REPORT NO. CDH-DTP-R-81-13

GEOTHERMAL ENERGY FOR HIGHWAY SNOW AND ICE CONTROL

Denis E. Donnelly
Colorado Department of Highways
4201 East Arkansas Avenue
Denver, Colorado 80222

Summary Report
November 1981

Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No. CDH-DTP-R-81-13	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Geothermal Energy For Highway Snow And Ice Control	5. Report Date November 1981 6. Performing Organization Code
7. Author(s) Denis E. Donnelly	8. Performing Organization Report No. CDH-DTP-R-81-13
9. Performing Organization Name and Address Colorado Department of Highways 4201 East Arkansas Avenue Denver, Colorado 80222	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Colorado Department of Highways 4201 East Arkansas Avenue Denver, Colorado 80222	13. Type of Report and Period Covered Summary Report 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for Colorado Department of Highways in cooperation with the U. S. Department of Transportation, Federal Highway Administration

16. Abstract

The feasibility of using geothermal water to maintain ice and snow-free structures in the Glenwood Canyon area has been investigated. Structures incorporating this feature would be located in high hazard locations as a result of structure alignment, lack of exposure to sunlight, or a rapid change in environment (i.e. in and out of tunnels).

Two technical reports have been published on the subject. The first dealt with the environment and natural resources within the canyon as well as various deicing alternatives. The second publication provided a technical evaluation of a prototype bridge deck heating system. This report provides a brief overall description of the study as well as a non-technical summary of the two published reports.

17. Key Words geothermal, heat pipe, energy, bridge, cost	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 21	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

Page

English/Metric Conversions

1 inch = 2.54 cm
1 foot = 0.3048 m
1 gallon = 3.7854 l
1°F = 1.8°C + 32
watt = 3.4129 btu/hr

I. INTRODUCTION

The Colorado Department of Highways is currently studying the feasibility of incorporating geothermal heating systems for snow and ice control at especially hazardous locations on the proposed new Interstate Highway through the geothermally active Glenwood Canyon. Tunnel entrances, sections having steep grades or curves, and locations that are especially prone to icing are some of the critical locations where this type of heating system may prove to be cost-effective.

To demonstrate the feasibility of using this relatively new concept on a major highway facility, a three-phase study was initiated. Phase A was designed to provide background information on the state of the art of geothermal heating. Phase B involved exploration of the existing geology and geothermal activitity in Glenwood Canyon. Phase C consists of design, construction, and operation of a prototype structure using geothermal water.

An Interim Report, "Evaluation of Geothermal Energy For Heating Highway Structures" was published in May, 1980 documenting Phase A and B of the study. Phase C was performed as a joint effort between the Colorado Department of Highways and the University of Wyoming, Department of Mechanical Engineering. CDOH was primarily responsible for the design, construction, and maintenance of the prototype structure. The University of Wyoming was contracted to provide the data collection and analysis. A Final Report on the system performance was written by the University, "Data Collection And Analysis For Geothermal Research," and published in August, 1981.

This Executive Summary is designed to summarize the information contained in the two project reports and provide a brief overall description of the study.

II. GEOLOGY AND FEASIBILITY

Since the study area is endowed with considerable geothermal activity, a study to determine the feasibility of using this geothermal energy in the design and operation of the highway was undertaken. The known geothermal springs are mostly concentrated in the alluvial deposits near the river at either end of the canyon. Other warm water springs have been reported on both the north and the south canyon rims and several miles southwest and northwest of Glenwood Springs. Travertine deposits (the mineral precipitates around the perimiter of geothermal springs) have been found several feet thick in the Hanging Lake Canyon. Other travertine deposits have been measured to 40 feet thick indicating that the area has been geothermally active in the recent past. It appears to be well worth the investment to sink exploration wells near the center of the canyon to determine the geothermal gradient and possibly discover geothermal sources near the structures to be heated.

Reports published by the Colorado Geological Survey include data on known geothermal areas and information on the legal requirements which are necessary to obtain the use of geothermal energy. The data includes temperatures, flow rates, and a chemical analysis of each known spring or well. Data and other reports available for the area were used as a data base for field verification of site locations. Many of the assumptions for this study are based on this information.

According to the preliminary feasibility studies, there is sufficient geothermal energy in the known springs to heat the planned structures in Glenwood Canyon; however, most of the water would have to be captured and transported to the structure sites. Drilling of exploratory wells may reveal additional sources closer to the target structures.

Several engineering firms in the country are working to assist agencies, industries, and individuals in the development and use of geothermal energy as an alternative to fossil fuel. These firms are working in this field under an agreement with the U.S. Department of Energy. EG & G, Idaho, Inc. is responsible for assistance and promoting the use of geothermal energy in the Rocky Mountain Region, and they performed a preliminary feasibility-cost study on this project.

Information from their study provided valuable support for the feasibility of this concept as well as suggestions as to the type of system to be considered. It was learned that the University of Wyoming (UW) and the

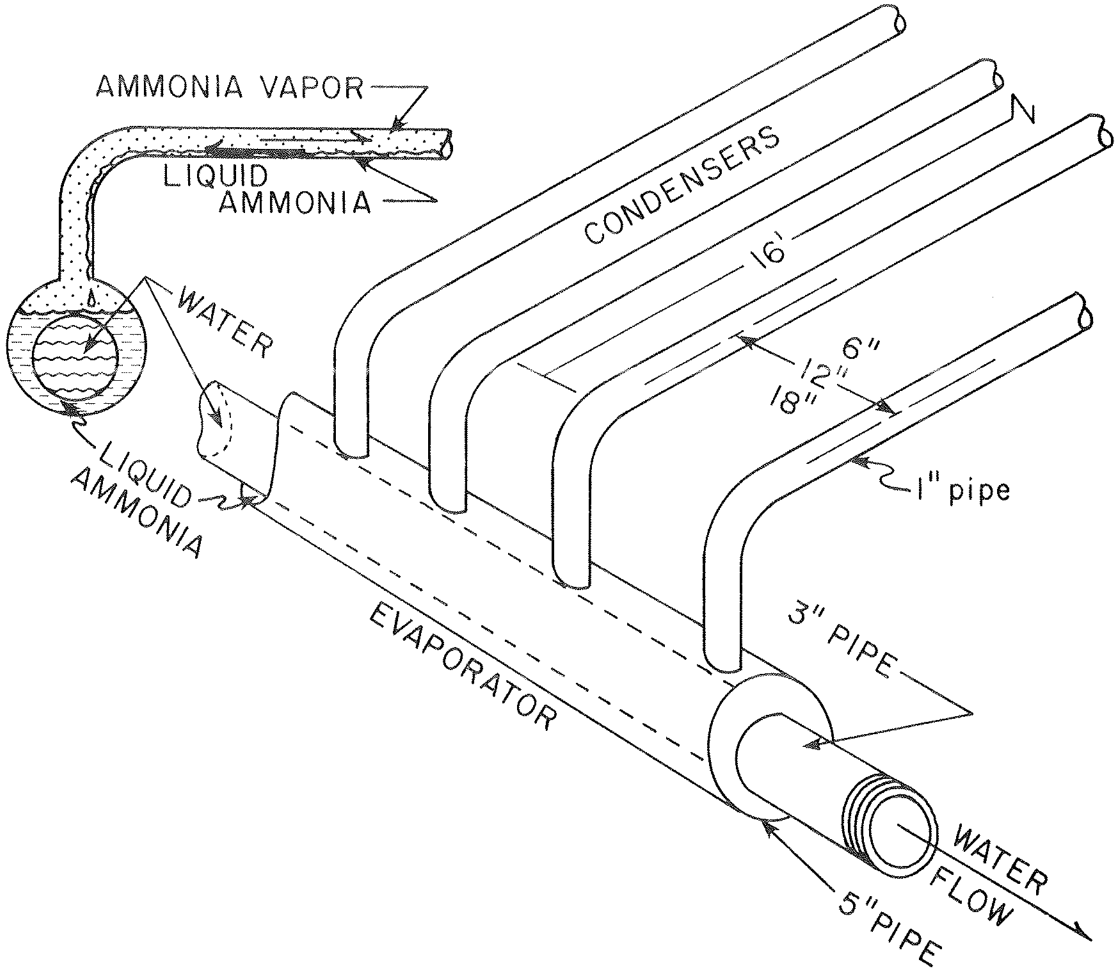
University of New Mexico (UNM) had been experimenting with and using heat pipes for some time. Preliminary design ideas and cost estimates from both universities encouraged CDOH researchers and the consultant in Idaho to combine geothermal and heat pipe technologies.

III. PROTOTYPE STRUCTURE DESIGN AND CONSTRUCTION

It was decided that a prototype bridge structure should be constructed in the Glenwood Springs Highway Department Maintenance Yard, making use of the warm water springs in the yard. The deck of this structure was heated by heat pipes supplied by both Energy Engineering Inc. (EEI) and SETA Corporation. Executives of these two companies are professors at UNM and UW respectively. Heat pipes are generally closed metal tubes which are thoroughly cleaned and evacuated. After evacuation the tubes are filled with a given quantity of working fluid (commonly ammonia) and shipped to the site. Typically, the pipes are attached to a heat source (in this case geothermally warm water) and bent to be embedded in the roadway.

The CDOH Bridge Design Branch drew plans for the construction of footings, end walls to support two 50-foot by 8-foot twin tees, and the concrete deck topping. This structure was designed to have a minimum of six feet of clearance so that air currents would not be obstructed. SETA Corporation of Wyoming and EEI of New Mexico prepared designs and cost estimates for constructing and delivering heat pipe systems to be used on the simulated bridge structure. The proposed 50 x 16 foot structure was divided into six 8 foot long sections to accommodate various spacing of heat pipes. SETA designed three heat pipe units of 8 x 16 feet. These units were designed to provide six, twelve, and eighteen inch spacing to experimentally determine the optimum design (See Figure 1). EEI designed two 8 x 16 foot heat pipe systems. The pipe spacing of these were six and eight inches (see Figure 2). Researchers designed the springs diversion system and the electrical and plumbing work for the geothermal fluid. The concrete twin-T deck was then overlayed with six inches of concrete encasing the reinforcing steel/heat pipe system.

A contract was awarded to begin construction in late January and continue through the first week of March, 1980.



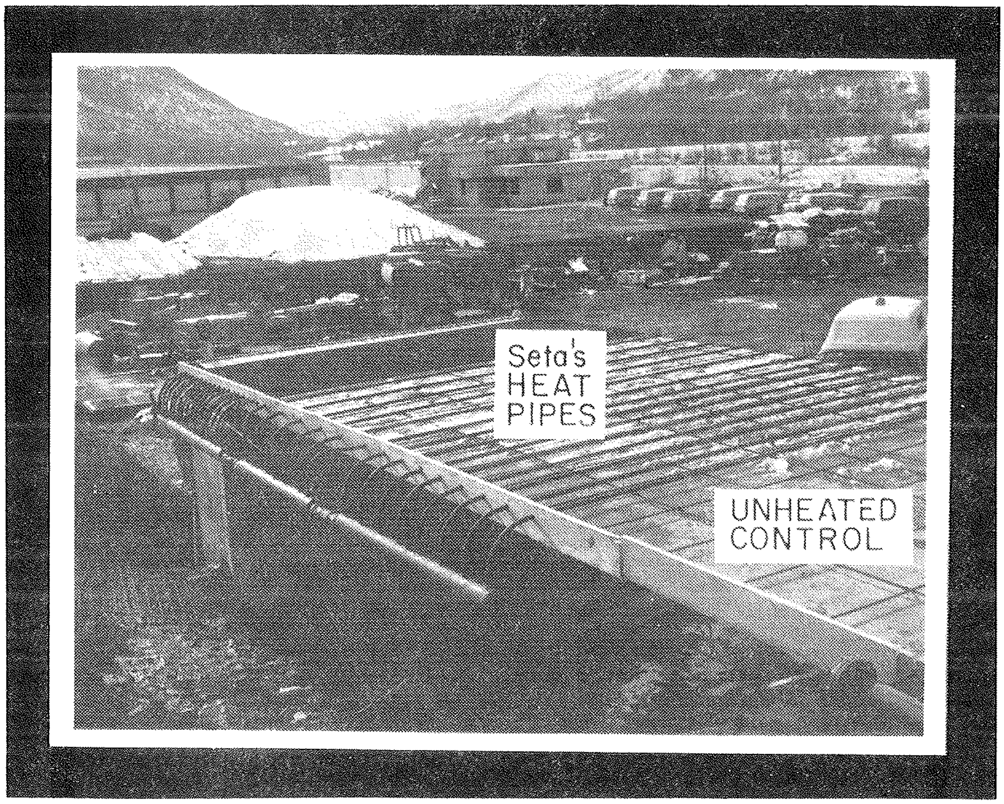


Figure 1. SETA's Heat Pipe Design for the Glenwood Springs Geothermally Heated Bridge

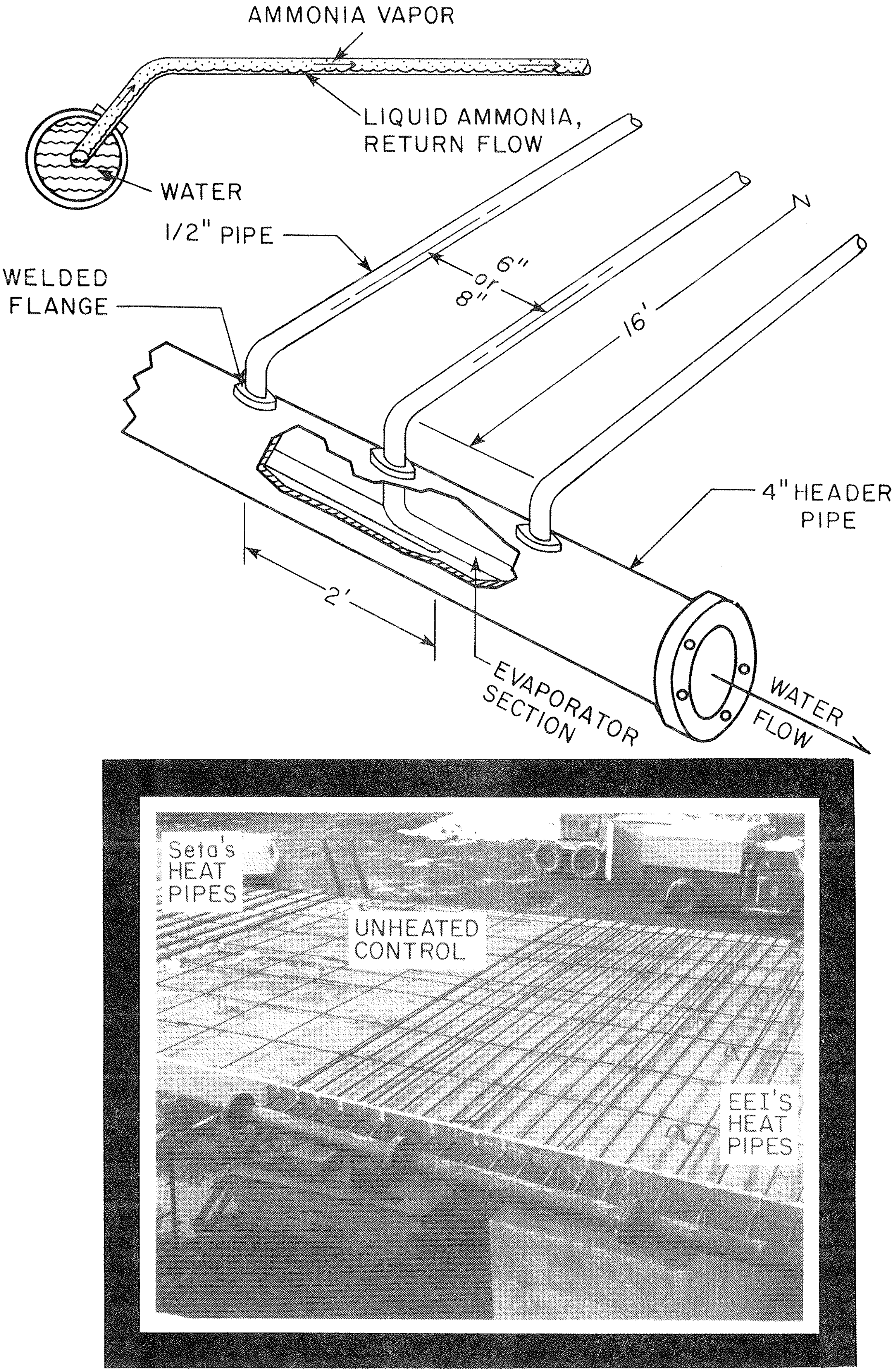


Figure 2. EEI's Heat Pipe Design for the Glenwood Springs Geothermally Heated Bridge

All instruments, recording devices, and time-lapse cameras were installed during construction. The data recorded includes wind speed and direction, barometric pressure, ambient temperature, relative humidity, solar radiation, and fluid and deck temperatures. Data was collected at each of the following locations in or on the deck: in the geothermal fluid within the headers, on heat pipes of each set of pipe spacings, at the deck midplane between heat pipes, at the deck surface in each section, at the bottom of the deck in each section, and in the standard section at equivalent locations to other sections. All of this data was assembled and analyzed with the aid of computers. Figure 3 contains a photograph taken from the time-lapse camera site of the overall structure site.

The heat pipe evaporators of all these units were of the fully flooded type with the evaporators placed lower than their respective condenser sections. Anytime the water flowing through one of these evaporators was warmer than the attached condensers which were embedded in the deck, energy was transferred from the geothermal water to the bridge deck. This energy was conducted through the walls of the evaporator pipe and vaporized a portion of the liquid ammonia in contact with the water pipe. The ammonia vapor then rose into the condenser fingers until it came in contact with the surface whose temperature was below its boiling point. It then condensed to give up the heat of vaporization to the bridge deck and the condensate returned to the evaporator under the influence of gravity to repeat the above process.

The boiling of the liquid and the condensing of the vapor provide the required pressure difference to force the vapor from the evaporator to the condenser. It is for this reason that these types of systems are called thermal syphons. The thermal conductance of these heat exchangers is large even though the energy may be transferred over a considerable distance; thus, the name "heat pipe."

The geothermal water that was pumped through the manifolds located along one edge of the deck was obtained from a dammed drainage ditch that ran through the Glenwood Springs Maintenance Yard. The water was drained just below the same dam after it had passed through the last heat exchanger. The flow rate was varied between 30 and 100 gallons per minute.

The most graphic comparison between the surface conditions and snow

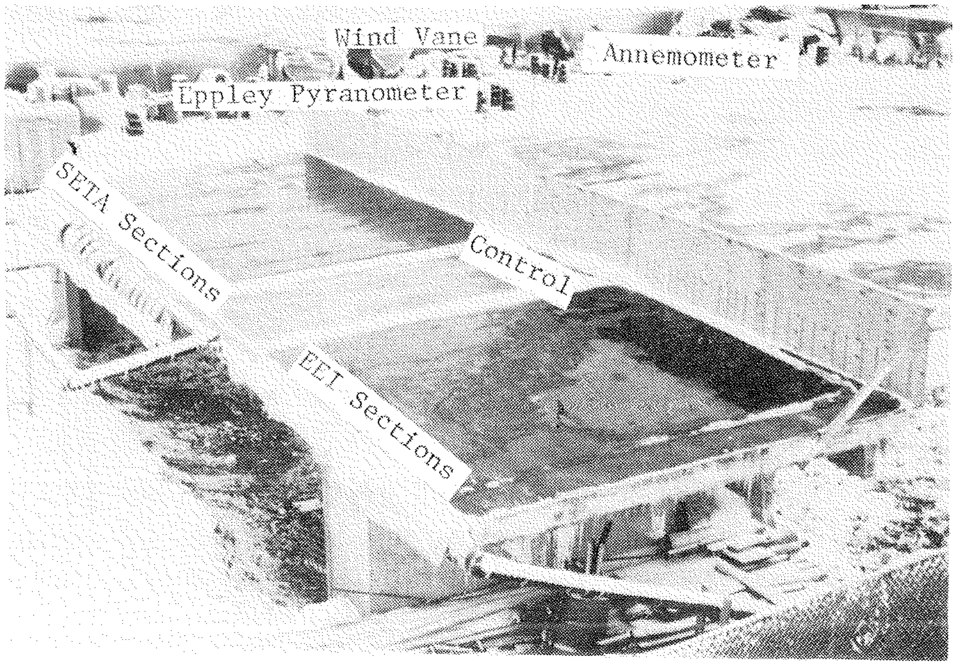


Figure 3 Typical Snow Event with an Ice Covered Control Section and Wet Heated Surfaces.

melting capabilties of the six different test sections was provided by the time-lapse camera which photographed the deck on a 24-hour basis at 10-minute intervals.

The system was activated on March 21, 1980, terminated for the summer on April 11, 1980, reactivated on September 19, 1980, and finally shut down on April 30, 1981.

IV. DATA ANALYSIS AND FINDINGS

The photographs indicate that the unheated control section was completely covered with snow or ice for approximately 545 hours and partly covered with snow for an additional 115 hours during the 1980-81 winter. During these icy surface conditions the heated section of the bridge deck was icy only 3 percent of the time.

A major storm resulted in snow cover remaining on the control surface for a total of thirteen days. This was primarily because the air temperature remained fairly low - dropping to 0^0 F, which was the coldest temperature recorded during the experiment and caused all the deck sections to freeze. The amount of precipitation was not recorded, but it appears to have been substantial since all the test sections except the EEI 6" section had some snow accumulation over several hours. The data clearly indicates an extended period of melting snow recorded surface temperature near 33^0F over all the heated sections.

Figure 4 contains the photograph and a plot of the data recorded during this snow storm. The first photograph on this figure shows the onset of the storm when snow began to accumulate on the control section. In the second photograph, all but the EEI 6" section was partly snow covered. In the third photograph the control was noted as snow covered, SETA 18" was partly snow covered, and the other sections were noted as clear.

It should also be noted that the control surface temperature, when it was not snow covered, appears to have dipped below the dew point on possibly fourteen occasions due to the locally high relative humidity. It would imply

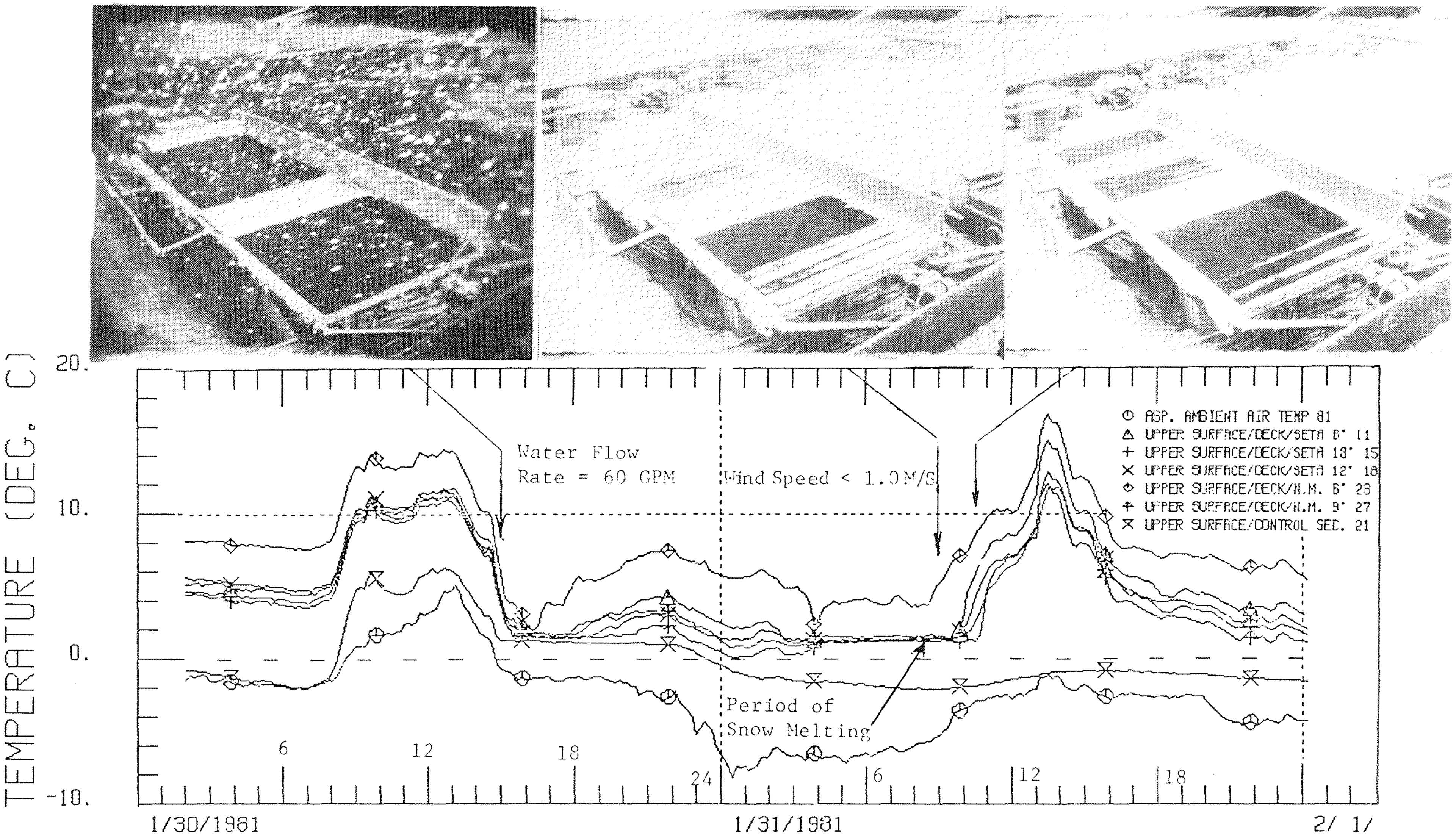


Figure 4 Upper Surface Temperature at the Onset of the Second Major Snowstorm

that the control surface temperature was below the dew point temperature for a total time of 65 hours. One of these events should have produced a "black ice" condition since the recorded surface temperature fell below both the freezing point and the dew point. The resolution of the photographs from the time-lapse camera did not permit confirmation of this possibility.

The measured inlet geothermal water temperature varied between 75 and 85^{0}F during this experiment. Presumably a flow rate of 50 GPM would be adequate to support a fairly large number of these units in series since the five experimental units did not cause any measurable drop in the water temperature.

A review of this data for the colder weather conditions show that the weekly average temperature increase on the heated surfaces was between 5 and 11^{0}F when the average air temperature was 40^{0}F and rose to between 7^{0} and 18^{0}F when the air temperature was near the freezing point. The hierarchy of the various heat pipe systems in terms of the observed surface temperature increases was generally:

EEI 6" $>$ SETA 6" $\geq$ SETA 12" $>$ SETA 18" $\sim$ EEI 8".

The data base implies that the unheated control surface was frozen 22% of the time but this frozen time was reduced by 85 to 99% by the heat pipes. The heat pipe system reduced the degree-days below freezing by 93 to 99% and the number of surface freeze-thaw cycles by 66 to 95%.

The system was disassembled on June 24, 1980 for examination. There appeared to be a very minor sludge deposit which could be easily removed inside the PVC pipes. Deposits observed in the metal water pipes shows a 1/4" thick deposit that had formed in the SETA 6" water pipe over a three month period. This sludge layer caused a 30% blockage to the flow and interposed a high resistance to the heat transfer. A dense rust layer was bounded to the pipe surface and separated the pipe from a water saturated sludge layer which could be easily removed by mechanical means.

A chemical analysis of the sludge layer above the dense rust layer shows that this layer also had a very high iron oxide content (65%). The bright red color of the scale made this finding fairly obvious.

One method used to size the required heating system is to calculate the power spectrum and total energy required. The results of this analysis for part of a single year indicates that a system supplying 9.3 watts per square foot (w/ft^2) would have handled 82% of all the events requiring power to hold the surface at 33^0F under dry conditions while only 2% of all the events required more than 18.6 w/ft^2. The total specific energy consumption of a system that was capable of handling all the events over the 1980-81 winter would have been at least 17 kwh/ft^2.

In order to keep the surface at 33^0F under wet conditions a 9.3 w/ft^2 system should have been capable of handling 72% of the recorded events with snow while 18.6 w/ft^2 would have managed 91% of the precipitation events. The most demanding event in the recorded data base occurred on December 7, 1980 when it is estimated that around 102.2 w/ft^2 would have been required to melt the snow and bring the surface to 33^0F.

Obviously it is not physically or economically practical to design a heating system capable of handling all the events. The design goal for some actual heating systems is limited to just preventing preferential freezing or to just keeping a surface clear during moderate storms and allowing it to become slushy to snow-packed during the heavy to severe storms. Traffic or limited snowplow activity would then aid the removal process. The required power spectra obtained from the above models for a given environment coupled with the observed performance of actual systems in known environments would aid the designer in sizing an "under designed" heating system. The results of the models should therefore be used more as a qualitative tool giving an upper limit than a precise quantitative tool.

The major resistances to heat transfer in the order of importance are (1) from the fouling, (2) in the concrete, (3) in the evaporator, and (4) in the convective heat transfer from the water. The fouling resistance is an order of magnitude greater than any other resistance and mitigating this problem should be the first priority.

The large thermal resistance through the concrete can be decreased by increasing the thermal conductivity of the concrete. There are several possible ways of doing this but the simplest is just the careful selection of the concrete aggregate to insure that it has a high thermal conductivity. Decreasing the concrete cover above the condenser pipes will also increase the conductance significantly where the condenser pipes are epoxy coated to protect them from corrosion. A concrete cover of this magnitude would have resulted in approximately a 17% increase in conductance by itself. Minimum depth of cover will depend on design and standard specification requirements, however.

The use of 1/2" condenser pipes would significantly reduce their cost but would only decrease their performance by 9%. A design incorporating these 1/2" condenser pipes, a concrete with a 0.352 w/ft^{o}F thermal conductivity, and 1-1/2" cover above the condensers would result in 16% increase in specific conductance over the Glenwood Springs' reference case.

Due to water's large heat capacity, a substantial number of heat exchangers can be connected in series without a significant decrease in the power that the latter units deliver. The analysis assumes that the surface temperature is constant for all the modules which would essentially be the case during snow melting events. The data indicates that 200 of these heat exchangers with a 100 GPM flow rate could be attached in series with a 50% degradation in the performance of the last module relative to the first.

All of the analyses assume that the bottom surface of the heated deck was insulated. It has been estimated that the energy loss through the uninsulated bottom of a heated deck would be of the order of 25% or greater while the loss is only around 3% if insulated with 4" of a styrofoam type insulator.

A major consideration for those planning to use a heating system is cost. Following completion of the study, the SETA Corporation was asked to provide a cost estimate for various heat pipe designs. The Appendix contains the response with cost estimates for various treatment areas, heat pipe spacings and terrain using power requirements developed in this study. Costs vary from

$6.75 per square foot for a large area to be treated to approximately $14 per square foot for small sections with high power requirements. These costs reflect fabricated heat pipe systems delivered to the Glenwood site. General features of design common to the estimate are also included in the Appendix.

VI. CONCLUSIONS

The conclusions that can be made from the experimental results are as follows:

1. All of the heat pipe modules reduced the time that their respective surfaces were snow covered by at least 96%. This was accomplished using 77°F water at 35 GPM. It should be noted the 1980-81 winter was relatively mild. The total time that surfaces of the individual heated sections were frozen was reduced between 85 to 95% relative to the unheated control and the number of freeze-thaw cycles experienced by the heated sections was correspondingly cut by 66 to 95%.

2. The units with 6" condenser spacings appear to be able to obtain average surface temperature increases of the order of 16°F during the mid-winter months. The data analysis indicates that the 18" module should have produced a surface temperature increase greater than the 11°F average that was observed during its mid-winter operation. This temperature increase can be expected if no fouling takes place in the geothermal water pipes; however, fouling apparently prevented this unit from ever experimentally demonstrating this.

3. The unfouled 6" modules can be expected to provide surface temperature increases of the order of 0.4 times the temperature difference between the water and the unheated surface temperature while this temperature difference ratio should be around 0.3 for the unfouled 18" module.

4. Fouling and corrosion on the metal surfaces exposed to the geothermal water proved to be extreme. The fouling caused about a $5^{\circ}F$ average drop in its mid-winter surface temperatures and the corresponding temperature difference ratio dropped from 0.4 to approximately 0.25. Even with performance drops of this order all the units, including the 18" condenser spacing, were capable of handling the environment.

The overall performance of the manifolds with 18" condenser element spacing indicates that they would be suitable for heating applications in the Glenwood area except that these modules left sizable ribbons of unmelted snow between the condenser elements during the initial phase of some snow events. Under normal traffic conditions, much of this ribbing would be broken up and mixed by the vehicles and it would probably not cause any major problems.

The use of ammonia may be questioned, but its excellent thermal properties (in particular its large latent heat of vaporization) and low cost make it a superior working fluid in applications where it's toxicity is of little consequence. For these reasons it is currently the most important industrial refrigerant.

In summary, the water heat pipe system using ammonia as the working medium appears to have a tremendous potential in this application if the fouling-corrosion problem is solved. Its heat transfer capabilities coupled with its simplicity, reliability, and flexibility to meet local demands by varying the condenser spacing, condenser depth and/or the flow rate make it very attractive. An economy of quantity should be realized if a simple standard design could be accepted. Substantial improvements in the modules' performance are still possible with a negligible economic penalty.

VIII. IMPLEMENTATION

The fouling and corrosion must obviously be curtailed if this heat pipe system is to be viable. Since fouling did not occur to any significant extent in the PVC service lines, there is a good possibility that this problem can be solved with the use of a protective and durable coating or liner. This subject has been presented to the CDOH Research Council and has been recommended for further study.

The effect that variations in the water temperature and/or environment has on the expected temperature increase of the heated surfaces can be scaled through the use of the coefficient of performance. An increase between 3 and 5^{o}F is estimated to occur for a 45^{o}F water temperature (typical of ground waters). Similarly a 1^{o}F increase should occur for water temperatures of the order of 35^{o}F which are typical of flowing rivers in the winter. This preempts the investigation and feasibility studies for incorporating geothermal heat on a project by project basis.

As designs for tunnels, ramps and hazardous roadway conditions within Glenwood Canyon are developed the cost effectiveness and benefits of geothermal heat should be investigated. The information developed from this study should provide the tools to use in this investigation. Final implementation, as appropriate, will be made at that time.

REFERENCES

1. Nydahl, J., Pell, K., et al., "Data Collection And Analysis For Geothermal Research," Report No. CDH-UW-R-81-11.

2. Swanson, H., "Evaluation of Geothermal Energy for Heating Highway Structures," Report No. CDOH-DTP-R-80-6.

APPENDIX

SETA CORPORATION

P.O. Box 4057
Laramie, Wyoming 82071
Phone: 307/742-6563

Kynric M. Pell, Ph.D., P. E.
President

John Nydahl, Ph.D.
Vice President

September 28, 1981

Mr. Harvey R. Atchison, Director
Department of Transportation Planning
Colorado Department of Highways
4201 East Arkansas Avenue
Denver, Colorado 802222

Dear Mr. Atchison:

We are pleased to have the opportunity to provide cost estimates for a manifolded heat pipe system. In order to cover a number of possible applications I will quote a variety of combinations as presented on the enclosed sheets. It should be noted that the coefficient of performance (0.4) mentioned in your letter of September 15, 1981 was the highest observed for the 6" spaced manifolds and is in addition not theoretically possible even with an idealized, "perfect", evaporator for 18" spaced condenser elements. In view of this I have provided quotes for 12" and 18" condenser spacings which can be expected to provide coefficients of performance between 0.2 and 0.3 depending on the number of units placed in series.

The quotes provided for 1/4 mile may be used for any lesser quantity in which case we will absorb the major portion of the capital cost of the equipment required to start up the production facility.

For quantities involved between 1/4 mile and 1 mile some automated equipment would be installed and a firm quote would depend on the quantity involved. For quantities involved beyond 2 miles an asymptotic limit for the 18" spacing, single header, of approximately $6.75/square foot is approached. The enclosed graph may be of some use in projecting costs.

I trust that the material provided is in a useful form, however; if additional information is required, please do not hesitate to call us.

Sincerely,

Kynric M. Pell, President

SETA CORPORATION

Enclosures:

KMP/abp

Plant and Offices: Soldier Springs Road, 2-1/2 Miles South of Laramie

General Features of Design Common to Each Estimate

1. External epoxy coating (DOT Approved) of steel components which are to be placed in the slab. (Condensers)
2. Expansion joints which also have lateral flexibility to allow for manufacturing tolerance of the concrete sections at each manifold interface.
3. A "Y" section (capped) on 100 foot intervals in the header for cleaning of the primary flow circuit.
4. Interior surface coating of the primary flow header. The estimates assume an epoxy coating at a price of $1.50/linear foot. Tests to be conducted may indicate an alternate coating, however; any cost differential should not be large.
5. Use of 150 pound slip on, raised face flanges at the header interfaces.
6. Use of 1/2" Ø (Seamless) Grade B steel for condenser fingers.
7. Use of 3" Ø (ERW) Grade B steel for header
8. Use of 5" Ø (Seamless) Grade B steel for manifold.
9. Price includes gaskets and bolts for field connection of the manifolds.
10. Estimate includes delivery of fabricated manifolds to a site within 30 miles of Glenwood Springs, Colorado.
11. The estimate includes labor to connect up the manifolds after placement, but not the labor required to set the manifold in place in the slab prior to pour.
12. Plumbing, pumping and related costs associated with providing and exhausting water for the manifolds is not included.
13. A field service nipple for possible recharge of the manifold with ammonia is provided.
14. Insulation of exposed portions of the manifolds is not included in the estimate. SETA is working on a novel insulation technique which should be very cost effective, however; we are not in a position to provide an estimate at this time.
15. This estimate was made September 28, 1981 in terms of entering into an agreement within 90 days of that date. No inflationary considerations are included.

Cost Estimates for Manifolded Heat Pipe Systems

Cost estimate for 1 mile (5280 feet) of 40 foot wide pavement assuming a superelevated road requiring a single header:

Assuming 18" condenser spacing	$7.61/square foot
Assuming 12" condenser spacing	$8.35/square foot

Cost estimate for 1 mile (5280 feet) of 40 foot wide pavement assuming a flat road requiring two headers:

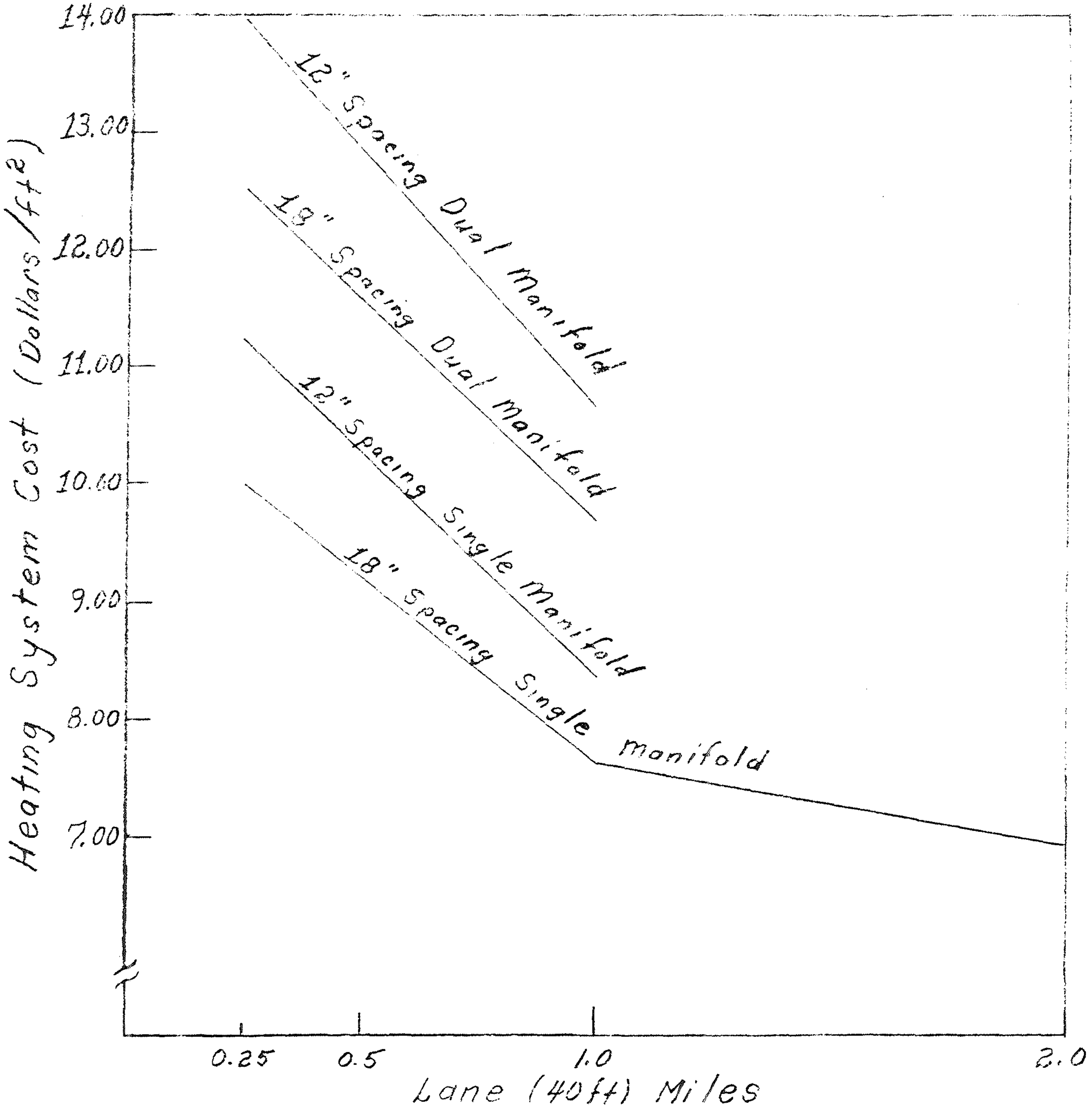
Assuming 18" condenser spacing	$9.68/square foot
Assuming 12" condenser spacing	$10.65/square foot

Cost estimate for 1/4 mile (1320 feet) of 40 foot wide pavement assuming a superelevated road requiring a single header:

Assuming 18" condenser spacing	$10.00/square foot
Assuming 12" condenser spacing	$11.21/square foot

Cost estimate for 1/4 mile (1320 feet) of 40 foot wide pavement assuming a flat road requiring two headers:

Assuming 18" condenser spacing	$12.52/square foot
Assuming 12" condenser spacing	$13.99/square foot


Heating System Cost (Dollars/ft²)
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
12" Spacing Dual Manifold
18" Spacing Dual Manifold
12" Spacing Single Manifold
18" Spacing Single manifold
0.25
0.5
1.0
2.0
Lane (40ft) Miles

9/28/81
KMP.