AQUACULTURE AND GEOTHERMAL HEAP PUMP SYSTEMS

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ABSTRACT

The objective of this study is to examine the feasibility of aquaculture tank heating with geothermal heat pump (GHP) systems. Both closed- and open-loop GHP systems are examined for heating uncovered and greenhouse-covered tanks at three locations across the U.S. A net present value analysis is conducted for a 20-year life-cycle for various GHP base-load fractions with natural gas-fired boiler peaking. The fraction of GHP capacity to the peak load yielding the lowest life-cycle cost is plotted at various GHP installation costs and natural gas rates.

Heating load calculations show that covering aquaculture tanks with a greenhouse-type structure reduces the heating requirements by over 50%. Economic analyses for closed-loop GHP systems show that, the lowest life-cycle cost at natural gas rates of \$1.00/therm (\$0.35/m^3) is observed when the GHP system is sized for 10-20% of the peak load. At that fraction, 30-55% of the total annual heating load could be handled. At low loop installation costs of \$4/ft-\$6/ft (\$13/m-\$20/m), approximately 55-70% of the annual heating load could be handled.

Open-loop GHP systems show considerably more favorable economics than closed-loop systems. In all situations examined, at natural gas prices of \$1.00/therm (\$0.35/m^3), the lowest life-cycle cost is observed when the open-loop system is sized for about 40% of the peak load. At that size, the GHP system can handle over 80% of the annual heating requirements. At low-to-moderate installation costs of \$200-\$700/ton (\$57/kW-\$200/kW), over 90% of the annual heating load could be handled. Of course, open-loop systems would need to be sited at locations with sufficient groundwater supply.

INTRODUCTION

The success and economic benefits of aquaculture operations with low-temperature geothermal resources (i.e., groundwater temperatures >140ºF (60ºC) has lead to the question of whether or not lower temperature resources could be exploited with the aid of geothermal heat pumps (GHPs). This study seeks to answer that question, and therefore, the objective is to determine the feasibility of heating fish tanks with GHP systems. Both closed- and open-loop systems are examined at three locations across the United States: Boston, MA; Dallas, TX, and Denver, CO. A number of GHP base-load combinations are examined for the three locations to find the lowest 20-year life-cycle cost at various natural gas rates and GHP installation costs.

AQUACULTURE TANK HEATING SYSTEMS

In a comparison study of this type, assumptions need to be made about the fish tank heating system that is being displaced by the GHP system. It was assumed that a conventional system would consist of a number of above-ground tanks; where, water is heated by a natural gas-fired boiler system. The alternative is a water-to-water GHP system.

AQUACULTURE TANK HEATING LOADS

Hourly heating loads were calculated for above-ground aquaculture tanks with a total surface area of 10,000 ft^2 (930 m^2) and a depth of 5 ft (1.5 m). Typical meteorological year (TMY) data for Boston, MA; Dallas, TX, and Denver, CO, were used to compute loads for two scenarios: (1) tanks uncovered and (2) tanks covered by a greenhouse structure. Heat transfer processes included in the calculations are shown in Figure 1. The tank set point temperature was 80ºF (27ºC).

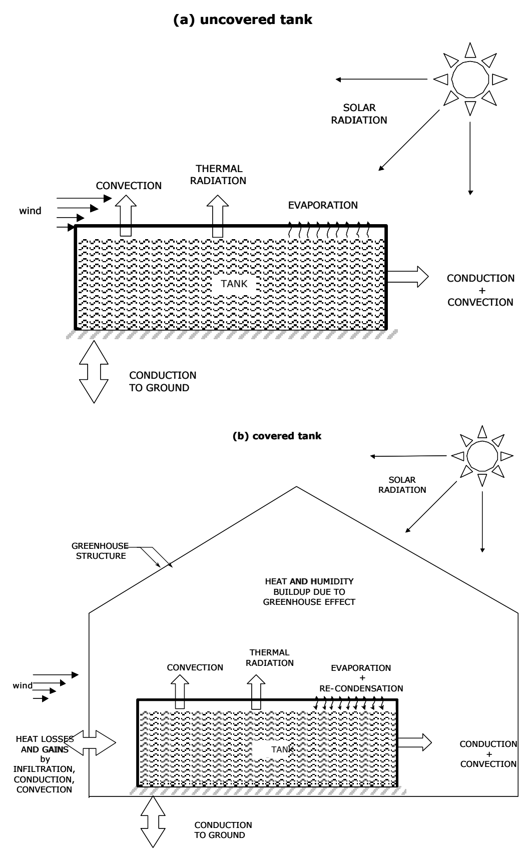

Figure 1. ***Heat transfer processes in covered and uncovered aquaculture tanks.***

Hourly heating loads for the year are shown in Figures 2 and 3. As might be expected, Boston and Denver show more extreme heating loads than Dallas. In all cases, covering the tanks with a greenhouse structure results in approximately a 50% reduction in heating load. An interesting and important result is shown in Figure 4, which

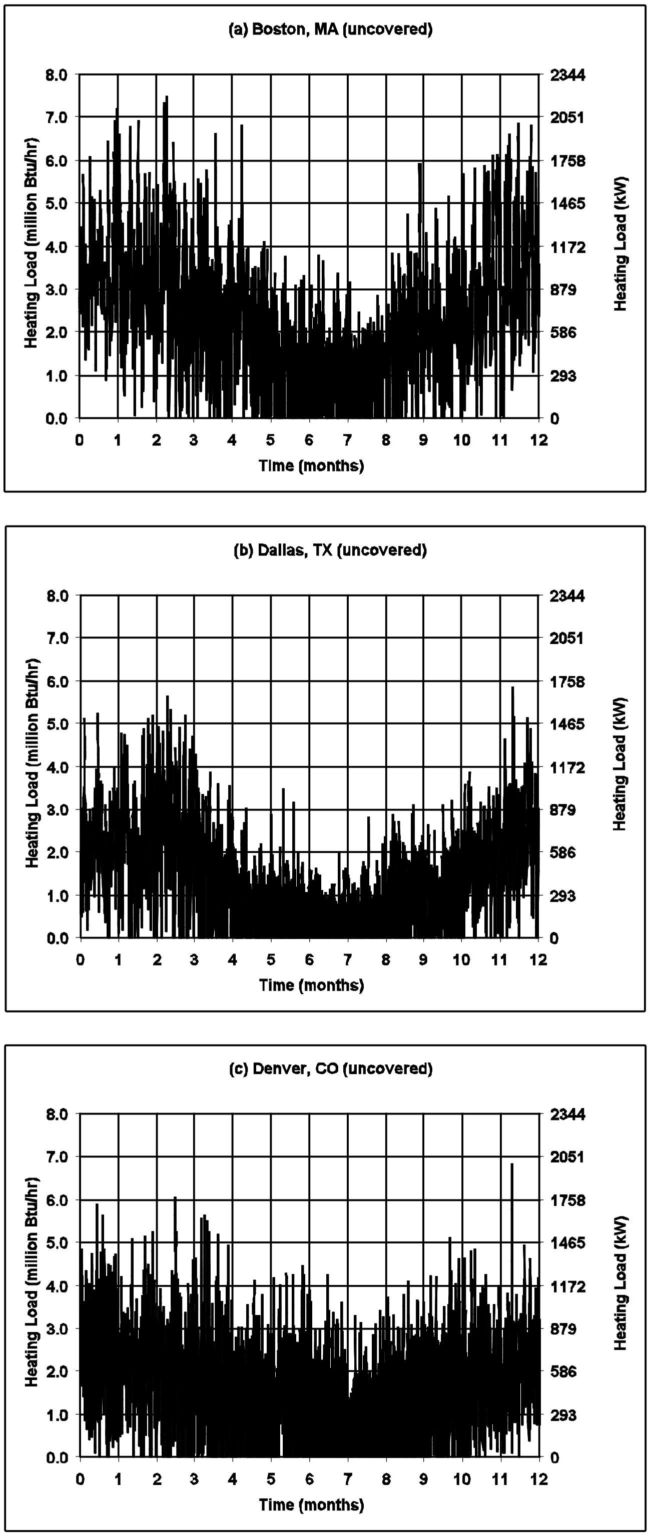

Figure 2. ***Hourly heating loads on an annual basis for uncovered aquaculture tanks.***

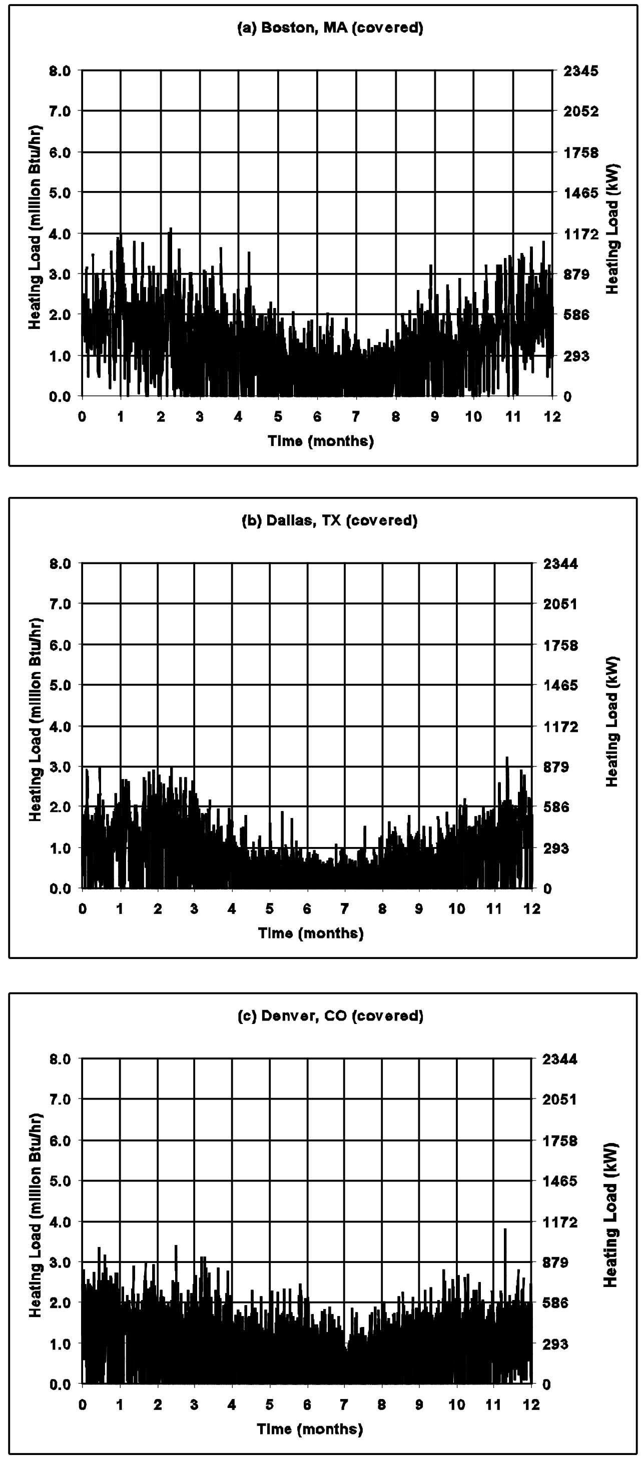

Figure 3. ***Hourly heating loads on an annual basis for covered aquaculture tanks.***

is a plot of the fraction of total annual heating demands versus the fraction of the peak load that a base-load system would be designed to handle. This is significant since a base-load system (the GHP system in this case) sized at 50% of the peak load could meet about 92% of the total annual heating requirements.

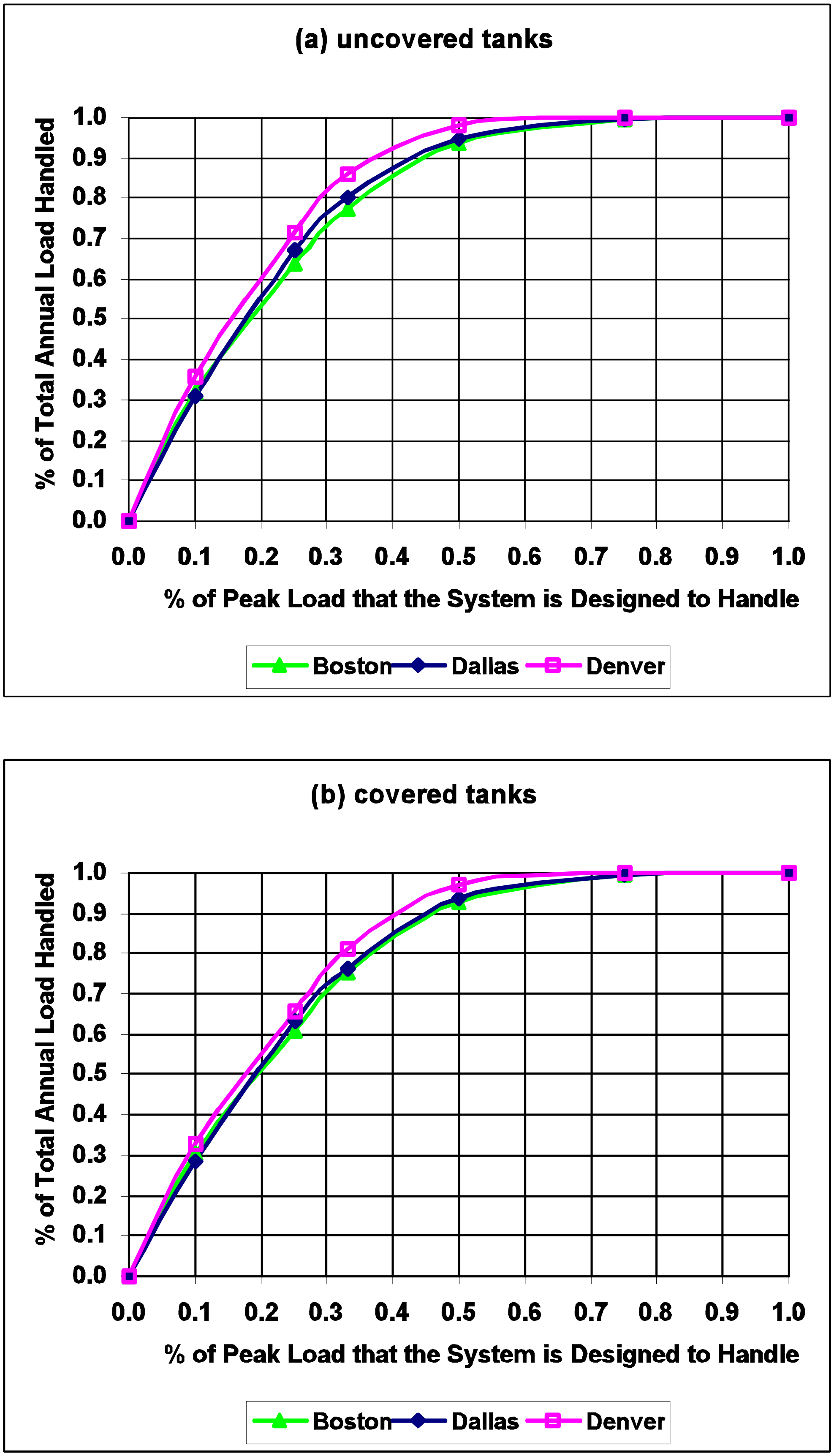

Figure 4. *Fraction of total annual heating load actually handled versus design fraction of peak load for a base-load system.*

ECONOMIC ANALYSIS

Closed-Loop GHP System

The hourly loads shown in Figures 2 and 3 were converted to monthly total and peak loads, and using a software program, ground loops were sized for each location for several GHP part load cases (100%, 75%, 50%, 33%, 25%, 10%, and 0%). The remainder of the load is handled by a natural gas-fired-boiler system. The loop-sizing software also computes heat pump power consumption.

A net present value (NPV) analysis of a 20-year life-cycle was used to compare alternatives for the various part load cases. Equipment costs for natural gas-fired boiler systems were taken from R.S. Means Mechanical Cost Data and water-to-water heat pump material and installation costs were assumed at $1000/ton ($284/kW) of heat pump capacity. Ground-loop installation costs are commonly reported per foot of vertical bore, and for this study, a range of $4/ft to $12/ft ($13/m to $39/m) was examined, which is representative of the widely varying values observed across the U.S.

Annual operating costs included fuel and maintenance costs. A range of natural gas costs from $0.50 to $2.00 per therm ($0.18/m^3 to $0.70/m^3) was examined. Electricity cost was fixed at $0.10/kW-hr. Annual boiler maintenance costs were assumed at 2% of capital cost. A discount rate of 6% was assumed.

Results of the closed-loop economic analysis are presented in the form of contour plots in Figure 5 for uncovered tanks and in Figure 6 for greenhouse-covered tanks. Results were similar for all three cities examined. The plot shows contours of the GHP fraction of the total heating system that yields the lowest NPV at various natural gas rates and ground-loop installation costs.

A review of Figures 5 and 6 reveals that at natural gas prices above about $0.50-$0.60/therm ($0.18/m^3-$0.21/m^3), it would be economically justifiable to heat a portion of aquaculture tanks with a closed-loop GHP system, depending on the installation costs. For **uncovered** tanks at natural gas costs of $1.00/therm ($0.35/m^3), for example, the lowest life-cycle cost is seen to range from a GHP sized at about 7% of the peak load at installation costs of $12/ft ($39/m) to about 22% of the peak load at installation costs of $4/ft ($13/m). At these sizes, the GHP system could handle from about 25% to about 65% of the total annual load, respectively. For **covered** tanks under the same conditions, the lowest life cycle cost is seen to range from a GHP sized at about 12% of the peak load at installation costs of $12/ft ($39/m) to about 25% of the peak load at installation costs of $4/ft ($13/m).

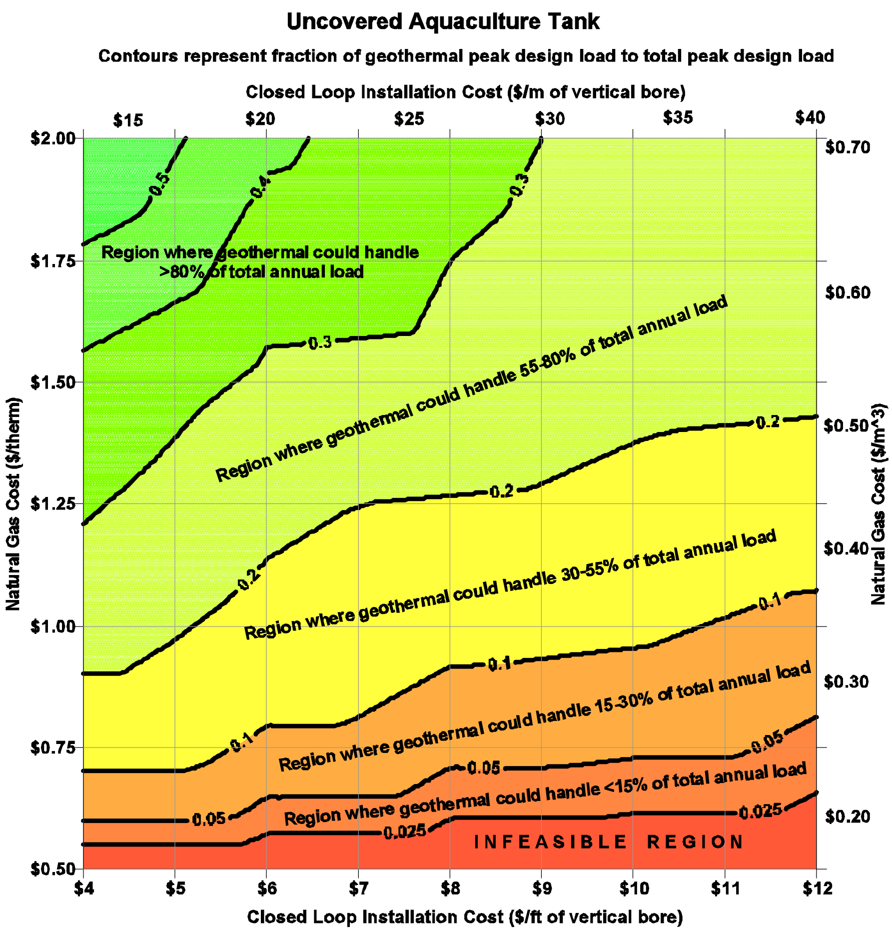

Figure 5. Closed-loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and closed-loop installation costs used to heat uncovered aquaculture tanks (Results derived from Boston, Dallas and Denver climate data).

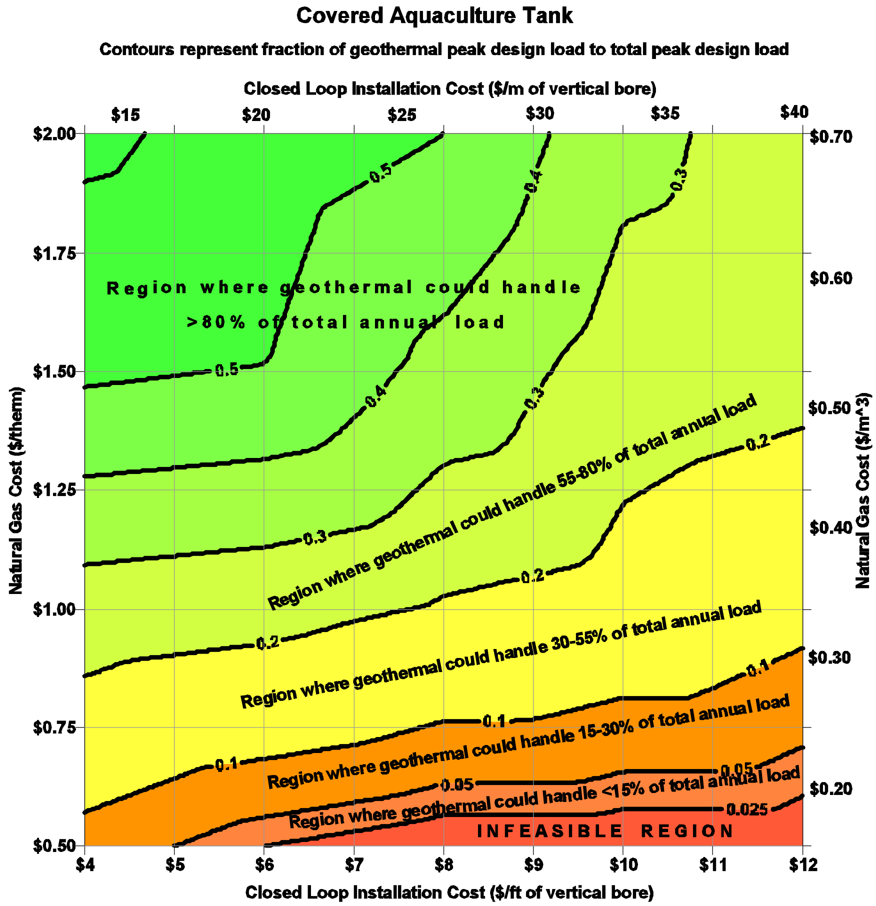

Figure 6. *Closed-loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and closed-loop installation costs used to heat covered aquaculture tanks (Results derived from Boston, Dallas and Denver climate data).*

Open-Loop GHP System

The same overall approach was taken in the economic analysis of the open-loop systems as for the closed-loop systems with the following differences. The capital cost range of the open-loop systems were taken from *Outside the Loop Newsletter* (Vol. 1, No.1, 1998). These costs, shown in Figure 7, are expressed per ton (and kW) of delivered capacity for various well configurations and include costs of production and injection wells, well tests, pumps, piping to the building, heat exchangers, controls, and 15% contingency.
For the operating costs, additional electrical loads were included to account for a submersible pump operating under an assumed vertical head of 100 ft (30.48 m).

Results of the open-loop economic analysis are presented in Figure 8 for uncovered tanks and in Figure 9 for greenhouse-covered tanks. The plots show contours of the GHP fraction of the total heating system that yields the lowest NPV at various natural gas rates and open loop installation costs. A review of Figures 8 and 9 shows greater feasibility of aquaculture tank heating with open-loop GHP systems over closed-loop systems. The lowest life-cycle cost at natural gas rates of $1.00/therm ($0.35/m^3), is seen for the GHP system sized at about 40% of the peak load, being capable of handling over 90% of the annual heating load, at installation costs up to

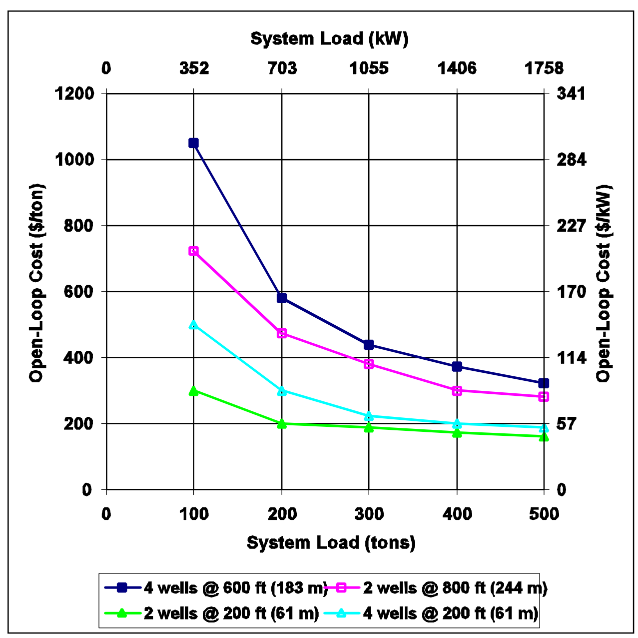

Figure 7. *Open-loop system costs for 60^{o}F groundwater (Source: Outside the Loop Newsletter, Vol. 1, No. 1, 1998).*

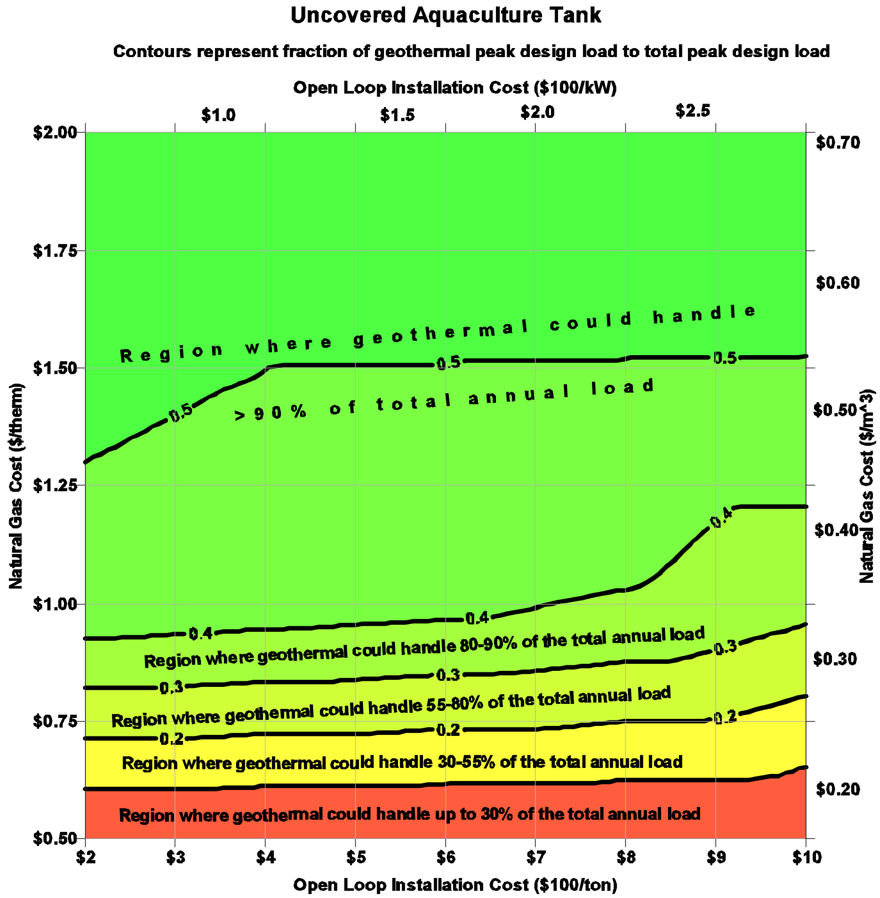

Figure 8. ***Open-loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and closed-loop installation costs used to heat uncovered aquaculture tanks (Results derived from Boston, Dallas and Denver climate data).***

$700/ton ($200/kW) for uncovered tanks and up to about $875/ton ($250/kW) for covered tanks. Above these costs per ton (kW), an open-loop system could still be installed to handle 80-90% of the annual load for either covered or uncovered tanks. Note also the relative "flatness" of the 0.1 to 0.4 curves in Figures 8 and 9. This reflects the economies of scale with open loop systems; only two to four wells are needed if enough ground water is present. Thus, a greenhouse would need to be sited at a location where there is sufficient groundwater supply.

CONCLUDING SUMMARY

This study has examined the feasibility of aquaculture tank heating with closed- and open-loop GHP systems. Heating loads were computed for three climates across the U.S. The net present value of a 20-year life-cycle was determined for various GHP base-load fractions.

The results of this study show that the practice of covering aquaculture tanks with greenhouse-type structures can reduce heating demands by 55%. The economic analysis has shown that the feasibility of heating aquaculture tanks with closed-loop GHP systems is strongly dependent on the natural gas cost and the ground-loop installation cost. The lowest life-cycle cost was observed when the closed-loop GHP system handles only a portion of the total annual heating requirement. At natural gas rates of $1.00/therm ($0.35/m^3), depending on loop installation costs and whether or not the aquaculture tanks are covered, a closed-loop GHP system sized at 7-25% of the peak load could be installed to handle from about 25-70% of the annual load.

The economics of open-loop systems for the cases examined, as may be expected, are more attractive than closed-loop systems. In all situations examined, at natural gas prices of $1.00/therm ($0.35/m^3), the lowest life-cycle cost was observed at the GHP system sized at about 40% of the peak load. At that size, an open-loop system could handle over 80% of the annual heating load. At low-to-moderate installation costs of $200-$700/ton ($57/kW-$200/kW), over 90% of the annual heating load could be handled.

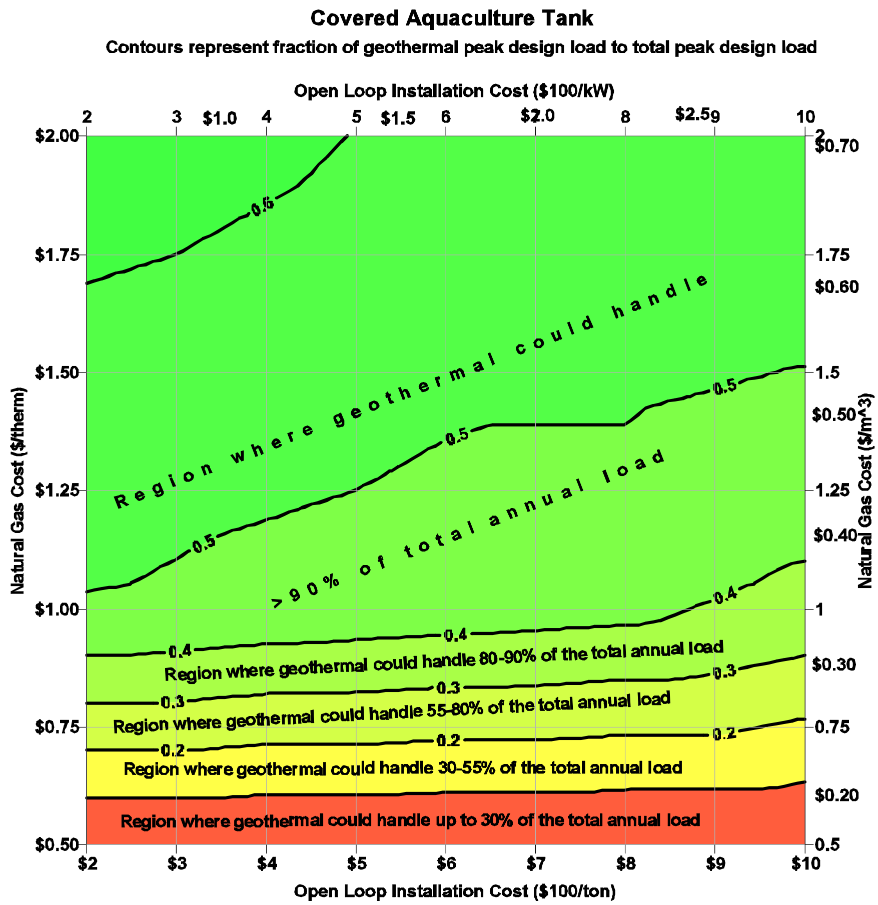

Figure 9. Open-loop GHP system fraction providing lowest net present value of a 20-year life-cycle at various natural gas costs and closed-loop installation costs used to heat covered aquaculture tanks (Results derived from Boston, Dallas and Denver climate data).