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STORY OF AIR-INFLATED DOUBLE-LAYER POLYETHYLENE GREENHOUSE AND ITS RECENT APPLICATION IN TAIWAN

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Abstract: On June 4 of 2004, the Society for Engineering in Agricultural, Food, and Biological Systems (ASAE) dedicated the first air-inflated double-layer polyethylene greenhouse (AIDLPG) as the 44th (since 1926) Historic Landmark of Agricultural Engineering in recognition of this development and in honor of Professor Emeritus William J. Roberts. Professor Roberts, along with his colleagues and students, made many improvements in greenhouse structures, coverings and energy conservation practices worldwide over his long career. This paper will first briefly introduce the development of such design and talk about the history, impact, worldwide extension and the landmark dedication held in 2004. The second part of this paper will introduce the application of AIDLPG concept and heat pump to help *Phalaenopsis* growers of Taiwan in reducing energy cost, and to prepare them in facing the happening energy crisis.

Development of Air-inflated Double-layer Film Glazing

History

The earliest work on plastic film covering for a greenhouse happened to be motivated by a need to create a structure to conduct studies on heat stress in poultry. This early experimentation at Rutgers University used a fan to create a bubble house from a single sheet of plastic with the edges buried in the ground. This fan provided only minimum ventilation from air leaks but did keep the plastic film taught and the structure erect for the experiments that were conducted within.

An early use of plastic film in agriculture was by some growers who were using low-cost polyethylene film on simple wooden frames to construct greenhouses used primarily for spring transplant production and for bedding plant operations. One early concern was the tendency for a single layered roof to collect condensation that dripped on the small seedlings causing problems. To ameliorate this problem, a second layer of film was added by fastening it to the underside of the frame creating an airspace, and keeping the inner layer warmer. This was a very cumbersome process in these simple structures which were built with minimum vertical clearance. In the early 1960's, Extension Agricultural Engineer Bill Roberts was working with some of these growers. His next step was to install a single layer over the frame first, and fasten it to the rafters with 2x2 inch (5x5 cm) spacers, then add on a second layer on top of the 2x2's and fasten it down with a 1x2. This was a significant improvement but still required two fastening steps for every rafter.

Recognizing the importance of the double layer covering on a greenhouse to reduce condensation and looking for a way to simplify the construction he then tried using a small, low pressure fan to inflate the space between the layers and found he could remove half the nailing strips reducing the work. Bill then tried fastening the two sheets together around all four edges and used the small, low-pressure fan to inflate the space between. It was quickly noted that not only was there a significant reduction in the required construction materials and labor time, but the tension in the film due to the slight air pressure reduced the film flexing and flapping in the wind, reducing the likelihood of tearing the film, thereby increasing structural reliability and extending film life. The first greenhouse on which this concept was successfully applied is a wooden frame structure designed for the width of polyethylene sheeting available at the time. This structure is still in use at the university and has been designated as an Agricultural Engineering landmark.

This concept was next applied to a portion of a large, gutter-connected commercial greenhouse in Allentown NJ, (Kube-Pak, Inc., then managed by Aart VanWingerden). Several companies then developed frame structures for multi-span and single span structures. Probably first among these were VanWingerden with steel frames and PolyGrower with aluminum. Bill also designed wooden greenhouse frames of several sizes to match available film widths, as well as a pipe frame structure and pipe bender to assist hand bending of the hoops. He developed the engineering plans and drawings for these easy-to-construct greenhouses. These plans were made available through the cooperative extension service. The early popularity of these designs and their rapid commercial acceptance was due primarily to their low-cost relative to conventional greenhouses glazed with glass or fiberglass. It was also noted that the insulation properties of the inflated air space reduced heat requirements by over a third, which became a more highly appreciated advantage in the years following the energy crisis of 1973. Finally, it should be noted that this development could not have taken place when it did nor have spread into commercial practices so rapidly and broadly without the contributions of commercial growers who took the early risks. The leaders among these were Aart VanWingerden and Kenneth Bryfogle, who also started the first companies to provide gutter connected structures of steel and aluminum, respectively, and Frank Stuppy who developed the first extruded aluminum film fastener.

Professor David Mears (Rutgers University) worked with Bill Roberts on some aspects of the early research and contributed the engineering analysis of film stress as related to the geometry and size of the coverings and the structural loads. Later, David and a series of graduate students advised by him and Bill did further research on structural aspects, energy conservation & management, and film properties. The key to all of these advances was the simplicity and functionality of the concept of using air to inflate the space between the layers, a concept that was developed by Bill.

Impact

In 1999, approximately 23,125 acres (9,250 ha) of air-inflated double-layer polyethylene greenhouses were in production in the US (1,705,125 acres or 682,050 ha worldwide) (Takakura and Fang, 2002, Climate under Cover, 2nd edition, Kluwer Academic Publishers. 190 pp.). Today, approximately 65% of all commercial greenhouses in the United States use the air-inflated system. While the total area for greenhouse production may seem small, production in these greenhouses occurs year-round, often producing multiple high-value crops. Therefore, the production on an area basis is much higher in greenhouses compared to field production. In addition, especially in lower-income countries, the AIDLPG is the only economic alternative for year-round production helping local farmers secure living wages and providing the local population with affordable produce even when adverse weather conditions prevent outdoor production. The total worldwide area in 2003 is estimated at 3,000 square miles (the quoted 1999 data plus 12%, representing a 4% annual increase which was the annual increase reported in the reference between 1991 and 1999) or roughly the size of the states of Delaware and Rhode Island combined. The development of the AIDLPG at Rutgers University set in motion successive developments of the movable thermal insulation screens and in-floor root zone heating systems. While much of the research at Rutgers University leading to subsequent advances in greenhouse engineering has been conducted in other facilities, the original AIDLPG structure has also been used continuously for a variety of research studies. It was also the first greenhouse in which developments in floor heating and movable insulation/shade curtains were attempted. The method of fastening the film has been upgraded from the original wooden strip fastening method (Roberts and Mears, 1969) to various designs involving aluminum extrusions. Otherwise, the first AIDLPG frame remains virtually the same as constructed in the early sixties.

Worldwide Extension

In 1978, Bill Roberts built Japan’s first AIDLPG, and was later followed by local researchers (Okada and Hayashi, 1983). The most recent related project was lead by Dr. Shimaji of National Institute of Floricultural Sciences in Tsukuba. A 3 layer covered greenhouse with roof ventilators for natural ventilation was constructed. This greenhouse has an advanced feature capable of collecting solar energy on the roof and storing heated water under the floor. (Sase, 2004).

In 1986-1988, David Mears was invited to India to work with USAID on a number of projects. During that time and later he helped facilitate their development of greenhouse technology as well as design the quarantine facilities for the National Bureau of Plant Genetic Resources. A wide span AIDLPG was built.

In 1989, a US-Taiwan joint research project was initiated by K.C. Ting (then, Chair of Dept. of Biological and Agriculture Engineering, Rutgers University) and visiting Professor Hang Sun Chang (former chair and emeritus professor of Dept. of Agricultural Machinery Engineering, National Taiwan University). The first AIDLPG in Taiwan equipped with fan and pad system was built in 1989 and another identical greenhouse was built in Taichung of Taiwan in the following year. These 2 greenhouses had survived several Typhoons. In 1989, Bill Roberts and K.C. Ting traveled to China on a 40 days trip and help to build 3 AIDLPG in separate cities. At that time, little greenhouse area covered with single layer film was built in China.

Landmark Dedication

The unveiling of the commemorative plaque was performed by Acting Executive Dean of Cook College Dr. Keith Cooper, ASAE President Dr. Robert J. Gustafson, and Professor Emeritus William J. Roberts. Following the unveiling, several invited speakers reminisced about and attested to the national and international impact of the AIDLPG system. These speakers included Dr. K.C. Ting (Ohio State University, now in University of Illinois at Urbana Champaign), Dr. Merle Jensen (University of Arizona), Dr. Sadanori Sase (National Institute for Rural Engineering, Japan), Dr. Wei Fang (National Taiwan University, Taiwan), and Dr. David Mears (Rutgers University). Professor Roberts concluded the program with personal recollections. For additional information please visit the web site at: http://aesop.rutgers.edu/~horteng

Application of AIDLPG in Taiwan

Introduction

AIDLPG was introduced to Taiwan in 1989. The robustness of the structure had been proven by several Typhoons per year. However, the warm climate of Taiwan had limited the acceptance of AIDLPG technology in Taiwan in spite of the merit of its robustness in structure. The features of energy conservation of AIDLPG were not appreciated until now.

Due to the rapid increase of the energy cost and the business model of the *Phalaenopsis* (also known as the moth orchid) industry, AIDLPG now plays an important role in reducing energy cost for our local growers.

The flower stalk of *Phalaenopsis* will emerge in winter at the plain area of Taiwan and full bloom in days near the Chinese lunar New Year. *Phalaenopsis* is now so popular worldwide, consumer demand for flowers is year round. So, means to inhibit or to promote flower stalk emergence in any time of the year becomes important.

Air conditioning systems are used for promoting flower stalk emergence (spiking) and air heating systems are used to prevent flower stalk initiation. To prevent spiking of flower stalks, the greenhouse indoor temperature should be kept no less than 28 degree C. Even in Taiwan, 70~80% of the outdoor temperature is below 28 degree C. Thus, for this requirement, energy cost is high, thus, greenhouse heating is now finally an important issue.

Before this, heating is required only for those hours of “extremely cold” weather that is in between 5 to 10 degree C, outdoor. In the plain area of Taiwan, 5 degree C is the lowest. So, one can tell, not much heating is required. For greenhouse heating, indirect air heating systems using oil burners is most popular here. Hot water systems using boilers or gas burning engines were not used until recently.

Air conditioning and heat pump (ACHP)

Air conditioning (AC) and heat pump (HP) are two faces of the same thing. The traditional dual system of AC and HP was actually AC or HP. When in AC mode, heat was expelled outdoors and when in HP mode, cold was expelled outdoors. A real dual system was design for the orchid industry making use of AC and HP at the same time.

The idea of air-inflated double-layer PE (AIDLP) was used in designing a *Phalaenopsis* production greenhouse for both flower stalk initiation and inhibition. The greenhouse gutter height may be 3.5 m or above and the AIDLP reduces the space required for cooling or heating. The air gap in between two layers plays an important role in energy conservation to keep cold or heat inside the greenhouse, thus reducing the cooling/heating cost. This double layer also can guarantee the tightness of the structure, thus reducing infiltration.

ACHP and AIDLPG

An ACHP system with AIDLPG was integrated and installed in a commercial greenhouse producing *Phalaenopsis*. The cooling cost and heating cost were dramatically reduced for the last two years of operation. For example, the flower forcing cost of this company is less than 10 NT$ per plant but in another company is as high as 40 NT$ per plant.

In Summer, the AC part is needed and HP part if not used will expel the heat to the atmosphere as the traditional system did. In Winter, the HP part is required most of the time, but AC part is still needed from time to time and maybe due to global warming, the Winter in Taiwan is getting shorter than before. The COP of the HP is at least 3.5 at design cold/hot water temperatures. Based on local data, the HP system using 2 kW.hr of electricity produces the same amount of thermal energy as a boiler burning 1 Liter of diesel oil.

In Spring and Fall, the AC part of the ACHP system is required for flower the forcing greenhouse, and the generated heat created by the HP part can be stored for the heating required at night for the flower inhibition greenhouse. In this way, the heating at night is free. Energy cost can be greatly reduced by the combination of ACHP and AIDLP system through out the year.

Conclusion

From this story we can learn that an engineer and a small group of people can change the world. No patent was applied for and the whole world benefits from AIDLPG technology. It is a different world now, in the era of knowledge economy, researchers are asked to convert their results into patents and even fortunes. Everything counts to evaluate your professional performance. In this aspect, Taiwan is not alone. I was shamed to learn that in Taiwan, some people applied for patents for the double layer roof, pad and fan system as well as the air-inflated double layer greenhouse, and they all got approved. As an alumnus of Rutgers University myself and a greenhouse engineer, I would like to promote these technologies in Taiwan and fight with those patent owners if they become an obstacle to the spread of these technologies.

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