SOLAR ASSISTED
CULVERT THAWING DEVICE

PHASE II

by

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Abstract

A reflective type concentrating solar collector system has been designed, constructed and installed on an ice plugged roadway culvert as a means of melting a channel for water flow. The system consisted of four reflecting collectors, a circulating pump, and a thaw pipe mounted in the culvert. Photovoltaic panels were used as the source of power for the pump. A design analysis and performance characteristics are given for the solar collectors, circulating pump, and photovoltaic panels.
Introduction

Roadway flooding and icing is a major problem in Alaska, especially during the spring thawing period or "break-up" season. Below freezing soil temperatures surrounding roadway culverts at this time of year can cause water to freeze inside. The subsequent damming and backing-up of the run-off waters can result in roadway flooding and icing.

The Alaska Department of Transportation presently utilizes four methods of thawing culverts where flooding and icing is a problem. One method uses a hot water boiler which requires the installation of a thaw pipe in the culvert. The boiler, transported to the problem site by truck or trailer, is connected to the thaw pipe in a closed loop circuit as a means of circulating an anti-freeze solution through the culvert to melt the ice. The amount of time required to thaw an opening in an ice filled culvert is determined on-the-spot by the maintenance crew or from previous site history. In some cases, just initiating water flow is sufficient to maintain the culvert flow for sometime. In other cases, the culvert must be thawed daily to maintain flow. A second method, uses a steam generator and a steam probe which is forced through the ice in the culvert. A third method of culvert thawing utilizes oil-fired barrel stoves, commonly called "moose warmers". These barrel stoves, set in the flow line upstream of the culvert, are 55-gallon drums with simple burners which are ignited to burn fuel oil. The water passing around the barrel is warmed which melts the ice to maintain a free
flow through the culvert. A consumption of 50 gallons of fuel per culvert per day is typical for the moose warmers and therefore a daily delivery is required at all locations using this system, Connor (1982). All three of these methods of culvert thawing are labor-intensive and expensive. The fourth method uses electrical heat tape installed in the culvert. For this case maintenance labor costs are minimal, but the problem site must be situated close to electrical power lines.

For the 1982 breakup season a parabolic trough solar collector system was built and installed as an alternative to the flat plate collector system constructed in 1981, Zarling and Miller (1981). It was felt that a reflecting collector system may be less prone to vandalism than a flat plate collector. Bullet holes through the reflector of a concentrating collector would reduce its efficiency and only by piercing the receiver, a relatively small target, would damage occur to the point where it would not operate.

**COLLECTOR EFFICIENCY**

A reflecting solar collector, Fig. 1, consists of a metal tube or receiver, of diameter D and a reflector of width W. The ratio of entrance aperture area to the receiver area per unit length of collector defines the effective concentration ratio $C_e$, or

$$C_e = \frac{W}{mD}$$

If the intensity of solar radiation passing through the entrance aperture is $I$, then the rate of heat gain by the receiver, $Q$,
FIGURE 1: CONCENTRATING SOLAR COLLECTOR
is

\[ Q = \eta_0 W I \]

per unit length of collector, where \( \eta_0 \) is the optical efficiency. The rate of heat loss, \( Q_\lambda \), per unit length of the cylindrical receiver is

\[ Q_\lambda = U n D (T_r - T_a) = U W (T_r - T_a) / C_e \]

where

- \( U \) is the overall heat transfer coefficient, Btu/hr-ft\(^2\)-\(^\circ\)F
- \( T_a \) is the ambient outdoor temperature, \(^\circ\)F
- \( T_r \) is the average receiver temperature, \(^\circ\)F

The net heat gain \( Q_u \), to the collect fluid per unit length of collector is

\[ Q_u = Q - Q_\lambda = \eta_0 W I - U W (T_r - T_a) / C_e \]

The efficiency of the collector is simply described as the ratio of useful energy delivered to the radiation incident on the collector, or

\[ \eta = Q_u / W = \eta_0 - U (T_r - T_a) / C_e I \]

Typical values for the parameters in the above equations are \( \eta_0 \) of .65, \( U \) of 1.0 Btu/Hr-ft\(^2\)-\(^\circ\)F, and \( I \) of 280 Btu/Hr-ft\(^2\) for clear skies at solar noon in Alaska. Substituting these values into the above equation yields

\[ \eta = .65 - (T_r - T_a) / 280 C_e \]
By examining this equation it is seen that: (a) higher concentration ratios increase efficiency, and (b) larger temperature differences between ambient and receiver reduces efficiency. Because higher concentration ratios result in higher receiver temperature and a higher overall heat transfer coefficient, the overall parabolic collector efficiency will depend upon the relative change in these interdependent parameters.

**COLLECTOR ORIENTATION**

Parabolic trough collectors can be mounted in either a fixed position or made to track on the sun. Due to the lack of maintenance at remote sites where solar assisted culvert thawing devices would be used, the short season during which the system is required, and budget constraints, it was decided to mount the reflectors in a fixed position. East-west or north-south mounting of the long axis of the collector is possible. The east-west orientation has the advantages of maximum output, simple low cost supports and simple alignment. The main disadvantage of this mounting is the cosine loss at off-noon hours. The cosine loss is zero at solar noon when the sun's rays impinge directly on the aperture area perpendicularly and the loss increases before or afternoon as the sun's rays are focused "upstream" or "downstream" of the point where they are reflected from the reflector. In a fixed nontracking mode, the tilt of the trough about the main axis would have to be adjusted. Although this method of operation is
the simplest, output from the collector only occurs when the reflected rays are focused on the receiver. During the spring and fall of the year, solar altitude changes most rapidly on a day-to-day basis and the tilt of the trough must be adjusted more often. Usually, it is desirable to adjust the tilt so focusing is perfect at about 1 to 1/2 hours before solar noon so the sun's rays stay focused on the receiver for 4 to 6 hours per day.

Parabolic troughs can also be mounted with their main axis oriented in the north-south direction. In this case, the tilt of the unit is important as the sun changes elevation through the seasons of the year. A fixed mounted collector tilted at the latitude angle would be 23.5° too high in mid-summer and 23.5° too low during mid-winter. Therefore, the end losses are \( \cos(23.5°) \) at these times of the year at solar noon. If the collector is totally fixed in this position, then the sun's rays will remain focused on the receiver for only a fraction of the hour centered on solar noon.

Table 1 shows the variation in the angle of the plane containing the sun's rays and receiver tube with the horizontal beginning on March 1 and ending on May 1 at a latitude equal to 60°N.

<table>
<thead>
<tr>
<th>TIME</th>
<th>MAR 1 (( \delta=-7° ))</th>
<th>MAR 21 (( \delta=0° ))</th>
<th>APR 8 (( \delta=7° ))</th>
<th>MAY 1 (( \delta=14° ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noon</td>
<td>25.7°</td>
<td>30.0°</td>
<td>34.5°</td>
<td>39.3°</td>
</tr>
<tr>
<td>11,1</td>
<td>25.7°</td>
<td>30.0°</td>
<td>34.5°</td>
<td>39.3°</td>
</tr>
<tr>
<td>10,2</td>
<td>25.7°</td>
<td>30.0°</td>
<td>34.5°</td>
<td>39.4°</td>
</tr>
<tr>
<td>9,3</td>
<td>25.7°</td>
<td>30.0°</td>
<td>34.5°</td>
<td>39.4°</td>
</tr>
<tr>
<td>8,4</td>
<td>25.7°</td>
<td>30.0°</td>
<td>34.5°</td>
<td>39.4°</td>
</tr>
</tbody>
</table>
As seen in Table 1, the tilt of an east-west parabolic trough does not require adjustment during the day in order to maintain focus of the sun on the receiver near the equinox seasons of the year. However, during the two months of time covered by the table, the east-west oriented collector would require a 14 degrees adjustment in tilt to maintain true focus. Therefore, the parabolic collectors were mounted on a hinged panel so that the tilt angle could be adjusted.

The collectors used in this project have a $C_e$ of 9.3 which yields a theoretical maximum acceptance angle of $6.1^\circ$, Rabl (1976). In order to determine the actual acceptance angle of these parabolic trough collectors, a 15 watt fluorescent tube of approximately the same diameter of the receiver was positioned at the receiver location. Then the divergence of the reflected light pattern was measured with a light level meter on a plane a distance of 18 feet from the collector. By measuring the point at which the intensity had dropped-off by 29% from the main collector axis, the half power points were determined. The half angle subtended by this measurement defined the actual acceptance angle. For the Energy Harvester Collectors used, the acceptance angle was measured to be 3.7 using this technique. In terms of the above table, these collectors could be set at a tilt of $30^\circ$ and the receiver would receive slightly less than half of the solar energy incident on the aperture area on the first on March and the eighth of April. Between these dates, the power would rise to a maximum on March 21. Adjusting the collectors several times during the
spring season would extend their period of usefulness and increase system effectiveness.

The test site selected for the thawing device was at the intersection of Murphy Dome Road and Goldstream Road 15 miles northwest of Fairbanks. In years past, this intersection has become flooded during the spring thaw. Several acres of land bounded by Murphy Dome Road and Goldstream Road to the northeast and upstream of the culvert, Fig. 2, have been reported to remain under several feet of water/ice as late as June because of the plugged culvert. The assumed source of the problem is a spring/creek located 75 yards north of the culvert. The State of Alaska Department of Transportation had already installed thaw pipes in the culvert for steam thawing the accumulated ice.

APPARATUS

The solar-assisted culvert thawing system consisted of the following components:

1. Four (4) EH-100 concentrating parabolic solar collectors
2. One (1) EH-2000 photovoltaic power module
3. One (1) EH-1000-1 circulating pump
4. 1-1/2 inch nominal diameter SCH 40 steel pipe
5. 3/4 inch diameter premium heater hose

The collectors, photovoltaic power module, and pump were purchased as a complete system from Energy Harvester, Inc. located in San Diego, California. The collectors were plumbed in series, Fig. 3, with the pump being located on the suction side of the collectors. The photovoltaic panel powers the D.C. motor directly. The simplicity of the photovoltaic cell and pump arrangement
allows the pump to circulate only when there is enough solar radiation incident on the panels to produce the minimum power required by the pump. Thus, the pump will operate from morning to afternoon under clear sky conditions while sufficient solar radiation is striking the panel. Cloud cover will reduce the length of operating time and the performance of the pump. Solar voltaic panel and pump performance is described in a later section of this report.

A 60 foot length of 1-1/2 inch diameter SCH 40 steel pipe was installed inside the problem culvert in November 1981. At each end of the pipe, two foot long vertical risers were installed to aid the escape of melt water. Heater hose was then installed inside the steel pipe during the month of March. An eccentric bayonet tube heat exchanger design was used for the thaw pipe. The heater hose delivers the hot fluid to the discharge end of the culvert, Fig. 4. The fluid then returns through the annular area between the heater hose and SCH 40 pipe. It is believed that the hot fluid should be injected in the annulus at the discharge end of the culvert to enable the melt water from the thawing process to flow and escape downstream. The bayonet tube arrangement also allows the inlet and outlet to be located at the upstream end of the thaw pipe adjacent to the collectors.

At the upstream end, the heater hose enters the steel pipe through the adapter shown in Fig. 5. This adapter consists of a six inch long, 3/4 inch diameter pipe nipple inserted halfway through a bushing and welded to form a watertight seal. The bushing was then screwed into one end of a 1-1/2 inch pipe tee and union assembly located on top of the upstream riser. The hot
Figure 4
CONCEPTUAL VIEW OF THE THAW PIPE
fluid enters the heater hose through the nipple and exists the thaw pipe via the branch of the 1-1/2 inch diameter pipe tee. Preformed pipe insulation 3/4 inch thick was later installed around the heater hose to reduce heat loss while the fluid was in transit to and from the collectors to the thaw pipe. The collectors support structure was installed approximately 20 feet east of the upstream end of the culvert. The parabolic collectors, photovoltaic panel, pump and expansion tank were mounted on two 4 feet by 8 feet sheets of plywood. The plywood was fastened to two 4 inch by 4 inch crossbeams which had been previously bolted to the utility poles Fig. 6. These poles were set 8 feet apart and 4 feet into the ground during November of 1981. The plywood was hinged to the top crossbeam to allow tilting of the system. A strut was hinged to the bottom of each sheet of plywood and extended to the lower crossbeam to serve as a support to maintain a fixed tilt. Several holes were drilled in the struts and a 1/2 inch bolt was then inserted through the struts into the crossbeam to allow for adjusting the tilt angle of the system. The four collectors were mounted on one sheet of plywood, while the photovoltaic panels, pump and expansion tank were mounted on the second plywood sheet, Fig. 3. The collectors were connected together in series using insulated heater hose.

The east-west axis of the collectors were tilted at a very slight angle from horizontal to allow air in the piping to flow to the top of the system for venting. At the end of the collector piping and at the top of the plywood mounting sheet, a 1-1/2 inch
Figure 6: Support Structure for Parabolic Collectors and Photovoltaic Panels
diameter steel pipe 24 inches in length was inserted into the piping system to serve as an expansion vessel and to allow air to escape. The two foot section of pipe also served as the initial fill point for the ethylene glycol and water mixture.

**DESIGN ANALYSIS**

The performance of the culvert thawing system can be simulated utilizing the overall efficiency relationship for the collectors, the heat exchange process in the thaw-pipe and culvert and the overall thermal energy balance for the system. The efficiency of the EH-100 parabolic collector was quoted by the manufacturer as:

\[
\eta = 0.784 - 0.19(T_i - T_a)/I
\]  

[1]

where \( T_i \) = entering temperature of fluid, °F  
\( T_a \) = ambient air temperature, °F  
\( I \) = incident solar radiation, Btu/hr-ft\(^2\)  
\( \eta \) = collector efficiency

The efficiency is equal to the useful thermal energy delivered by the collectors divided by the incident solar radiation on the total aperture area of the collectors, or

\[
\eta = Q_u/IA
\]

where \( Q_u \) = useful thermal energy delivered by collectors, Btu/hr  
\( A \) = collector aperture area, ft\(^2\)

Upon combining the above two equations, the thermal energy
delivered to the thaw pipe, assuming no line losses, is equal to:

\[ Q_u = 0.7841A - 0.19(T_o - T_a)A \]  

[2]

The total thermal energy supplied by the system according to the First Law of Thermodynamics is also equal to:

\[ Q = mc_p(T_o - T_i) \]

where \( m \) = mass flow rate, lb/s

\( c_p \) = specific heat of fluid, Btu/lb\(^\circ\)F

\( T_i \) = inlet temperature to collector, \(^\circ\)F

\( T_o \) = outlet temperature from collector, \(^\circ\)F

The thermal energy delivered by the thaw pipe to the ice in the culvert is equal to the thermal energy gained from the collectors, if heat loss through the insulated heater hose is neglected. Performing an energy balance on a differential element of the bayonet tube heat exchanger shown in Fig. 7 yields the following differential equations:

\[ \frac{d\hat{t}}{dx} + B(\hat{t} - \hat{t}') = -\beta \]

\[ \frac{d\hat{t}'}{dx} + B\hat{t} - C\hat{t}' = -\alpha - \beta \]

where \( \hat{t} = t - t_o \)

\( \hat{t}' = t' - t_i \)

\( A = \frac{UP}{mc_p} \)

\( B = uP/mc_p \)

\( C = A + B \)

\( \beta = B(t_o - t_i) \)

\( \alpha = A(t_i - T) \)
SECTION OF BAYONET TUBE HEAT EXCHANGER, FLOW IS COUNTER-CURRENT
and boundary conditions
\[ \hat{T} = 0 \quad \text{at} \quad x = 0 \]
\[ \hat{T}' = 0 \quad \text{at} \quad x = 0 \]

Integrating this system of first order ordinary differential equations yields the following solutions for the temperature profile in the inner tube and annulus
\[ t = T + C_1 \exp(D_1x) + C_2 \exp(D_2x) \]
\[ t' = T + C_1[1+D_1/B] \exp(D_1x) + C_2[1+D_2/B] \exp(D_2x) \]

where
\[ C_1 = -\{B(t_0-t_i)+D_2(t_0-T)\}/(D_1-D_2) \]
\[ C_2 = \{B(t_0-t_i) + D_1(t_0-T)\}/(D_1-D_2) \]

\[ D_1 = A(1+1+4B/A)/2 \]
\[ D_2 = A(1-1+4B/A)/2 \]

The temperature distributions, Eqns. [3], can be equated at the far end of the bayonet tube heat exchanger to yield the return temperature as a function of the entering temperature, mass flow rate and the overall heat transfer coefficients \( u \) and \( U \), or
\[ t_i = t_0 + \frac{(t_0-T)D_1D_2[\exp(D_2L)-\exp(D_1L)]}{(D_2 \exp(D_2L)-D_1 \exp(D_1L))B} \]  \[ \text{[4]} \]

The overall heat transfer coefficients \( u \) and \( U \) defined in the parameters \( A \) and \( B \), can be determined from the following equations.

\[ u = \frac{1}{\frac{1}{h_1P_1} + \frac{\ln(D_2/D_1)}{2\pi k_1} + \frac{1}{h_2P_2}} \]
where

\[ D_1 = \text{inside diameter of heater hose} \]
\[ D_2 = \text{outside diameter of heater hose} \]
\[ K_1 = \text{thermal conductivity of the hose} \]
\[ P_1 = \text{inside perimeter of the heater hose} \]
\[ P_2 = \text{outside perimeter of the heater hose} \]
\[ h_1 = \text{inside convective heat transfer coefficient} \]
\[ h_2 = \text{outside convective heat transfer coefficient} \]

\[
U = \frac{1}{h_3P_3 + \frac{\ln(D_4/D_3)}{2\pi K_2} + \frac{1}{h_4P_4}}
\]

where

\[ D_3 = \text{inside diameter of steel pipe} \]
\[ D_4 = \text{outside diameter of steel pipe} \]
\[ P_3 = \text{inside perimeter of steel pipe} \]
\[ P_4 = \text{outside perimeter of steel pipe} \]
\[ K_2 = \text{thermal conductivity of steel pipe} \]
\[ h_3 = \text{inside convective heat transfer coefficient} \]
\[ h_4 = \text{outside convective heat transfer coefficient} \]

The calculation of the convective heat transfer coefficient inside the heater hose can be performed using the relation for forced convection in a circular tube, Kreith (1976). Because the flow was laminar (Re < 2000), the Nusselt number can be determined for a circular duct with uniform wall temperature. The convective heat transfer coefficient is then calculated as

\[ h_1 = \frac{K_1}{D_1} \text{Nu} \]

The convective heat transfer coefficient on the outside of the heater hose, \( h_2 \), and on the inside of the steel pipe, \( h_3 \), can be estimated using the methods outlined in Shah and London
(1978) for eccentric annuli. At this point the equations describing the performance of the collector system and the bayonet tube heat exchanger have been given. Equations [2] and [4] will provide the total system performance for a culvert thawing device provided that \( u, p, I, U, P, \) and \( mc_p \) are all specified. However, the heat transfer coefficients for the eccentric annulus have not yet been fully determined for the boundary conditions particular to this heat exchanger system nor has the coefficient between the thaw pipe and ice. It is beyond the scope of this project to develop these coefficients.

**FIELD PERFORMANCE**

The system was placed into operation the first week of April 1982. That same week the DOT maintenance crew steamed thawed the culvert which remained thawed for the remainder of the thaw season. It is difficult to assess how much the solar culvert thawing system contributed to the non-necessity of the DOT maintenance crew to return for rethawing of the culvert. At the time the culvert was steamed thawed, the solar device had already created a one inch annulus in the ice at the downstream end and a one-half inch annulus at the upstream end of the thaw pipe.

The rubber hoses leading to and from the collectors were insulated with preformed pipe insulation after initial installation. This is recommended for all future installations. Using the photovoltaic panels without the battery banks and thermostat switching circuits, used on the flat plate collector system, proved to be a reliable and simple means of providing
pump power and control. During the summer of 1982, the 1-1/2 inch thaw pipe was shortened and the pipe joints resealed in anticipation of spring 1983. The thaw pipe was filled in the fall of 1982 with antifreeze, however when the system was checked in mid-March 1983 it was found the thaw pipe had developed a major leak. Determining the location and cause of this leak will have to wait until summer when all the ice has melted from the site. It is recommended future installations consider the use of high density polyethylene pipe to overcome the joint leakage problem and provide a greater safety factor against freeze-thaw damage.

A persistent problem that has plagued the solar assisted thawing devices has been leaks in the piping systems and air pockets or bubbles at the high points in the piping. Eliminating as many joints as possible would help solve the leak problems. Designing the piping to minimize high spots and where high spots due occur including air bleed values should elevate this problem.

A performance test on the installed system was conducted. Thermocouples were installed in the inlet and discharge piping of the series connected solar collectors. A flow meter was inserted in the discharge piping from the collectors. On April 22 and 23, 1982 inlet and outlet temperatures and flow rates through the collectors were measured, solar insulation was measured with a hand held pyranometer and ambient temperature was also recorded. The data taken during these tests is presented in Table 2.
TABLE 2
COLLECTOR SYSTEM PERFORMANCE DATA

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>I</th>
<th>FLOW</th>
<th>(\dot{m})</th>
<th>(t_i)</th>
<th>(t_o)</th>
<th>(t_a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Btu/ft²</td>
<td>GPM</td>
<td>lb/s</td>
<td>°F</td>
<td>°F</td>
<td>°F</td>
</tr>
<tr>
<td>4/22/82</td>
<td>11:30</td>
<td>350</td>
<td>1.0</td>
<td>.153</td>
<td>45</td>
<td>38</td>
<td>40</td>
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<tr>
<td></td>
<td>12:00</td>
<td>350</td>
<td>1.1</td>
<td>.168</td>
<td>43</td>
<td>36</td>
<td>43</td>
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<td></td>
<td>2:00</td>
<td>252</td>
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<td>3:00</td>
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<td>43</td>
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<tr>
<td>4/23/82</td>
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<td>0.4</td>
<td>.061</td>
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<td>.168</td>
<td>40</td>
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<td>43</td>
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<td>1.3</td>
<td>.199</td>
<td>44</td>
<td>37</td>
<td>43</td>
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The data was used to calculate the energy delivered to the culvert and the collector system efficiency. Plots of incident solar radiation, energy delivered, and system efficiency are shown in Figs. 8 to 10. From these plots it is noted that the maximum normal incident solar radiation is about 350 Btu/hr-ft², maximum energy gain by the four solar collectors is about 3,200 Btu/hr, or 940 watts and the maximum system efficiency is about 40%. At peak output, approximately 19 watts/ft of power is available to melt the ice in the culvert.

A breakdown of the 1982 component costs making up the system is given in Table 3.

TABLE 3
COMPONENT COSTS

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Cost</th>
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<tr>
<td>Photovoltaic Panel, Four Parabolic Collectors and D. C. Pump</td>
<td>$2,300</td>
</tr>
<tr>
<td>Panel Support System, Piping and Hoses</td>
<td>1,500</td>
</tr>
<tr>
<td>Miscellaneous Fittings, etc.</td>
<td>300</td>
</tr>
<tr>
<td>Antifreeze</td>
<td>100</td>
</tr>
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</table>

TOTAL $4,500
FIGURE 8
SOLAR RADIATION VERSUS
TIME OF DAY

APRIL 22, 1982

SOLAR RADIATION (BTU/HR-FT²) vs TIME (HOURS)
FIGURE 9
THERMAL ENERGY VERSUS
TIME OF DAY

APRIL 22, 1982

THERMAL ENERGY (BTU/HR)

TIME (HOURS)
FIGURE 10

EFFICIENCY VERSUS TIME OF DAY

APRIL 22, 1982

COLLECTOR EFFICIENCY (Q_{Delivered} / Q_{Incident})

TIME (HOURS)
SOLAR PANEL MEASUREMENTS

A series of measurements were undertaken to evaluate the capability of the solar electric panels to provide the necessary power to operate the circulating pumps. Each individual panel, 12 inches by 48 inches, has 33 individual silicon disk solar cells 4 inches in diameter connected in series to obtain the 15 v nominal output voltage. Figure 11 is a photograph illustrating the configuration of the solar electric panels.

Fig. 11 Individual solar electric panels.

Panels may be connected in series or parallel to obtain either higher voltage or higher current as the application may require.
Solar flux received at the surface of the earth may be measured in at least three commonly used unit systems. Examples of these three unit systems are: a) British thermal units per hour per square foot (BTU/hr-ft²); b) Langley per hour (L/hr) (1 Langley is one calorie per centimeter squared); or c) milliwatts per centimeter squared (mW/cm²). The solar constant or maximum solar flux available is 1353 Watt/m² or 135.3 mW/cm². The relation between the unit systems may be obtained from the equations 150 BTU/hr-ft² = 40 Langley/hr = 48 mW/cm². The solar flux measurement used in this section of the report is the unit mW/cm².

Two solar electric panels were tested. The voltage current characteristic curves were obtained for each individual panel at a given solar flux reading. Figure 12 shows these data for the example of 90 mW/cm² solar flux. Both panels are almost identical. Because at least two solar electric panels would be required to operate one of the pumps provided for testing it was decided that the characteristic curves of volt-amperes versus solar flux would obtained for the two panels connected in parallel.
FIGURE 12

VOLTAGE - CURRENT CURVES FOR THE INDIVIDUAL SOLAR PANELS AT A SOLAR FLUX OF 90 MILLIWATTS/cm²
Figure 13 shows the electrical circuit used to measure the volt-ampere characteristics as a function of solar flux for the two panels in parallel. The highest solar flux measured was 95 mW/cm² obtained on an exceptionally clear, warm day in July 1982. The different values of solar flux were obtained by observing the sky over a period of two weeks and taking data as different weather conditions changed the incoming solar flux values.

Figure 14 presents the voltage-current characteristic curves for eight different values of solar flux ranging in value from 5 mW/cm² to 95 mW/cm². These curves are typical of solar cell performance indicating the voltage is fairly constant for a given solar flux until the current limit is reached. At that point, the cells exhibit a near constant current characteristic. Solar cell
VOLTAGE - CURRENT CURVES FOR TWO SOLAR PANELS IN PARALLEL AS A FUNCTION OF THE SOLAR FLUX IN MILLIWATTS/cm² AT 64.9° N. LATITUDE

LOAD VOLTAGE, VOLTS

LOAD CURRENT IN AMPERES

95 mW/cm²

58

35

25

5

90

80

70
panels are most often used to charge batteries which in turn operate the associated equipment. The panels are connected to the batteries by means of a regulator control circuit. The solar panels are protected by a blocking diode to prevent battery voltage from causing any current through the solar cells. When the solar flux is sufficient to place the panel voltage above the battery voltage then charge may flow into the battery for storage. If the battery is fully charged, the solar panel regulator will bypass the solar panel output with a shunt current path back to the solar panel. As current is required to charge the batteries, the shunt current is reduced and a larger portion of the current flows through the batteries.

The maximum output power occurs at the knee of the characteristic curve before the current drops rapidly to zero. Figure 15 presents the maximum power output for the two panels in parallel as a function of solar flux input. This shows the linear power output with solar flux input to the panels. An input solar flux of 95 mW/cm² may provide a maximum power output at 4 amperes and 13.7 volts or 54.8 Watts. At other values of current or voltage with 95 mW/cm² solar flux, the power output will be less.

PUMP TEST

Two different pump designs were tested to determine the power required to maintain fluid flow for several different values of discharge pressure. The setup for these tests is shown in Fig. 16.
FIGURE 15

MAXIMUM POWER OUTPUT
FROM 2-PANELS AS A FUNCTION
OF SOLAR FLUX IN MILLIWATTS/CM²
Fig. 16 Experimental setup to determine the power to maintain fluid flow.

The two pumps were significantly different in their flow characteristics at different values of discharge pressure and the amount of electric motor power required to maintain that flow and pressure. For example, for Pump #1 (M-P 12300 pump and Universal Electric Motor) to maintain 3 gal/min flow with 5 psi pressure requires about 55 watts of power. This is shown in Fig. 17. However, Pump #2 (Energy Harvestor) only requires 25 watts to maintain 3 gal/min with a pressure of 5 psi. The power required of Pump #2 is shown in Fig. 18. Both pumps were designed to operate with a nominal 12 volt power supply system.

These curves of Figs. 17 and 18 do not tell the complete story relating these solar electric panels and the characteristic of these particular pumping units. The example of a flow of 3 gal/min and 5 psi pressure required 55 watts as stated but that
FIGURE 17
POWER INPUT REQUIRED AT THE SPECIFIED PRESSURE TO MAINTAIN FLUID FLOW

POWER INPUT, WATTS

FLUID FLOW IN GALLONS/MINUTE
FIGURE 18
POWER INPUT REQUIRED AT THE SPECIFIED PRESSURE TO MAINTAIN FLUID FLOW

PUMP #2

POWER INPUT TO PUMPS, WATTS

FLOW IN GALLONS/ MINUTE

7 psi

6 psi

5 psi

4 psi

3 psi
data did not delineate the further condition that the voltage was 16 volts and the current required was 3.5 amperes. The solar panel test data presented in Fig. 15 shows that at 16 volts the current available is never greater than 3.0 amperes. Pump #2 can be operated satisfactorily with 3 gal/min at 5 psi. Its power requirement is 25 watts with the further conditions that the current be 1.0 ampere and the voltage required was 15.5 volts. Any day when the solar flux is greater than 58 mW/cm² will provide the voltage, current and the power necessary to operate Pump #2 at this flow and pressure.

CONCLUSIONS

The northern environment leads to culverts becoming plugged with ice and the resulting creation of aufeis and/or flooding of roadway surfaces. DOT maintenance personnel spend many work days during the breakup season thawing ice clogged culverts to avoid roadway flooding. Therefore, the use of solar assisted culvert thawing devices has the potential to reduce maintenance costs associated with this problem.

Two types of systems have been designed, built and installed by Mechanical Engineering Department of the University of Alaska-Fairbanks. The first unit was a flat plate collector system with a photovoltaic panel powered pump installed at Grenac Creek on Farmers Loop Road north of Fairbanks. This spring, 1983, the system did thaw an annulus in the ice plugged culvert allowing run-off water to freely flow through the opening. The second unit, described in this report, was marginally successful the first year, 1982, of operation. However, a leak in the thaw pipe developed
during the past winter which rendered the system inoperable this spring.

The installed cost of the flat plate collector system exceeded the installed cost of the reflecting collector system by approximately $1,500. Redesigning the support structure for the flat plate collector system and eliminating the batteries and electronic motor controller would reduce the cost to about the equivalent of the reflecting collector system. Disregarding the vandalism consideration, it is believed that flat plate collectors will offer superior overall performance. The flat plate collector will yield higher efficiency at lower labor costs as the need for focusing is eliminated.

Recommendations concerning further development of this concept are:

1. Use of high density polyethylene piping to avoid system leaks and freeze-frost heave damage.

2. Use photovoltaic panels for direct power to pump motors to avoid batteries and electronic switching circuits.

3. Design permanent vandal proof installations that avoid annual labor cost associated with annual installation of the units.

4. Evaluate a thermosyphon concept which avoids the requirement for the D.C. pump.

5. Evaluate heating elements directly connected to photovoltaic panels for thawing culvert ice.

6. Evaluate heat pipe technology as a means of transporting heat energy to culvert ice without the use of the D.C. pump.
IMPLEMENTATION

Thawing of ice-plugged culverts using solar energy can be cost effective when used under the right conditions. Because these devices are dependent upon sunlight and require a modest first cost, it is recommended that solar culvert thawing devices be used only when the following conditions are met:

1. Electrical power is not readily available.
2. Ice buildup occurs during the spring months.
3. Repeated thawing of the culvert is required.
4. The horizon is sufficiently low to allow exposure to sunlight.
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