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ENERGY CONSUMPTION AND COMMERCIAL APPLICATIONS OF LIQUID FOAM INSULATION TECHNOLOGY FOR GREENHOUSES

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ABSTRACT It is well known fact that operating a commercial greenhouse in northern Latitudes requires large amounts of energy. As energy prices continue to fluctuate, it is critically important to provide growers with a tool that gives them greater control of their micro-climate. Sunarc of Canada has developed an energy saving system for commercial greenhouse growers. The liquid foam insulating system was installed at site 1 over an area of 14,700 ft² (Chatam, ON, Canada), as well as at site 2 (Leamington, ON, Canada) over an area of 43,000 ft². Both facilities were monitored for energy use during the 2007 winter period. Night-time energy savings ranged from above 60% to below 10% depending on outdoor temperatures with greater savings occurring during colder outdoor temperatures. Monthly average night-time energy savings resulted in values from February, March and April 2007 of 46.6, 42, and 32.3% respectively. Following initial commercial testing the liquid foam system was reengineered to improve and optimize operations, reduce fill time, and improve liquid foam formulas. The new system was installed at site 3 (Laval, QC, Canada) as a demonstration unit. The company is presently negotiating international distribution writes with several partners.

Keywords: Greenhouse, Energy saving, Cover material, Insulation, Foam.

INTRODUCTION In Canada, more specifically in Ontario and in Québec, the climate is characterized with cold winters and hot summers. To produce greenhouse crops successfully, significant heating is required in the winter. Furthermore, on hot summer days, considerable cooling/shading/ventilation is needed to maintain suitable greenhouse microclimate. A dynamic liquid foam technology has been developed by Sunarc of Canada and has demonstrated energy savings of 42% in winter *(Villeneuve et al, 2004)*. In cold weather, daytime solar energy enters the greenhouse and heats the environment. When the sun sets, the temperature decreases rapidly in a greenhouse, liquid foam is infused into the cavity formed by the two layers of polyethylene membrane covering the greenhouses, conserving the daytime heat through the night. At day break, the remaining liquid from the collapsed foam is drained back into the surfactant reservoirs and recycled to be used again the next day. The concept of the liquid foam system is illustrated in figure 1. Insulation maintains the thermal equilibrium in the greenhouse structure by admitting, converting and retaining solar energy in a controlled environment. As a result, optimal temperature conditions during each 24-hour cycle can be maintained, while heating fuel requirements are reduced.

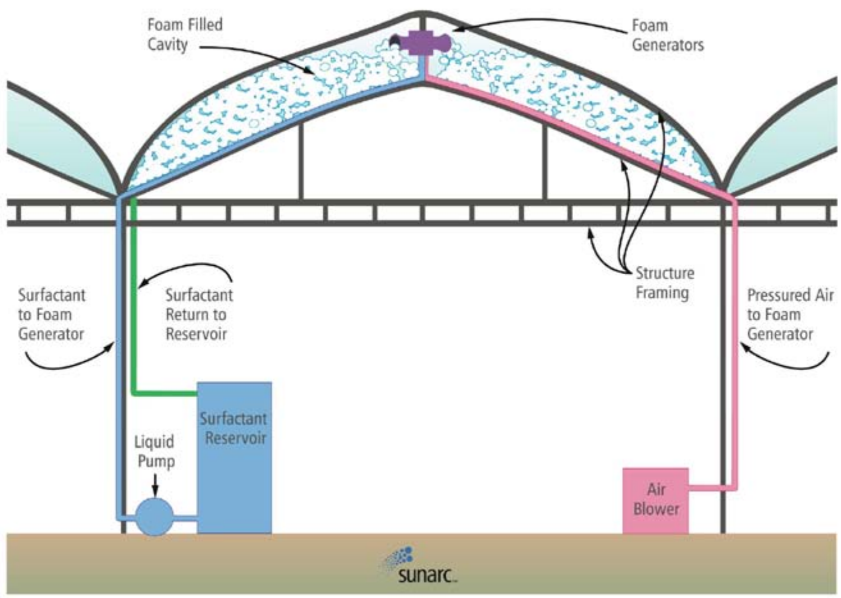

Figure 1 Cross-section view of multi-section greenhouse installation of a Sunarc System

MATERIALS AND METHODS The paper details experiments that were concluded on two large commercial scale growing operation in Ontario as well as the evolution of the engineering aspect of the technology. The engineering aspects discussed in this paper are based on the results that were obtained during the test period on the large scale demonstration trials. During the same period as the commercial trials were taking place the technology was also being analyzed by Agriculture Canada greenhouse crops research center in Ontario (Harrow), Canada were energy savings varied between 40 and 55% over a 3 year trial period (Alberkani, 2009).

Experimental setup

The first commercial application test site was located in southern Ontario (Chatam), Canada. . The two test zones were identical in size, shape, roof configuration, and method of heating. Each zone is approximately 107,9 m long by 12,8 m wide or 1,381 m² (2 greenhouse bays of approximately 6,4 m x 107,9 m) (figure 1). Natural ventilation was assured with gutter roof vents that open along the entire length of the greenhouse. The liquid foam system was controlled by Priva greenhouse control system, using a modified cooling and a modified thermal screen application. One exception between the 2 zones is that the control zone shares approximately 12,8 m of exterior wall with the warehouse area.

Figure 2 test zone, first commercial greenhouse trial

The second commercial application test site was located in southern Ontario (Leamington), Canada. The two test zones were identical in size, shape, roof configuration, and method of heating. Each zone is approximately 68,3 m long by 58,5 m wide or 4,000 m² (8 greenhouse bays of approximately 7,3 m x 68,3 m) (figure 2). The liquid foam system was controlled by DGT greenhouse control system, a specific control strategy was developed by local DGT control system programmer. Natural ventilation was assured with gutter roof vents that open along the entire length of the greenhouse. One exception between the 2 zones is the Test zone shares approximately 36,6 m of exterior wall with the biomass boiler area.

Figure 3 test zone, Second commercial greenhouse trial site

Monitoring of the interior greenhouse climate was performed on the following items during this experiment: Boiler Water Flow, Zone Dry-Bulb Temperature (ºC), Zone Relative Humidity (%), PAR Light (uE), Black Body Temperature (ºC), Solar Radiation (W/m2), Hot Water Return Temperature (ºC), Hot Water Supply Temperature (ºC).

Historical data was also collected from the in-house control systems at both the above test sites. Zone Air Temperature (ºC), Vent Opening (%), Zone Relative Humidity (%), Hot Water Return Temperature (ºC), Hot Water Supply Temperature (ºC), Sunarc Foam System (ON/OFF), Sunarc Rinse System (ON/OFF). Outdoor environmental data was also collected via the internal control system and weather station: Wind Speed (m/s), Outdoor Temperature (ºC), and Solar Radiation (W/m²).

Following experience undertaken in Ontario commercial greenhouse facilities, Sunarc of Canada reengineered the liquid foam injection system to increase efficiency and prepare the product for large scale production. The market ready technology was installed and operated on a commercial greenhouse in Quebec (Laval), Canada.

Technology improvements and evolutions

The technology has gone threw several stages of development before achieving a final commercial design applicable to large scale greenhouses. During this evolution several aspects of the system changed and were improved. Nevertheless, certain aspects of technology remained unchanged during these evolutions of the system (such as the liquid flow pressure and volume, air flow pressure and volume). To achieve liquid foam with constant bubble size and mechanical resistance, it is necessary to control air flow and foaming liquid accurately (*Emil, 2005*). Liquid and air are mixed in a “foam generator” (Figure 4). Liquid is sprayed on the surface of porous synthetic material, air pushes the liquid threw the sieve where bubbles are formed on the outside surface of the sieve. The foam covers the entire surface of the greenhouse roof in approximately 20 to 30 minutes. In order to improve filling time and effectiveness, pressure sensors combined with mechanical louvers were installed to evacuate excess air when foam was being produce.

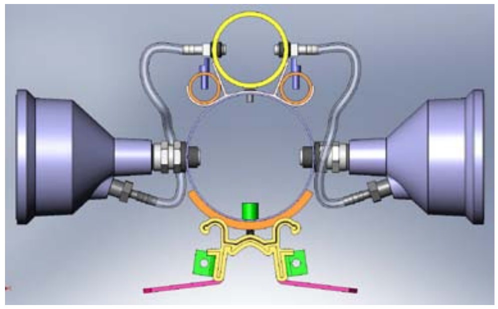

Figure 4 Cross-section of the foam generator assembly apparatus (ref: Sunarc of Canada)

With the intention of improving reliability, reducing manufacturing cost installation time, reducing heat losses and eliminating leaks in the system, numerous modifications were performed. The total height of the cross-section was reduced from 28 cm to 15, 2 cm; this enables the use of standard size polyethylene to cover the greenhouse. The design of the previous system was higher and required the use of the polyethylene membranes of larger widths then normally used to cover the same greenhouse surface. Polyethylene sheets are sold in increments of 1,2 m to 1,8 m, so when a large size is required this increase cost and waist of plastic.

The liquid feedpipe (Figure 5), was originally made of aluminum and was replaced with a high density polyethylene (HDPE) pipe where joint in the pipe are butt-welded to be leak proof (Potente, 1985). The foam rinsing system was originally made of aluminum as well and was replaced with low density polyethylene (LDPE) pipe rolls that are continuous the length of the greenhouse. Injection nozzles are directly punched into the pipe with an easy to use hand tool. The base of the system is a 7, 3m aluminum extrusion that supports the 10 cm air injection aluminum pipe. These sections are welded and assemble in lengths (7,3 m) with a 3D EPDM joint that ensures water tight seal between sections.

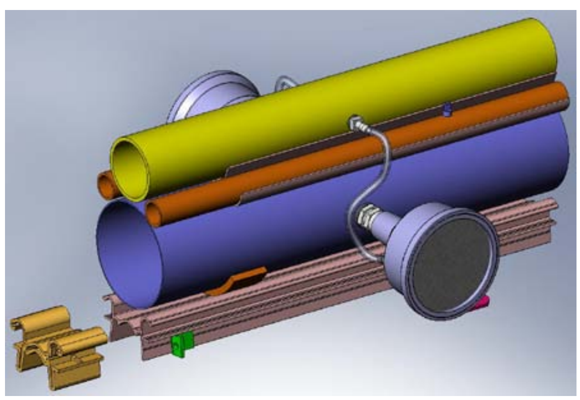

Figure 5 3D image of liquid foam system (ref: Sunarc of Canada)

The liquid is re-circulated and reused in the system with 7,3 m extruded aluminum gutters (Figure 6). These gutters are bolted to the existing greenhouse and connected together with a 3D EPDM joint. This aluminum gutter replaces the existing looking mechanism that normally keeps the polyethylene membranes fastened to the greenhouse.

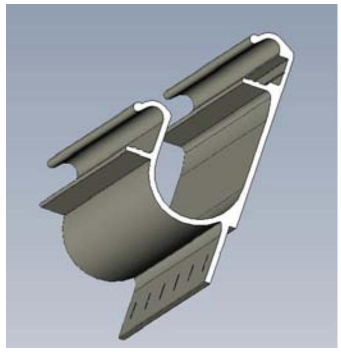

Figure 6 Liquid return gutter (ref: Sunarc of Canada)

RESULTS Night-time energy savings ranged from above 60% to below 10% depending on outdoor temperatures with greater savings occurring during colder outdoor temperatures. Monthly average night-time energy savings resulted in values from February, March and April 2007 of 46.6, 42, and 32.3% respectively. Table 1 below shows sample data of a select number of night-time energy use, average outdoor temperatures, and the resulting percent savings values during the times shown. All data are for the hourly time periods shown; 6pm to 5am in February and 6pm to 4am in March as this reflects the time period when the Sunarc system was operational. The combined average energy savings percentage is only for the sample data set for the indicated time periods.

Table 1 Leamington Ontario, Total Energy Savings and outside temperature

Date	Week	Control Q(sum_Btu/hr)	test Q(sum_Btu/hr)	Outside Temp (C)
Feb1/2	6pm-5am	16029757	9683615	-2,1
Feb2/3	6pm-5am	29552396	15240348	-9,1
Feb9/10	6pm-5am	23201848	13126840	-6
Feb14/15	6pm-5am	23901298	12240423	-10,1
Feb15/16	6pm-5am	24135130	12579611	-7,8
Feb16/17	6pm-5am	23764678	10446327	-9,4
Mar5/6	6pm-4am	22772990	15233827	-6,5
Mar11/12	6pm-4am	18981292	12697125	2,5
Mar15/16	6pm-4am	14266545	9180996	-1,1
Mar17/18	6pm-4am	16675821	9185207	0,1
Mar20/21	6pm-4am	21508658	13598179	0,4
	Total Average:	234790413	133212498	
		Net Savings:	101577915	
		Net Savings (%):	**43%**	

Table 2 Chatam Ontario, Total Energy Savings and outside temperature

Date	Week	Control Q(sum_Btu/hr)	test Q(sum_Btu/hr)	Outside Temp (ºC)
Jan 6/7	6pm-7am	5068484	4251199	2,1
Jan 12/12	6pm-7am	4518223	3045324	7,3
Jan 13/13	6pm-7am	5449971	4369651	-0,7
Jan 14/14	6pm-7am	5038068	4554398	-1
Jan 24/24	6pm-7am	4926280	3542374	-3,7
Jan 26/26	6pm-7am	5938145	5582614	-7,7
	Total Average:	30939171	25345560	
		Net Savings:	5593611	
		Net Savings (%):	**18%**	

CONCLUSION The liquid foam technology has demonstrated significant energy savings in variable environments. Energy savings of 10 to 60% can be expected based on exterior conditions and use of the technology. The technology has significant benefits as it can help reduce energy consumption, increase night time leaf temperature and reduce growing times. The technology can also be used as a shading material during hot summer months to reduce plant stress and greenhouse air temperature and improve working conditions.

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