shutter for thermal vinyl tunnel

The idea of heating space reduction is not new concept in energy saving technology development. In fact, in the southern province of Korea, the greenhouse heating is not necessarily required but space reduced due to relatively warm weather during the winter season. In addition, the temporary vinyl tunneling inside greenhouse was found to protect crops from frosting during the winter season. However, covering and removing vinyl thermal tunnel every night and morning required a lot of labors and only applied in warm southern region.

Therefore, we developed the new opening and closing method for the thermal tunnel curtain for all greenhouse cultivation crops to reduce this tedious labor input. This new method does not require manpower for the opening and closing of the thermal tunnel curtain, thereby cutting down the greenhouse heating cost during the winter by as much as 70%. The new thermal tunnel system is an automatic rolling shutter (ARS) for double layer PE film. It consists of several pipe holders with three-point supporting roller, an aluminum pipe of  $\text{Ø}25$  mm, tunnel frames, tunnel hangers, one DC motor and a double layered PE film. One edge of double layered PE film is folded and the other is separated. The folded edge is fixed on the surface of this aluminum pipe and the twofold PE film is wound on the surface. In addition, each vinyl sheet of the separated edge is put on the tunnel frame. And then for the smooth operation of vinyl opening & closing, the steel wire with the weight over  $0.3\text{kg/m}$  is fixed to the end tip of each vinyl sheet in the longitudinal direction of thermal tunnel (Figure 4 and 5).

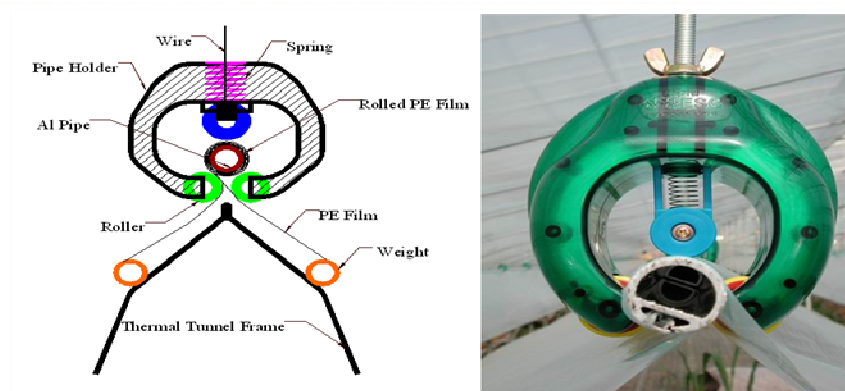


Fig. 4 Design of Automatic Rolling shutter



Fig. 5 Installation of Automatic Rolling Shutter

The thermal insulation effects of thermal tunnel is showed as the temperature difference between tunnel air and ambient air (Figure 6). The ARS thermal insulation effect on large and small tunnels was  $5.3 \pm 0.6$  and  $7.4 \pm 0.6^\circ\text{C}$ , respectively. The elapsed time for the opening and closing of thermal tunnel was measured and then compared to the usage of human labor for a greenhouse area of 0.1ha. The elapsed time using the ARS was 10 minutes, while human labor required 60 minutes. The energy saving effect of the thermal tunnel was analyzed in comparison to the single span greenhouse

without thermal curtain. The conventional hot air heater was employed in the controlled greenhouse as a heat source. In the thermal tunnels, the conventional hot water boiler was employed. The energy costs of large and small tunnels were 64% and 70%, which were less than the ones of the controlled greenhouse.

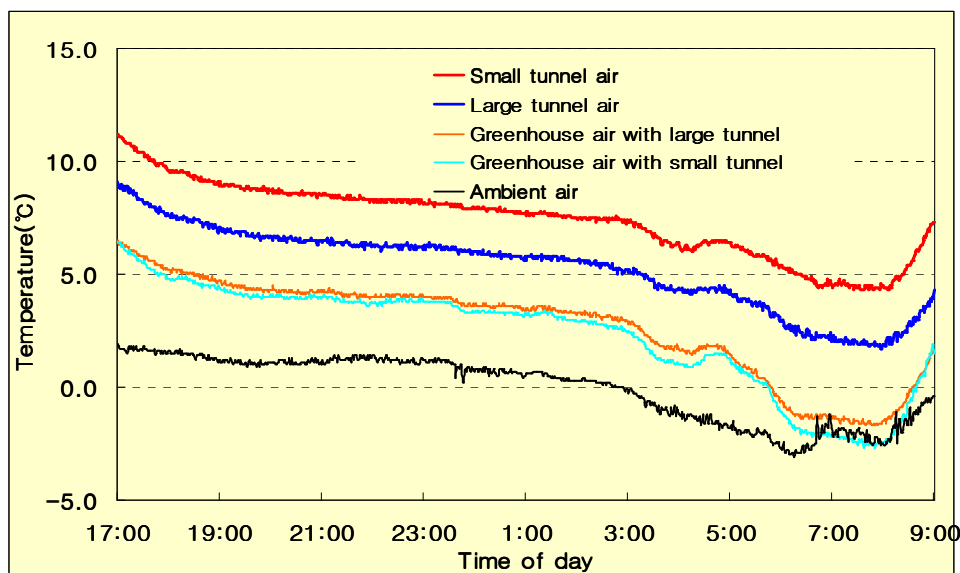


Fig. 6 Thermal insulation effect of thermal tunnel

### 2-3. Energy saving dehumidifier for greenhouse

During the winter season in Korea, the relative humidity inside a greenhouse at night often exceeds 90% because air temperature inside a greenhouse is usually controlled by a heater and closed windows to minimize heat loss. Thereby, it requires the use of a dehumidifier that can maintain the optimal humidity levels of 70 to 80 percents to provide the better growth condition for greenhouse crops. Such a high humid condition could cause the development of pest, such as, insects, fungi or diseases. However, the usage of most conventional dehumidifiers for low temperature dehumidification is limited because their performance could be degraded by frost accumulation on the surface of the evaporator coil.

To control the relative humidity of air inside the greenhouse, the dehumidifier functioned by a refrigeration cycle was designed and manufactured in the National Academy of Agricultural Science (NAAS), Rural Development Administration (RDA) of Korea. The dehumidifier developed in NAAS has separated condenser and evaporator in the heat exchanger part in order to increase the

dehumidifying capacity under the low temperature. When temperature and relative humidity of incoming air to the dehumidifier was 15~25°C and 70~95%, the condensed water was 5.7~7.0 kg/hr. The relative humidity difference was not greater than 5 percent at various locations inside the greenhouse due to proper distributing of dehumidified air through vinyl duct. Energy saving effect was contributed by dehumidified air with increased temperature, and the latent heat was 12,000kcal/hr that was about 10 percent of the total heating load in the greenhouse sized of 0.1ha (Figure 7).

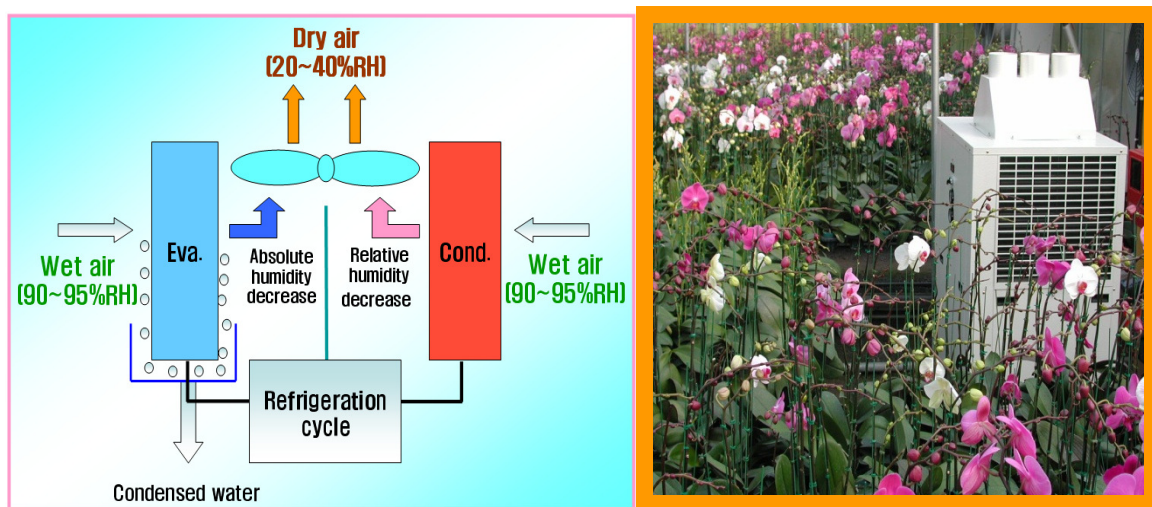


Fig. 7 The principle of the humidifier and its prototype

#### 2-4. Fully-open roof system for soft-covered multi-span greenhouse (1-2W Type)

To ensure year-round production of high quality agricultural crops, the fully-open-roof system for the multi-span arch-typed greenhouse was developed to improve natural ventilation inside a greenhouse during the summer. The fully-open-roof system was designed using the winding roof film drive, and the roof film can resist the wind velocity of up to 45m/s by four-edge fixation with changing band tension. This system can be used in soft films, such as a vinyl, fluorocarbon film and textile etc. without opening stroke limitation of the roof. The opening and closing of roof vinyl was designed as winding type for the fully-open-roof in the multi-span arch-type vinyl house. The guide roller moving along with guide frame, which constructed at both ends outside the greenhouse, maintained the direction of the winding bar during its operation. It was also connected to the winding bar and motor (Figure 8).

On the other hand, the band of resisting lift force caused by wind was regularly located along with the roof of the multi-span greenhouse to maintain roof stability. An eccentric disk cam and its shaft

connected to the driving motor were also installed in the gutter, and the tension of the band was controlled by half rotation of the disk cam. The outside diameter of the aluminum winding bar was fixed at 50mm, and the capacity of the winding motor was DC-24V-80W in the 100m length greenhouse. In the gutter, the settling part of the winding bar (A6063 aluminum) with 248.4mm<sup>2</sup> of the cross sectional area located at both edges of the gutter maintained the tension of the vinyl when the roof vinyl was fully closed. Accordingly, when the roof was closed, the winding bar in the slot of the settling part can be protected from the slot without deviation caused by wind, and the roof film increased light transmission by vinyl tension without the crumpled sheet (Figure 9).

As results, the maximum electric power loads of the winding bar were 30.5W, 38.8W and 33.1W under the free load, the opening load and the closing load of the roof, respectively. Considering the opening net-load of 8.3W, the predicted net-load for 100m length of the winding bar was 25.1W, with no significant difference compared with the theoretic net load of 27.3W electric power. The effect of natural ventilation on the internal temperature and humidity was also investigated.

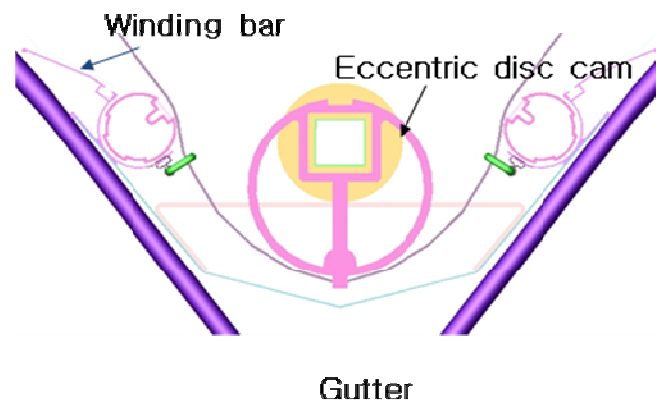


Fig. 8 The schematic diagram of gutter assembly

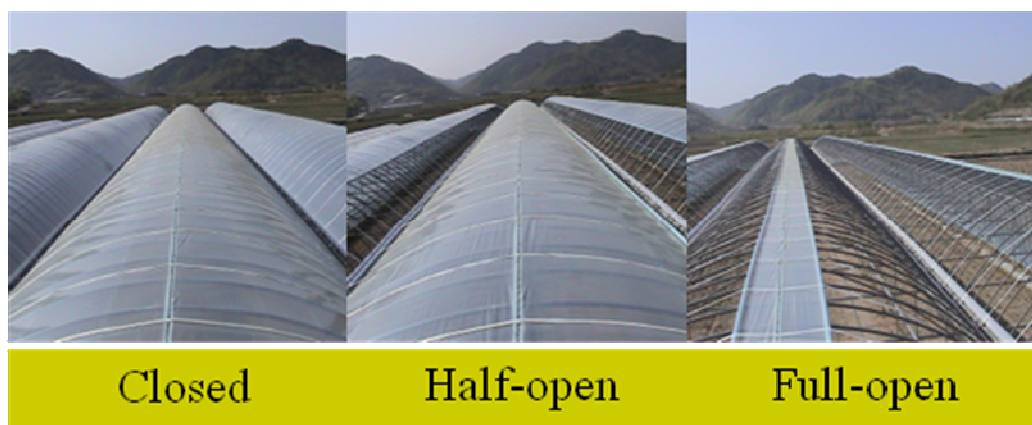


Fig. 9 The prototype greenhouse covered by PE and installed with three-span of 100m



## 2-5. Improvement of heat exchanger in a hot-air heater

A widespread use of agricultural air heaters (about 178,430) has led the increase of greenhouse heating cost up to 574 billion won per year in Korea. Therefore, this study was conducted to promote the energy consumption efficiency by replacing a circular straight arrangement tube tank in a conventional hot air heater with a hexagonal stagger arrangement tube bank (Figure 10). The performance of improved and conventional hot air heaters was compared.

As a result, the energy consumption efficiency of a hot air heater with a hexagonal stagger arrangement heat exchanger developed in this study was 11%, which was higher than that of a conventional hot air heater. This indicates the heating energy saving rate was increased up to 14.3% (Figure 11, Table 1). Furthermore, it is expected to save about 82.1 billion won per year ( $574 \text{ billion won/yr} \times 0.143$ ) by using a hot air heater with a hexagonal stagger arrangement heat exchanger developed in this study.

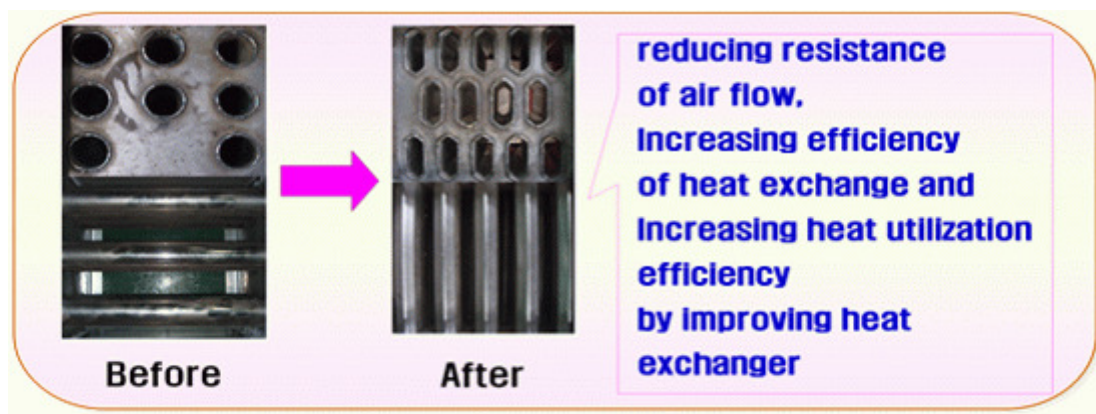


Fig. 10 Rearrangement of a tube bank in a heat exchanger

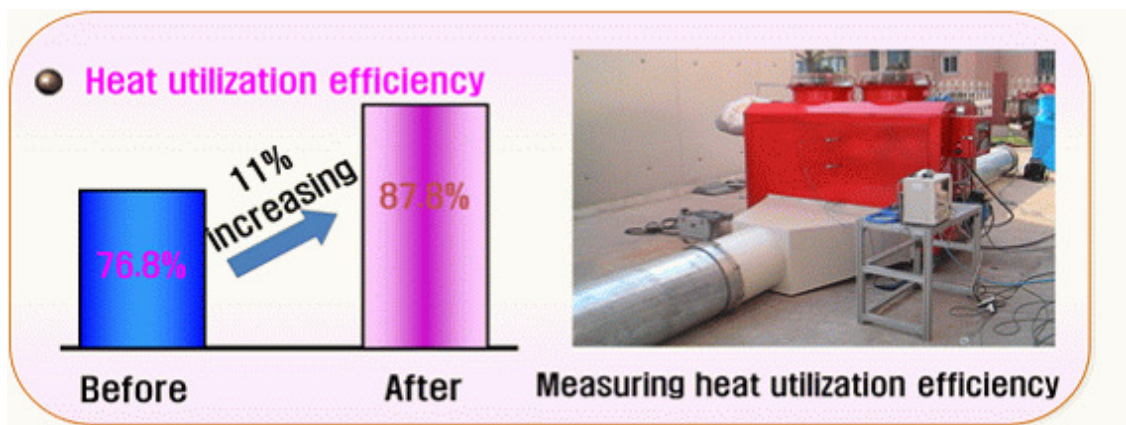


Fig. 11 Heat utilization efficiency and its measurement

Table 1 Analysis of energy consumption efficiency for conventional and improved hot air heaters

| Items                                       |       | Conventional hot air heater<br>(Circular straight arrangement) | Improved hot air heater<br>(Hexagonal stagger arrangement) |
|---|-------|--|--|
| Air flow rate<br>(m <sup>3</sup> /h)        | Right | 10,558   | 11,514   |
|   | Left  | 11,120   | 11,667   |
| The amount of heat (kcal/h m <sup>2</sup> ) |       | 14,192   | 18,873   |
| Energy consumption efficiency (%)           |       | 76.8   | 87.8   |
| Combustion efficiency of burner (%)         |       | 90.4   | 90.5   |
| Temperature (Deg)                           | Right | 57   | 59   |
|   | Left  | 56   | 58   |

### 3. New and Renewable Energy Technologies

#### 3-1. Geothermal heat pump system with thermal storage tank and horizontal heat exchanger

The geothermal heat pump system uses the earth as a heat source in heating mode and a heat sink in cooling mode. This study was conducted to heat/cool farm facilities and obtain basic data for a practical application of the horizontal-geothermal heat pump system. The horizontal-geothermal heat pump system with 10RT (Refrigeration Ton) scale was installed in a greenhouse sized of 6m × 40m (Figure 12). The heating and cooling performance of this system was estimated.

When the temperature inside the greenhouse was set to 10°C, the maximum heating load of the greenhouse was calculated as 39.91kW at an ambient temperature of -15°C. This maximum heating load corresponded to about 10RT. The horizontal-geothermal heat pump used in this study had the heating COP of 4.57 at a soil temperature of 14°C with a depth of 1.75m and the heating COP of 3.75 at a soil temperature of 7°C with the same depth. The stratification of heat tank was appeared within the entire heat rejection period.

According to the performance test from 2005 through 2007, the cost of heating energy was saved up to 78% when the horizontal-geothermal heat pump was used at farming households. For a recommendation to the new renewable energy policy of the Ministry of Knowledge Economy, we continue to distributing this heat pump to the gardening facilities sized of 91.1ha with the budget of

111 billion won in 2008 and this will be continued in the future.



Fig. 12 Vertical-typed geothermal heat pump system for greenhouse heating

### 3-2. Solar energy heating system for greenhouse

Several attempts have been made to use solar energy for supplemental greenhouse heating source for the last three decades. Successful outcomes came from solar hot water system for domestic purposes but practical or economically feasible results are hard to be justified considering the installation price of solar greenhouse heating system. Though considerable subsidy is provided, the price is still too high to be accepted by greenhouse owners.

Solar panel water heating system for greenhouse heating collects solar thermal energy heat, stores the heat in hot water form and circulates the hot water during night time. Another area of solar energy uses in greenhouse production is solar PV system for power source of greenhouse windows operation. DC electricity produced by the solar PV system of 150W photo voltaic panel plus 2kW capacity battery could open and close 19 windows automatically and simultaneously for five consecutive days under no battery charging. Though most greenhouse has no difficulty to reach electricity, but needs of this PV system are always existed in remote regions and emergency purposes. This solar PV system is the first application in agricultural productions to use solar energy as power to operate motors (Figure 13).



Fig. 13 Greenhouse window opening using the solar PV system

#### **4. Korea's Green Growth Strategy**

Current **“Low Carbon, Green Growth”** is a key catchphrase in Korea. Since the vision was proclaimed in August 2008, the Korean government has launched a series of bold green initiatives to help Korea leapfrog into a low carbon society.

##### **The 1<sup>st</sup> National Basic Energy Plan (2008-2030) and Comprehensive Plan on Combating Climate Change**

The concept of Green Growth was integrated into the national energy and climate change plans. National energy plan, which was passed on 20 August 2008, has set the goal of increasing the share of renewable energy to 11% by 2030. Climate change plan is the most comprehensive and ambitious plan Korea has developed in addressing climate change which includes adaptation and international efforts.

##### **‘Green New Deal’ Stimulus Package**

Announced on 6 January 2009, the Stimulus Package is an investment plan of 50 trillion KRW (385 billion USD) for the next 4 years on 9 key green project and some spillover projects that will create 956 thousand new green jobs. 2009 budget (including tax benefits) is approximately 2.6% of the annual GDP. The budget is already being implemented and proposed additional budget request will take the total number much higher.

9 Key project include 1) revitalization of 4 major rivers, 2) building green transportation, 3) building database on national territory and resources, 4) water resource management, 5) green car and cleaner energy program, 6) resource recycling program, 7) forest management & biomass

program, 8) green home, office and school, 9) greener landscape and infrastructure.

### **Comprehensive R&D Plan on Green Technology**

Endorsed by the National Committee on Science & Technology announced on 13 January 2009, the Plan called for a two-fold increase of R&D spending on Green Technology by 2012 (769 million USD in 2008) on 27 key technology areas such as climate change prediction & modeling, photovoltaic solar panel, LED, waste regeneration, carbon capture and storage, etc.

## **5. Summary**

Korea government has been paying more and more attention to the issues of agricultural energy and environmental problems. Technologies for energy saving and renewable energy must meet social, economic, and environmental objectives, as well as being affordable and cost effective. For an instance, energy conversion from sludge and wastewater is very complex technology depending on the economic factors. It is important to find more effective technologies which treat wastewater effectively while avoiding production of poisonous and harmful substances on environment.

Recently, “Energy Self-supporting Green Village” project which comprehensively utilizes biomass with strong ties between the community and local stakeholders is going like clockwork by supporting the Ministry for Food, Agriculture, Forestry, and Fisheries and the Ministry of Knowledge Economy. Technology developments in Green Village include methane fermentation, gasification of sludge and biomass-converting system suitable for the local region. This project covers the provision of information and capacity-building in the different regions.

The government can influence changes in three principal areas of the energy system: energy use, industrial structure, and energy production. The tools which the government may use to exert its influence are: support to research and development (R&D), demonstration and information dissemination, administrative policy measures, and economic incentives. These instruments may be applied separately or in combination. However, there is a need of coherent and effective policy for supporting the energy saving technology and renewable energy development.

The paper examines the technology development of agricultural sector, focusing on measures for reducing the use of energy and promoting renewable energy in Korea. Agricultural energy has played a small role in Korea’s energy balance so far, accounting for about 1.8 percent of the total consumer energy.

Improving greenhouse heating system that could reduce the greenhouse heating cost is one of the

hot topics for people in greenhouse industry. Enormous efforts on every aspect, such as, recycle of waste heat from a conventional oil heating system, solar energy utilization and geothermal heat pump system developed in NAAS/RDA, have been made, and some progress in efficient energy utilization ways for the greenhouse heating system was accomplished. In order to escape from excess dependency on conventional heating resource, which is oil combustion, the continuous effort is very critical to ensure the success of greenhouse farming in Korea.