12. Lightsey, G.R., C. George, P.C. Badger, and R.S. Pile. 1982. Stripping of ethanol from high solids feeds. Paper presented at AICHE Annu. Mtg., Los Angeles, Calif. Nov. 1982.
13. Monier-Williams, G.W. 1922. Power alcohol. Henry Frowde and Hodder, Stoughton, London.
14. Nolte, A.J., H.W. von Loesecke, G.N. Pulley. 1942. Feed yeast and industrial alcohol, Ind. Eng. Chem. 34 (6):670–673.
15. Office of Technology Assessment. 1980. Energy from biological processes. U.S. Govt. Printing Office, Washington, D.C.
16. Pile, R.S. and P.C. Badger. 1982. Integrated onfarm fuel alcohol production systems, phase III—July/Sept. 1982. Quart. Tech. Rpt. Tennessee Valley Authority, Office of Agricultural and Chemical Development, Muscle Shoals, Ala.
17. Reidenback, V.G. 1982. Sugarcane or sweet sorghum processing techniques for production of alcohol by fermentation. PhD Diss., Texas A&M Univ., College Station.
18. Sargent, S.A., J.F. Steffe, and B.R. Tennes. 1982. Apple pomace as a fuel for food processors. Michigan State Univ., East Lansing. ASAE Paper 82–6032.
19. Unzelman, G.H. 1981. Value of oxygenates in motor fuels. Paper presented at 46th refining midyear meeting. Ethyl Corp. AVI, Westport, Conn.
20. Whitehead, W.K. 1980. Food processing wastes management. Agr. Eng. 61(8):26–27.
21. Williams, D.W., R.V. Eastman, II, and H. Farnham. 1982. Integrated fuel alcohol production and cannery waste treatment, ASAE Paper 82–6026.
22. Wright, F.B. 1906. Distillation of alcohol from farm products. Spin & Chamberlain, New York.

Using Waste Energy in Greenhouse Crop Production

Herman Tiessen[1]
Department of Horticultural Science, University of Guelph, Guelph, Ontario NIG 2W1, Canada

The North American greenhouse industry has come under considerable financial stress in the past decade, with numerous firms leaving the industry. The main reason often given was the increased energy costs. Some growers of greenhouse crops have gone out of business because of energy costs. Recently energy costs have stabilized; this change, accompanied with higher returns for domestically grown greenhouse crops, has decreased the growers' concerns about the energy situation. We would be naive to think that energy costs will not rise again in the future.

We are limited in the extent that use of energy from conventional fuels can be reduced by continually incorporating more energy conserving techniques in greenhouses. It is conceivable, as energy from oil and gas becomes more scarce and costly, that the inefficient use of energy for greenhouse crop production will cease and may not be available at any price if energy is rationed, because greenhouse crop production will not have a high enough priority for its use. Thus, it is mandatory to consider alternate sources of energy for the greenhouse industry to survive and prosper.

Sources of waste energy

The bulk of waste energy used in greenhouses usually is low-grade or low-temperature and in the form of warm water. In limited cases, the temperature is high enough for it to be used directly in conventional piped hot-water heating systems. The air exhaust in gas turbines can be as high as 400C, which can be used in standard types of hot water boilers. However, by far, the largest source of reject heat is from electrical power station cooling water.

A modern 2000-MW base local thermal power station, consuming the equivalent of 5500 MW in fuel, gives off 3000 MW in cooling water and 440 MW fuel gases. Energy dispersed in the cooling towers of such a station is the equivalent to the peak heat load requirement of about 1000 ha of greenhouses. Thus, it is obvious that there is a tremendous potential in this cheap source of energy for greenhouse crop production.

Other industries that could be considered as potential sources of waste heat for greenhouse are oil refineries, glass factories, lead smelters, nuclear power stations, zinc refineries, ammonium fertilizer plants, gas compressor stations, smelters, chemical industries, and cement manufacturers (4). Small factories also can supply energy for an economic greenhouse complex.

There are many projects throughout the world using reject or waste heat for the production of greenhouse crops. In France, reject heat from a nuclear power station is used for heating greenhouses (6). The heat comes from steam turbines and not nuclear reactors. Heating is partly by pipe work and partly by warm water flowing through plastic tubes laid on the ground (G.F. Sheard, unpublished data).

Romania heats 800 ha of glasshouses with energy from industrial complexes served by a large central steam generating plant. Heat is supplied to the glasshouses in the form of pressurized water at 120 to 150C. It is not reject heat in the sense that we use the term, but it is an integrated industrial operation (G.F. Sheard, unpublished data).

The Agrotherm project in the Federal Republic of Germany has developed a power station cooling system using soil fields as the heat sink to grow agricultural crops by soil warming. The total heating area of four sites is $\approx$14 ha. The soil is heated through 60-mm polyethylene pipes laid 250 mm deep and 1 m apart. Yield increases from soil heating were 40%, 60%, and 50% for potatoes, sugar beets, and corn, respectively (G.F. Sheard, unpublished data).

The Drax Greenhouse Project at Campbellsforth in the United Kingdom is an example of two large companies uniting to develop a 8-ha greenhouse complex (3). Express Dairies and Central Electricity Generating Board of the United Kingdom formed a company called EXEL Products Ltd. Glass greenhouses receive 30C condenser cooling water from coal electrical generating plants. Warm water is passed through finned pipes in a heat exchanger located in the greenhouse. There are 80 heat exchangers distributed uniformly over a hectare. The greenhouse complex is equipped with one central computer connected to four terminals that monitor and control the nutrient film technique growing system (NFT) dosage, temperature, acidity, and conductivity. It also controls the heat exchangers to maintain air temperatures in each section of the house at the desired level. This operation is very successful and plans are underway to build additional acreage of glass. Energy supplies from this one electrical generating plant could heat more than 400 ha of glasshouses, almost the same area as the total greenhouse area in the United Kingdom. The operation is economically successful, and energy costs for heating a greenhouse are about 40% that of conventional fuels.

In North America, there are also a number of commercial operations using waste energy for greenhouse crop production. Some of the original work was carried out by the Tennessee Valley Authority at Muscle Shoals, Ala. (2). A pilot plant operation was initiated in 1973. In 1978, the Brown's Ferry waste heat greenhouse was built at the Brown's Ferry nuclear plant, consisting of 0.27 ha of greenhouses. Here, water flows over horizontal pads. Air flows through the pads, extracts the heat, and then exhausts it into the greenhouse. This operation was used for research until 1982 and then rented out to a commercial grower for the production of tomatoes, cucumber, and ornamentals.

In Minnesota, the Sherco Greenhouse Project was started in 1974 at the Shelbourne County Electrical Generating Plant of the North-

[1]Died 10 Dec. 1987.

ern State Power Company (1). This pilot plant demonstrated that 29C water could be used to supply the total heating requirement of greenhouses in a northern climate. Two-thirds of a hectare of commercial greenhouses have been built to grow flowers and vegetables. In this closed heating system, water flows through finned pipes over which air is passed, heated, and exhausted into the greenhouses. Water from the heat exchanger flows through plastic tubes in the soil, and is returned to the cooling tower.

Pennsylvania has a sophisticated system at the Montour Waste Heat Greenhouse complex that was developed in conjunction with Pennsylvania Power and Light Co. and Bryfogles Inc. (R.P. Johnston, personal communication). It is located at the Montour Steam Electric Station Washingtonville, Pa. A program was initiated in 1979 to heat greenhouses with water discharged at 42C from the PP&L coal-fired generating plant. One and one-fourth of a hectare of ornamental and pot plants are grown in these greenhouses. The heating system used was developed by Rutgers Univ., New Brunswick, N.J. The warm floor heating system consisted of placing a 0.5-mm (20-mil) vinyl liner that is designed to contain the water within the floor. More than 1.2 ha of vinyl was put down in 64-m wide strips. The strips were overlapped and joined with adhesives to form a continuous water-tight barrier under the entire area. A 30-mm layer of DuPont Microfoam was placed on the vinyl to protect the liner from puncture. Black polyethylene pipes (20 mm in diameter) were placed on the Microfoam and spaced ≈0.3 m apart for the entire 170 m length. A 0.2-m-thick layer of gravel was poured over the black polyethylene pipes. A porous concrete floor was poured on top of the gravel, which supports the floor and forms the water space for the underfloor pool. Finned pipes were installed overhead to use the same cooling water for additional heat. Another set of overhead finned pipes were installed for supplemental heat from a standby hot water boiler. Water temperature in the pipes coming from the cooling tower was 38C. An additional 2 ha of greenhouses have been developed at this site by the Campbell Soup Company to use this energy source to grow premium greenhouse vegetables for a select east-coast market. Present energy costs for this waste heat are about $16,200/ha per year.

Several greenhouse projects in Canada use reject heat. The Univ. of Guelph–Texaco project at the Texaco oil refinery in Nanticoke, Ont., started in 1979, using 22C refinery cooling water to grow 0.14 ha of greenhouse vegetables. Temperatures were increased, when required, to 27 to 30C in a steam jacket heated with waste steam (5). Night temperatures of 17C could not be maintained in single-layered fiberglass or glasshouses with outdoor temperatures below 0C. The crops, however, were kept from freezing even at −25C. Good commercial tomato yields were obtained with the NFT culture and the heating system used in this study. Minimum night temperatures of 17C might be maintained throughout the growing season by using more energy-efficient technological developments and more energy-efficient greenhouses.

The largest commercial operation in Canada using reject heat is the Nova Corporation in Alberta (personal communication). It has 0.8 ha of greenhouses at a natural gas compressor station at its Princess Plant, near Brooks, Albt. The first greenhouse was built in 1977 and the second in 1979. Exhaust heat from the gas compressor (400C) heats a 50 ethylene glycol : 50 water solution mix (v/v) to 98C. The glycol solution is piped to the greenhouse and heat extracted by overhead Modine heat exchangers in one-half of the greenhouse complex, while finned heating pipes are used in the other half. This is an easy and economical method of greenhouse heating. This site has the potential to heat ≈20 ha of greenhouses. Another operation is the 1.6-ha Joffrie greenhouse operation at Red Deer, Albt. (personal communication). Cooling water at 40C from the ethylene manufacturing plant is used to heat these greenhouses with unit heaters. Both of these greenhouse operations have been successful in growing flowers and vegetables; however, the initial investment for the physical plants was substantial.

General comments

It is obvious that using reject heat for greenhouse crop production from industry is not only feasible but desirable. In general, savings of 30% to 60% in energy costs usually occur, with the amount of savings depending on the temperature and supply of waste heat. There are, however, a number of factors that have to be considered when contemplating the use of waste heat for greenhouse crop production. Some of these are:

a) Most of the heat is low-grade at temperatures of 15 to 35C, with power station cooling water at ≈30C for long periods. Supplemental heat may be required during severe outdoor temperatures.

b) A continuous supply of waste heat is required to justify a greenhouse operation (e.g., small compressor stations could supply 80% of the energy).

c) Can reject heat be extracted economically when used for greenhouse production?

d) The greenhouse complex should be as close as possible to the energy source (cost of relocating); some old industries may not have available land economically nearby for a greenhouse operation.

e) Integration of a greenhouse operation with the heat supply must be considered, since the supply is large and demand variable in power stations.

f) The risk of pollution should be considered when crop production and industry are in close proximity (e.g., close to nuclear power plant, tritium radiation may pose a problem).

g) Energy conservation methods in greenhouses will still be required, especially where low-grade heat is used.

h) Growers may be hesitant to reinvest in a new greenhouse operation at another location.

i) The contract for energy by the user should be economically worthwhile for firms to relocate at the energy site.

j) Land lease arrangements with growers should be reasonable.

k) The possibility of heating hydroponic solutions that could use low grade heat should be considered.

l) Relatively cool water could be satisfactory with some crops, such as lettuce and carnations.

m) Large companies are getting into the greenhouse business, and are using waste heat because they have the capital needed for high start-up costs. Some incentives to assist small growers to use waste heat in greenhouse crop production might be considered.

Conclusion

There is no doubt that the future of the greenhouse industry in North America will be tied closely to use of reject heat as an energy source. We are still in the horse and buggy stage as far as methods for extracting and using reject heat efficiently for use in greenhouse crops are concerned. This aspect requires considerable engineering research.

I believe that the use of waste energy for greenhouse crop production is limited only to the extent of our imagination and to the prevailing state of our technology.

Literature Cited

1. Boyd, L.L., G.C. Ashley, J.S. Hietola, R.V. Stansfield, and T.R.C. Tomlinson. 1980. A demonstration of beneficial uses of warm water from condensers of electric generating plants. Northern States Power Co., Minneapolis, Minn. EPA-600/7-80-099.
2. Burch, D.W., I.J. Carter, and R.S. Pile. 1982. Waste heat greenhouse progress report II. Tennessee Valley Authority, Muscle Shoals, Ala.
3. EXEL Produce Ltd. 1981. Technical report—Drax. Report to Exel Produce Limited, Campbellsforth, North Yorks, U.K.
4. Resources Management Consultants Ltd. 1979. The potential impact of waste heat on the vegetable greenhouse industry in Canada. Report to Engineering and Statistical Research Institute, Agriculture Canada. Ottawa.
5. Tiessen, H. 1983. Energy conservation in greenhouse vegetable production utilizing recycled low temperature water from the refinery process as a heat source. Cooperative Texaco, Univ. of Guelph Greenhouse Research Project at the Texaco Nanticoke Refinery, Ont. Nanticoke, June 1983.
6. Winspear, K.W. 1975. Greenhouse establishments in France. DN/G/624/1000 Matu. Inst. Agr. Eng. Silsol. April.