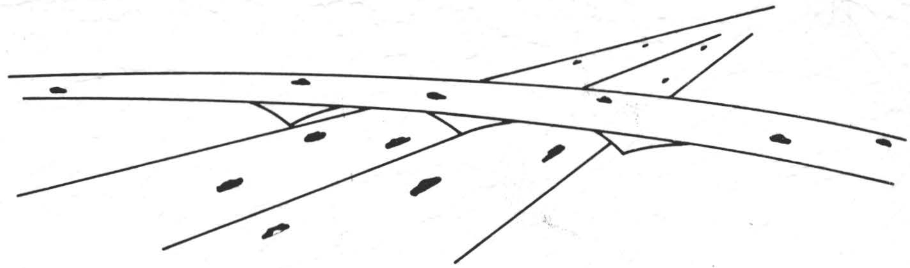


DEPARTMENTAL RESEARCH

Report Number 229-2F

USING SOLAR HEATING WITH ASPHALT STORAGE LUBBOCK, TEXAS

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-82/32+229-2F		

4. Title and Subtitle Using Solar Heating With Asphalt Storage-Lubbock, Texas	5. Report Date October, 1981 6. Performing Organization Code
7. Author(s) Kenneth D. Hankins	8. Performing Organization Report No. 229-2F
9. Performing Organization Name and Address Texas State Department of Highways and Pulbic Transportation Box 5051 Austin, Texas 78763	10. Work Unit No. 11. Contract or Grant No. 1-10-78-229
12. Sponsoring Agency Name and Address Same as 9.	13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

Study title: "Asphalt Tank with Solar Heating"
Work done in cooperation with DOT, FHWA.

16. Abstract

This is the final report of a project which used solar energy to heat a 12,000-gallon asphalt storage tank. A water heater was used as an auxiliary system. The report contains a history of the maintenance, performance, and costs. The asphalt heated was a rapid-cure cutback. (RC-2).

17. Key Words	18. Distribution Statement
Solar Heating Insolation Asphalt Stroage Tank Solar Collectors	No restrictions Report available from the National Technical Information Service, Springfield, VA. 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	31	

Form DOT F 1700.7 (8-69)

USING SOLAR HEATING WITH ASPHALT STORAGE - LUBBOCK, TEXAS

by

Kenneth D. Hankins

Research Report 229-2F

Research Study 1-10-78-229

Asphalt Tank With Solar Heating

Conducted by

Transportation Planning Division
Research Section
State Department of Highways
and Public Transportation

In Cooperation With The

U.S. Department of Transportation
Federal Highway Administration

October 1981

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

The United States Government and the State Department of Highways and Public Transportation do not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

Acknowledgements

The research reported herein was conducted under the supervision of Mr. John F. Nixon, Engineer of Research, and the general supervision of Mr. Phillip L. Wilson, State Transportation Planning Engineer.

Acknowledgement is given to:

Mr. Brad Hubbard, Mr. C. L. Goss, Mr. B. D. Cannaday, Mr. George Reid, Mr. David Edwards, Mr. Johnny Brauer, Mr. Doug Chalman, Mr. Randy Beck, and Mr. James Wyatt for the technical support received during this study.

Mr. Dwight Hixon and the research personnel in Oklahoma D.O.T. for the many aids which were offered in a helpful and cooperative spirit.

Mr. George C. Wall, Jr., District Engineer, Mr. James W. King, District Administrative Engineer and District 5 shop personnel for the interest and aid received in the development of this project and report. Large parts of the plans and specifications were prepared by District 5 personnel in Lubbock.

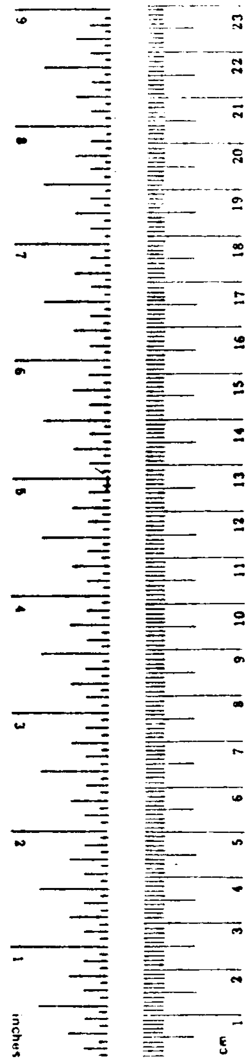
Mr. Edward Kristaponis, FHWA, for the interest and help received in design, construction, and the performance study throughout the project.

Mr. Charlie Johnson (retired), personnel of the Northeast Maintenance Section in Lubbock and particularly Mr. Marvin Anderson who collected data, performed the various debugging and maintenance operations on the system and, in general, watched the system during this project.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

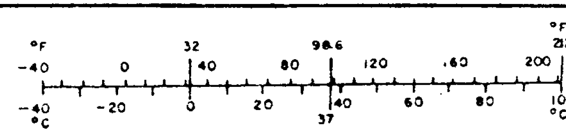


TABLE OF CONTENTS

Disclaimer. iii
Acknowledgements. iv
Metric Conversion Table v
List of Figures vii
List of Tables. viii
Implementation. ix

I. Background. 1
   Object 1
   Research Report 229-1. 1

II. A Two-Year History and Maintenance of the System. 4

III. Performance of the System 9

IV. The Pay-Off Period. 18

V. Summary and Conclusions 20

References. 21

Appendix A - Diary of System Maintenance and Associated Costs 22

Appendix B - Daily Performance Summary. 28

Appendix C - Monthly Performance Summary. 30

LIST OF FIGURES

1. Comparison of Flow and Energy as Obtained From a Btu Meter. 12

2. Comparison of Calculated Energy and Metered Flow From the Btu Meter 13

3. Comparison of Calculated Energy Input and Metered Energy 14

LIST OF TABLES

I. Flow Rate Studies 6

II. Lubbock Solar Heated Asphalt Tank 1980-1981 Summary 16

III. Study of Pay-Off Period 19

IMPLEMENTATION

The implementation of this report is inherent in that a solar-heated asphalt tank has been installed.

Experimentation with solar heating systems reveals this method of heating is viable and believed to be cost-effective. Only two years experience has been gained at this date, but it would appear the systems will operate for 20 or more years without major maintenance if constructed well. Experience to date would indicate that well-designed, efficient, flat-plate collectors should be used for cutback and emulsion asphalts. Insulation should be slightly over-designed with special attention given to exposed tubing.

Implementation should include installation of additional units as time and funding become available.

USING SOLAR HEATING WITH ASPHALT STORAGE
LUBBOCK, TEXAS

I. Background

The depletion and associated rising costs of fossil fuels have caused the United States to accelerate a program of using so-called renewable energy sources. With this in mind, the Texas State Department of Highways and Public Transportation and the Federal Highway Administration developed a research project to study the use of solar energy in heating asphalt in a stationary storage tank. The Department and local FHWA desired to become more knowledgeable in the use of solar energy with possible future application in some of the other approximately 400 tanks in the state, and use in other applications should restrictions on fossil fuel use develop.

Object

The purpose of this report is to provide the performance history and associated costs of the solar-heated asphalt storage tank. A previous report revealed the design, initial cost, plans and specifications of the system. A summary of the initial report follows.

Research Report 229-1 "Solar Heating An Asphalt Storage Tank"

Research Report 229-1 presented the design, construction specifications, fabrication, history, system components and initial costs of the solar and auxiliary system. The design of the system was performed by Mr. Stan Bond under the direction of Dr. Jerald Jones with the Mechanical Engineering Department of the University of Texas, Austin. Final recommendations were for 216 square feet of collector surface or six panels of a KTA collector. It was desired to maintain the cut-back asphalt at a temperature between 140°F and 180°F. After considerable equipment search, a 100,000-BTU, gas-fired water heater was selected as the auxiliary or backup heating system. A 1/4-horsepower pump was used to circulate a 50:50 water-antifreeze heat transfer solution. The heat transfer solution entered the collector system at one end and exited at the other, using the headers to the collectors to balance (give equal distribution to) the flow through the collectors. Some 200 lineal feet of 3/4-inch copper tubing was selected as a heat exchanger in the tank based on observations of existing systems.

The central control was similar to that used in commercial solar systems for residential water heating. The controller required a 9°F differential between the asphalt temperature and the collector temperature. This 9°F differential caused activation of the circulator which pumps fluid through the solar system. When the differential was lowered at 3°F (say in the evening) the system was shut down. Override controls were installed which permitted the auxiliary to be activated when the tank temperature was lowered to 140°F. The override controls also shut the entire system down when a 180°F asphalt temperature was achieved. The controls were so arranged that when the asphalt temperature was reduced to 140°F the auxiliary would start and not stop until 180°F was achieved. However, when a 9°F solar differential was available, the solar system would override the auxiliary system. The auxiliary would shut down during the solar hours but would again be initiated when the solar was shut down (differential reduced to 3°F). When the asphalt temperature increased to 180°F, the auxiliary system would be shut down and not initiated until the asphalt temperatuare dropped to 140°F. During this 180°F to 140°F period, solar energy was used if available.

The instrumentation consisted of continuous temperature measurements of the heat transfer fluid going into, and coming out of, the collectors. Continuous measurements were also obtained on tank and air temperatures along with insolation values using a pyranometer. The continuous measurements were collected on small, low-price, strip-chart recorders. Thermometers were used as backup and to check instrumentation on the asphalt, air, and input collector temperatures. Later in the project, a Btu-meter was installed which had a direct, odometer-type readout of Btu input into the asphalt as well as the total heat transfer fluid flow (gallons). Flow rates could be determined by obtaining readings of total heat transfer fluid flow at different times and dividing the flow quantity by time.

Report 229-1 contained plans and specifications for the complete system. The system included a new tank, cradle, tank foundation, collectors, instrumentation and instrumentation housing. A contract was prepared, advertized widely, and let with only one bidder responding at about 10 percent over estimated cost. The contract was awarded to this bidder for $24,650. The contractor began construction in early fall and completed the system in late spring of 1978-79. The cost of the solar components were estimated at about $10,000. Two inches of polyurethane foam insulation, with weatherproofing, were required, and the contractor indicated this cost was $1,800.

II. A Two-Year History and Maintenance of the System

Operation of the system began in May, 1979, and a diary of the maintenance performed may be found in Appendix A. Most of the system maintenance during 1979 was confined to cleaning the strainer which had been installed in the heat transfer fluid (water-antifreeze) tubing. The strainer would become clogged causing the fluid to flow very slowly. When the auxiliary heater was activated, the fluid would boil and blow out of the vent. At times, this action would cause considerable loss of fluid. This occurrence was finally associated with the auxiliary activation and it is believed the auxiliary would cause a scale or semi-solid particle to form in the fluid because of high temperatures. In January, 1980, the gas-fired auxiliary heater was found to have a warped intake manifold and to be leaking fluid. The gas-fired auxiliary was removed and replaced with a household-type electric water heater with a forty-gallon capacity. After this installation, very little "scale" was found and the strainer rarely needed cleaning. There was some concern because it was necessary to remove the gas-fired auxiliary. The gas-fired unit was selected because the cutback asphalt (RC-2) required relatively high temperatures (maintained between 140°F and 180°F).

During the design phase of this project, a household-type water heater could not be found which could produce temperatures much above 165°F. Therefore, a commercial water heater was selected. Since a commercial heater was necessary, it was decided to obtain a high-heat unit in order to input a relatively large amount of energy quickly and thus increase tank temperatures rapidly. The gas-fired unit specified could produce about 110,000 Btu per hour. As shown previously, this choice proved to be a poor design.

The auxiliary was designed to work in the same flow loop as the solar system. When in the same loop, the auxiliary system should have about the same heating capability as the solar system. The first unit selected did not meet this criteria and proved to be too powerful. However, the second (electric) unit has worked reasonably well in the flow loop. Asphalt tank temperatures between 170°F to 180°F can be achieved and maintained by using the electric heater with the solar and electric water heater auxiliary. However, during the initial stages of operation, rather low tank temperatures (130°F to 140°F) were found. This poor performance caused a re-evaluation of the design and construction of the system. FHWA, research, and District personnel met and decided on the following three revisions to the system to improve performance:

1. Heat Exchanger - Since little effort had been given to heat exchanger design, study and design of a heat exchanger for the system would be performed.
2. Pump - Input energy is a direct function of the flow rate of the heat transfer fluid. Therefore, the existing would be replaced with a unit which would increase the flow rate.
3. Tank Insulation - Some consideration was given to adding more collectors to increase the input energy. However, after evaluation it was decided the least costly method would be to reduce the energy loss by adding insulation to the tank (and a portion of the exposed tubing between collectors and tank).

A larger circulating pump (1/2 hp) was installed in January 1980. Some minor improvement in temperature was noted. However, theory and tests with this system indicate increases in flow rate do not increase energy input in a linear manner. Input energy tends to "tail off" with increased flow rates.

Table I shows the results of a study of the flow rate with the subject system. At very slow flow rates, high-output collector temperatures are found

TABLE I

FLOW RATE STUDIES

Tank Conditions
4,000 gallons RC-2
Tank temperature = 130°F

Collector Conditions
Collectors in parallel
Solar Noon 1:50 pm

TEMPERATURE (°F)					
COLLECTOR IN	COLLECTOR OUT	DIFF.	AIR	FLOW RATE (APPROX.)	APPROX. ENERGY INPUT Btu/hr
160	170	10	105	2.6 GPM	12,994
157	175	18	107	1.4 GPM	12,595
150	185	35	107	0.7 GPM	12,245
147	192	45	107	0.5 GPM	11,246
145	203	58	107	0.3 GPM	8,697

Energy Input = Specific Heat (Flow Rate) (Temp Differential) (Time) and large in-out differentials are noted, but because of the low flow rate, small amounts of energy are delivered to the asphalt.

A design of the heat exchanger indicated the heat exchanger size should be tripled. Originally, some 200 lineal feet of 3/4-inch copper tubing placed in the bottom of the tank was used as the heat exchanger. After considering several types of heat exchanger material, it was decided the lowest cost and most practical method of increasing the heat exchanger area would be to add similar material. Therefore, an additional 400 lineal feet of 3/4-inch copper tubing was installed in February 1980. The method was used to fabricate two additional tubing units and insert them in the tank after removing the end cover. (The tank was originally fabricated with a large, removable, bolt-on end cover.)

The new units were "stacked" or placed on top of the original, and each other, but separated by one-inch stand-offs. The units were connected to operate in a parallel-flow manner. Little observable increase in performance was noted. However, seasonal temperature changes were occurring during this period. Also, asphalt material use caused observations and energy calculations to be inaccurate.

A leak in the heat exchanger was found after two months of operation. The leak was repaired in May 1980.

An additional four inches of polyurethane foam was placed over the existing tank insulation in June 1980. The existing (originally placed) insulation was two inches of polyurethane foam with a 0.020-inch coating of butyl rubber as weatherproofing. No oil or asphalt existed on the surface but a little cleaning was performed on the existing weatherproofing before the second application. The additional foam went on well and to date has presented no maintenance problems. The additional foam was weatherproofed with synthetic rubber also at about a 0.020-inch thickness. Immediate improvement in tank temperatures was noted. Within ten days of the additional foam application the asphalt temperature had increased to 180°F, and the heating system had shut down.

III. Performance of the System

Performance information was collected on strip chart recorders and by daily observation by District 5 personnel. The daily observation included tank and air temperatures measured from mercury thermometers, asphalt usage, tank quantities, electric meter readings, weather information, and comments concerning equipment maintenance. Data were extracted from the strip charts at hourly intervals. Theoretical solar and auxiliary input energies were calculated along with energy loss. From these calculations a daily performance summary was prepared similar to that shown in Appendix B. The daily performance summaries were then used to construct monthly summaries similar to that shown in Appendix C.

The following methods were used to calculate energy:

1. Input Auxiliary Energy - developed from voltage and amperage measurements at the electric heater element.

2. Input Solar Energy - derived using the following equation:

$$Q_{SI} = S_h F (T_{in} - T_{out}) t$$

where:

Q_{SI} = Solar Input Energy (Btu)

S_h = Specific Heat of the 50/50 water antifreeze solution (0.78 Btu/16^oF)

F = Flow rate (16/hr)

T_{in} = Temperature of the water-antifreeze solution leaving the collectors (^oF)

T_{out} = Temperature of the water-antifreeze solution entering the collectors (^oF)

3. Energy Lost - energy lost from the system was calculated based on the energy lost from the tank and the energy lost from the external tubing or $Q_L = Q_{LTA} + Q_{LTU}$

$Q_{LTA} = UA\ (T_t - T_a)$

where:

Q_{LTA} = Energy loss from the tank (Btu)

U = Insulation Factor (Btu/hr ft^2 ^oF)

A = Surface area of the tank (ft^2)

T_t = Temperature of the asphalt in the tank (^oF)

t_a = Ambient or air temperature

$Q_{LTU} = U_r\ A_t\ (T_u - T_a)$

where:

Q_{LTU} = Energy loss from the external tubing (Btu)

U_r = Tubing insulation factor (Btu/hr ft^2 ^oF)

A_t = Surface area of the tubing insulation (ft^2)

T_u = Temperature of the water-antifreeze solution in the tubing.

A pyranometer was installed to determine the energy available to 215 square feet of the collector system. The pyranometer was placed at the same tilt as the collector to reduce the calculation effort. Pyranometer calibration values were provided by the fabricator of the equipment. Use of these calibration values resulted in a direct calculation of solar energy in Btu's. This value is somewhat similar to insolation values reported by weather stations.

Analysis of these data indicated the instrumentation selected for data collection was inadequate. For example, the chart reading error in the differential between collector (or heat exchanger) in-out temperatures was found to result in errors of 20 to 30 percent.

In an effort to speed data collection and obtain accurate data, a "Btu Meter" was purchased and installed in the system in January 1980. The instrument operated on the same principle as the prior equations; that is, the instrumentation measured an entering and exit temperature differential along with a fluid flow. Internal electronic processing converted this information to energy values. These energy values were displayed on an odometer-type counter in terms of Btu (assuming the liquid to be water). A display also revealed cumulative liquid flow (in gallons).

Repair of the meter was necessary in March 1981, however, the operation prior to repair included the period when asphalt had leaked into the water-antifreeze solution. Comparisons of flow and energy as measured from the instrument seemed to indicate a discrepancy in results. This comparison may be found in Figure 1. Figures 2 and 3 are comparisons of flow or energy and theoretical energy calculations. Flow seems to have a reasonable relationship with calculated values but the instrument's Btu value appeared to be erratic.

Therefore, much of the instrumentation produced data which was considered untrustworthy. However, tank and ambient temperatures were considered valid because of the cross check with the mercury thermometers. Also, the watt meter produced an acceptable measure of the auxiliary input energy. Therefore, an analysis procedure may be used as follows:

1. Use the watt meter to estimate input energy.
2. Use the tank and ambient temperature to calculate energy loss.
3. Disregard external input energy from the "hot" asphalt received from the incoming tanker. Note that during the first eleven months of 1980, little asphalt was received or used. After heat exchanger enlargement and repair, a full tank of asphalt was maintained for experimentation. During the spring and summer months of 1980, little asphalt was received or used and the tank was maintained about 3/4 full.
4. Disregard energy differentials due to changes in tank temperature. Once the additional insulation was added, little change in asphalt tank temperature was noted.

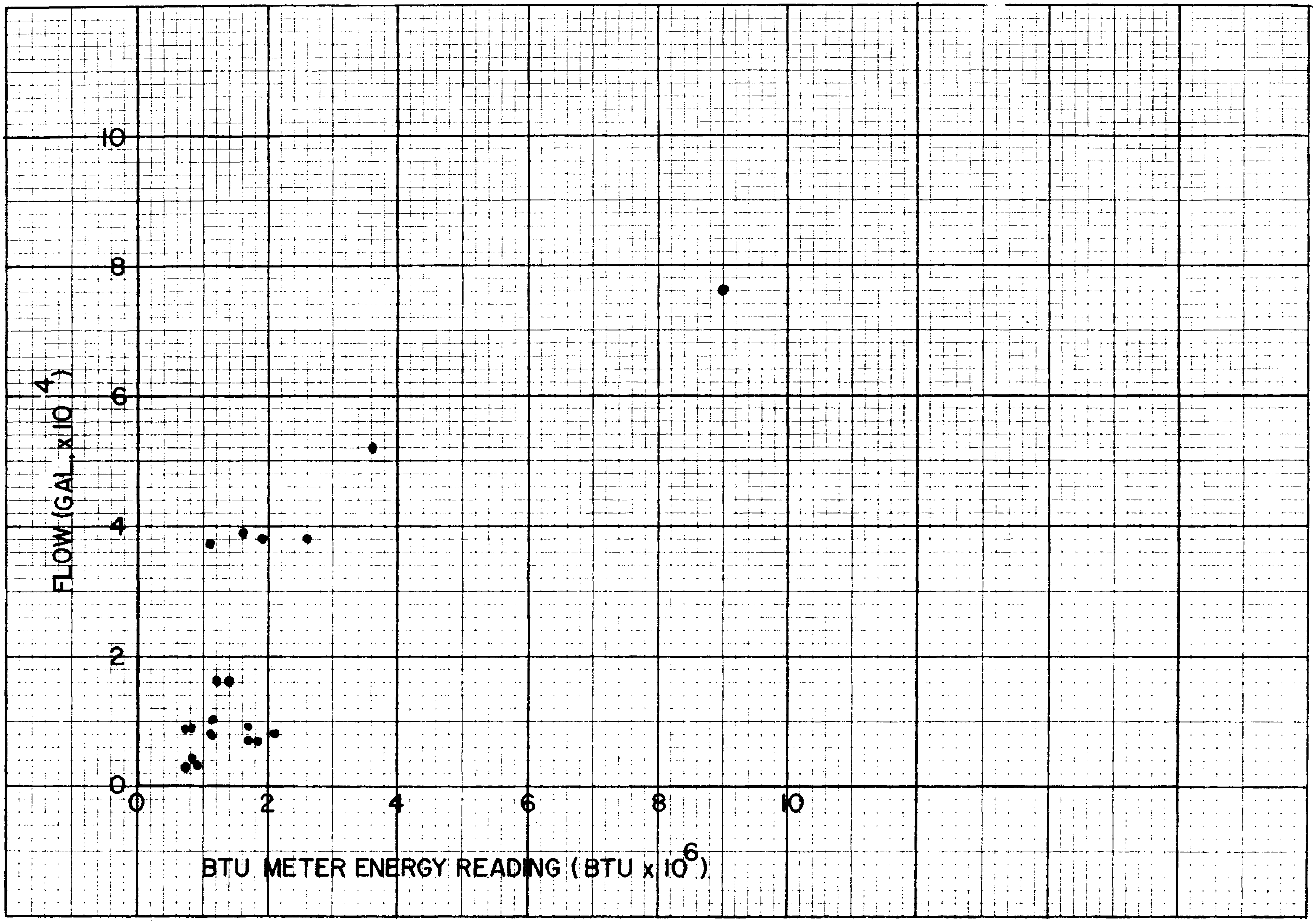


FIGURE I - COMPARISON OF FLOW AND ENERGY AS OBTAINED FROM A BTU METER

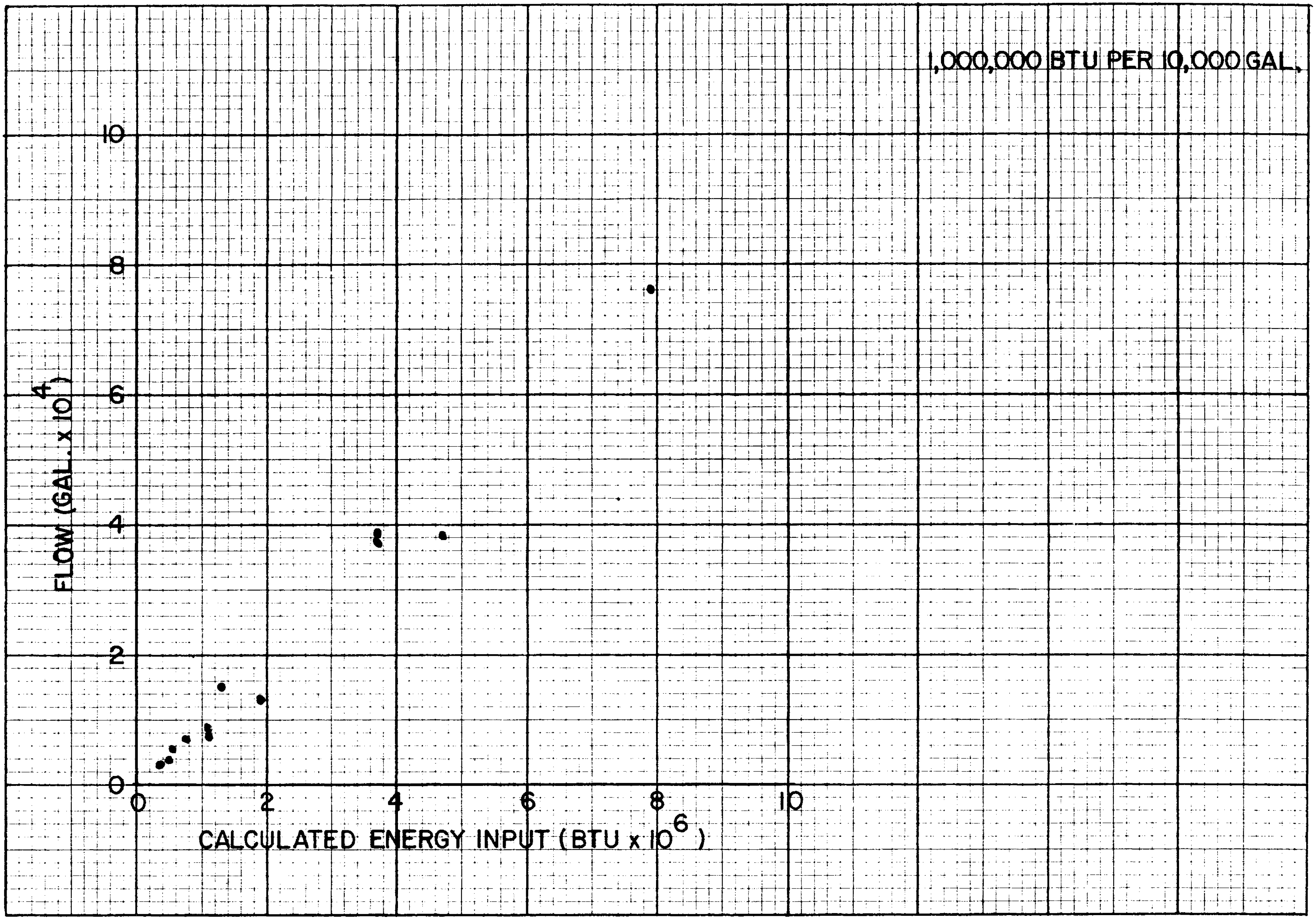


FIGURE 2- COMPARISON OF CALCULATED ENERGY AND METERED FLOW FROM THE BTU METER

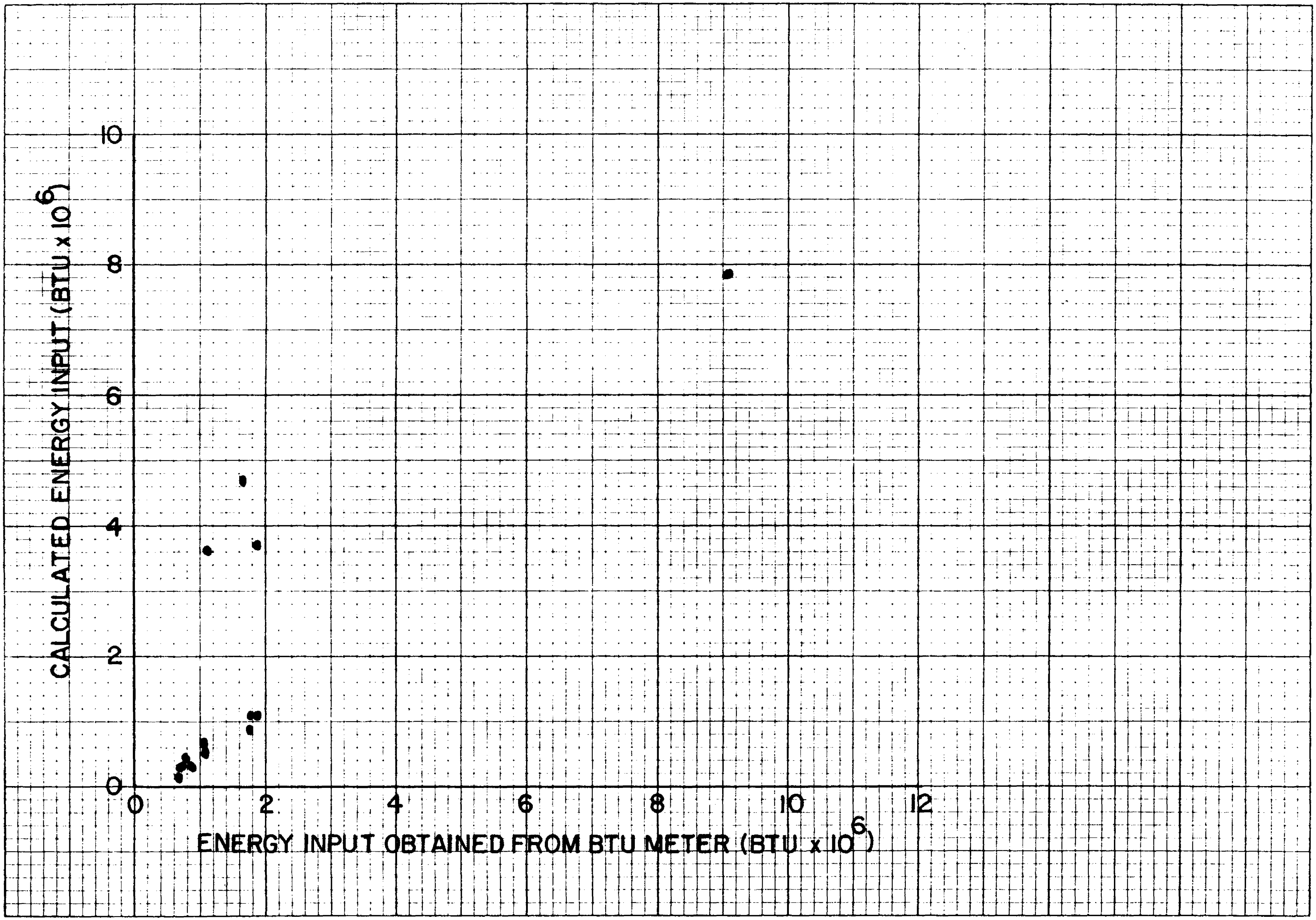


FIGURE 3- COMPARISON OF CALCULATED ENERGY INPUT AND METERED ENERGY

5. Estimate the solar input energy by subtracting the Auxiliary Input Energy from the Energy Lost.

The results of this analysis are shown in Table II.

Even with a relatively large amount of maintenance and debugging, the fact remains that the system can maintain a full tank of asphalt at a relatively high temperature. During the summar of 1980, the asphalt temperature was held between 164°F and 167°F on the average. On several occasions, the tank temperature climbed to 180°F within a 24-hour period and the system was shut down for a short period. Also, from late June to mid-November, 1980, no auxiliary energy was used. During the winter months, auxiliary energy was (or would be) necessary to maintain the tank at high temperature levels since this is the period the material is used most. During 1981, the tank temperature was maintained at an average temperature ranging from 156°F to 163°F.

The tank temperature during the summer months of 1981 was about 10°F lower as compared to the tank temperature of the summer of 1980. Also, auxiliary power was used during the 1980 period whereas no auxiliary power was used during the summer of 1980. These differences are probably due to a lower setting on the safety and auxiliary power controls; no other explainable reason is available.

Note the solar system appears to be capable of producing from 1.2 million to about 1.7 million Btu per month. The average production was 1.481 or about 1.5 million Btu per month when considering the values for full months of operation. This production compares favorably to the production of a sister system in San Antonio[1]. Solar collectors operate at lower efficiencies when producing in the upper temperature ranges where there is little differential between the storage media and the collectors.

TABLE II

SOLAR-HEATED ASPHALT TANK
1980-1981 SUMMARY

YEAR MONTH	AVG. TANK TEMP (^{o}F)	ELECT. CONSUMED (kWh)	AUXILIARY ENERGY FROM WATT M. ($Btux10^3$)	SOLAR ENERGY INPUT ($Btux10^3$)	ENERGY LOST ($Btux10^3$)	COMMENTS
1980						
Jan.	-	-	-	-	-	System Down HE Enlarg.
Feb.	-	-	-	-	-	System Down HE Enlarg.
Mar.	147	-	-	-	2,910	Part Month HE Enlarg.
Apr.	156	-	-	-	7,955	Part Month Leak in HE
May	134	-	-	-	399	Part Month Repair HE
June	156	-	-	-	1,765	Added Insulation
July	166	0	0	1,283	1,283	
Aug.	165	0	0	1,628	1,628	
Sept.	167	0	0	1,754	1,754	
Oct.	167	0	0	1,560	1,560	
Nov.	164	217	739	1,600	2,339	
Dec.	-	-	-	-	-	
1981						
Jan.	-	-	-	-	-	Leak in HE
Feb.	-	-	-	-	-	Leak in HE
Mar.	163	287	979	500	1,479	Part Month
Apr.	158	207	706	1,318	2,024	
May	161	203	692	1,510	2,202	
June	156	143	488	1,316	1,804	
July	157	59	201	1,326	1,527	Part Month 26 Days
Aug.	156	55	188	1,236	1,424	Part Month 38 Days

Authorities indicate that flat plate collectors are not capable of producing temperatures much in excess of 200^{o}F.[2] Therefore, when the temperature entering the collector is high, little additional energy can be added (to increase the exit temperature) and efficiencies are reduced. The collectors in the subject system must be operating in this manner.

IV. The Pay-Off Period

If the average solar input of 1,500,000 Btu/month were expanded to a full year, about 20,000,000 Btu would result. Converted to electrical energy, 20,000,000 Btu is equivalent to 5,865 kWh. Assuming electrical energy costs $0.05 per kWh the savings in dollars for 1981 would be $293. Based on discussions with the contractor and cost estimates of a similar system in San Antonio, Texas, the cost of the original solar equipment components of the system are estimated to be approximately $10,000.

Appendix A reveals the costs of maintaining the system for two years was $9,132. This maintenance cost is unreasonably large because of the modifications made to the system. Experience with the San Antonio system would indicate the annual maintenance cost should be on the order of $200 per year. However, since this report concerns the Lubbock system, the actual funds expended for this system will be considered, but a reduced annual maintenance cost should be anticipated.

Table III indicates the pay-off for the initial two-year cost will be between 19 and 20 years. The initial two-year cost includes the initial construction cost plus the initial two-year maintenance cost. Again it is believed a typical maintenance cost for a system similar to that described herein will be about $200 per year.

TABLE III

STUDY OF PAY-OFF PERIOD
(Based on a cost increase of 12% per year)

YEAR	SAVING ($)	CUMULATIVE SAVING ($)	COST ($)
1981	293	293	
1982	328	621	
1983	368	989	
1984	412	1,401	
1985	461	1,862	
1986	516	2,378	
1987	578	2,956	
1988	648	3,604	
1989	725	4,329	
1990	813	5,142	
1991	910	6,052	
1992	1,019	7,071	
1993	1,141	8,212	
1994	1,279	9,491	
1995	1,432	10,923	
1996	1,604	12,527	
1997	1,796	14,323	
1998	2,012	16,335	
1999	2,253	18,588	20,000
2000	2,524	21,112	

Summary and Conclusions

When considering solar-heated asphalt storage tank systems for the operational mode and out of the research phase, the solar systems appear feasible. The initial cost for systems similar to that described herein will be about \$10,000 in 1980 dollars. Upkeep or maintenance costs are believed to be around \$200 per year in 1980 dollars. Barring unusual events such as occurred with this system, pay-off will probably be in about 15 years.

Specifications should be developed in a manner different than that used in this project and should probably be based on the temperature desired and the Btu's delivered rather than specifying number and type of collector. Flat-plate collectors with auxiliaries composed of household-type water heaters can be used to provide temperatures sufficient for stored cutback and emulsion asphalts. In fact, temperatures will be sufficient for the use of asphalt directly from the tank. A well-made, efficient, flat-plate collector is recommended for future use. Insulation thickness should be slightly greater than design (as a safety factor) with special attention given to tubing insulation.

One of the big problems of the use of solar energy for asphalt storage in Texas will be retrofitting existing storage tanks. Future work should be directed toward a method to quickly and easily install heat exchangers in existing tanks. One method proposed by Austin FHWA personnel would be that of welding a small tank to the bottom of the existing (horizontally-mounted) storage tank. The top of the small flat tank would actually be the bottom of the storage tank. The small tank would then form a small water heater with piping from and to the collectors. Heat transfer would be through the skin of the storage tank.

REFERENCES

1. Hankins, Kenneth D., "Solar Heating An Asphalt Storage Tank in San Antonio, Texas;" Texas Department of Highways and Transportation; December 1980.

2. Duffie, John A., Beckman, William A.; "Solar Energy Thermal Processes;" Wiley-Interscience Publication; 1974.

APPENDIX A

DIARY OF SYSTEM MAINTENANCE

AND

ASSOCIATED COSTS

DIARY OF THE LUBBOCK
SOLAR HEATED ASPHALT TANK

MONTH	DATE	ACTIVITY	FUNDS EXPENDED ($) SALARY	EQUIP.	MATER.
May 1979	11	Began experiments with solar collectors.	0	0	0
	17	Experimented with various settings of gas-fired auxiliary heater.			
June	26	Clean glazing covers.	15	0	0
July	-	-	0	0	0
August	6	Added 3 gallons of ethylene glycol-water.	20	0	30
	10	Strainer stopped up.			
	14	Strainer stopped up.			
	22	Strainer stopped up. Added ethylene glycol-water.			
	23	Measured water flow. Max 2.6 GPM.			
Sept.	24	Strainer stopped up. Lost some antifreeze-water solution. Apparently a relationship between auxiliary activation and strainer clogging.	20	0	15
	25	Collector found leaking.			
October	8	System shut down until collector leak fixed.	120	10	15
	16	Collector fixed, system turned on.			
	22	Maintenance operations began using asphalt from tank.			
November	13	Flow valve opened to 2-1/2 turns - 2.6 GPM at 1:15 pm. Strainer cleaned.	20	0	0
	15	Six-inch gate valve found leaking asphalt. No fault of solar system.			
	16	Shut system down to repair valve.			
	20	Valve repaired system back in operation.	20	0	0
	30	Strainer stopped up after auxiliary being on.			

MONTH	DATE	ACTIVITY	FUNDS EXPENDED ($) SALARY	EQUIP.	MATER.
December 1979	27	Water and antifreeze blown out after auxiliary operation. Auxiliary still on when observed, then shut auxiliary off and started solar only operation.	30	0	20
January 1980	7	Two collectors leaking	400	40	450
	11	Change out gas-fired auxiliary and replace with electric hot water heater as auxiliary. Install Btu-Flow Meter. Install larger pump.			
	16	Electric meter installed to measure electric energy used in the solar system.			
	21	Auxiliary on continuously with solar override.			
February	15	Shut system down. Drained asphalt from tank preparatory to removing heat exchanger from tank for enlarging.	80	0	0
March	24	Heat exchanger enlargement complete. System initiated.	590	50	500
April	2	Calibrated flow rate and Btu meter output. Appears to be asphalt leaking into water-antifreeze circulation system. Hooked up both heating elements on auxiliary heater.	20	0	10
	28	Gasket out on centrifugal pump. System shut down.			
May	6	Found leak in heat exchanger (inside the tank).	585	60	200
	13	Removed heat exchanger and repaired the leak. (Heat exchanger caused system to be down from May 5, 1980 to June 4, 1980.)			
June	9	New steel expansion tank installed. Rerouted thermocouple wires and capillary tubes - running them in conduit prior to adding insulation.	80	20	3456

MONTH	DATE	ACTIVITY	FUNDS EXPENDED ($) SALARY	EQUIP.	MATER.
June 1980 (Cont)	16	From 2:10 pm to 7:30 am on June 18, the system was down while an additional 4 inches of foam insulation was added.			
	26	Additional insulation remarkable aid-system achieved 180°F with solar for first time.			
July	7	Washed collectors (9:00 am).	80	0	0
August	1	Ambient temperature recorder chart feed corrected. (Paper wrapped around feeder spool.)	0	0	0
	12	Chart shows auxiliary on at 6:50 am (Tank 170, Ambient 64). However, electric meter indicates no power used.			
Sept.			0	0	0
October			0	0	0
November	20	Cleaned contacts to allow hot water heater to function when auxiliary is on.	0	0	0
December	1	Ambient temperature and zone valve recorder not operating.	60	0	175
	2	Recorder sent to Austin for repair.			
	10	Collector In-Out recorder is malfunctioning.			
	29	Electric meter is inoperative.			
	30	Installed new electric meter (0000).			
January 1981	2	New electric meter not working.	567	13	80
	5	Problem not electric meter - auxiliary heating elements are out.			
	8	Replace heating elements. Found asphalt in heat transfer fluid. Shut system down.			
	9	Drained asphalt from tank.			
	14	Installed new filter in heat transfer fluid line to trap asphalt.			
	15	Operating system, cleaning filter screen twice per day.			
	16	Filter still collecting asphalt.			
	21	Located leak in heat exchanger in tank. Washed tank out.			

MONTH	DATE	ACTIVITY	FUNDS EXPENDED ($) SALARY	EQUIP.	MATER.
January 1981 (Cont)	22	Operating solar and auxiliary system in order to trap asphalt and clean asphalt from tubing and collectors.			
	29	Located exact spot of leak by using air pressure check. The leak is in an "ell." Placed fiberglass patch over leak.			
	30	Pressure check on fiberglass patch. Patch did not hold. Cut out "ell" and replaced it with new ell to which short lengths of tubing were soldered. Used brass pressure couplings with neoprene gaskets to attach "new" tubing to "old" tubing. Put heat exchanger under a 38 psi pressure check over the weekend. Covered collectors with black plastic to prevent collector damage. Sawed into leaking ell piece. Found original (contractors) soldering of tubing was not sweated to "ell." It was soldered by dobbing solder to near edge of "ell." Little solder penetrated past edge of "ell," did not flow between "ell" and tubing indicating heat applied to edge of "ell" not on main portion of "ell."			
February	2	The 38 psi pressure check held over weekend. Flushed heat transfer solution. Again using filter to trap asphalt.	300	0	50
	9	Drained heat transfer liquid, cleaned filter and recharged system with water (and small amount of antifreeze).			
	13	Drained system, cleaned filter and recharged with 50:50 solution of distilled water and antifreeze.			
	23	Reloaded tank with one transport of asphalt.			
	25	Start up system with normal operation. Btu meter not working.			
March	6	Installed new flow meter (repair of Btu meter) and Btu meter operable.	480	50	0

MONTH	DATE	ACTIVITY	FUNDS EXPENDED ($) SALARY	EQUIP.	MATER.
March 1981 (Cont)	17	Sandstorm with 60 mph winds. Collector glazing blown off and destroyed. Damaged a glass tube in one of the collectors.			
	18	Removed broken collector from rack. Bypassed the removed collector. Began operations with 5 collectors rather than 6.			
	30	Reset button kicked out on thermostat of auxiliary (water heater). Reset - and auxiliary back in operation.			
April	2	Pump causing circuit breaker activation.	196	0	100
	6	Reset circuit breaker.			
	8	Circuit breaker problems again.			
	9	Reinstalled collector after repair of glazing cover. Actually fabricated a new cover from plexiglass. Epoxied one glass tube. System back in operation with 6 collectors at 1:40 pm. Replaced circuit breaker.			
	24	Removed and repositioned several collector covers that had slipped out of place (down) during wind storm.			
May	4	Recalibrated Collector In-Out recorder. Worked on Btu meter.	100	0	5
	8	Repaired two cracked collector covers with glue. (Removed and replaced.)			
June			0	0	0
July	1	Found circuit breaker for water heater tripped. Reset circuit breaker, auxiliary came on with tank below 160^{o}F.	0	0	0
	6	Circuit breaker tripped - reset.			
August	31	Project ends.	0	0	0
		COST TOTALS	3,783	243	5,106
				9,132	

APPENDIX B

DAILY PERFORMANCE SUMMARY

DATE 7-08-80

FLOW RATE 2.9 GPM

11,764 GAL. Asphalt

LUBBOCK
SOLAR SYSTEM

	Coll. In Temperature	Coll. Out Temperature	Input Energy	Tank Temperature	Ambient Temperature	Pyranometer	Energy Loss
AM 12-1			0	169	73		5067
1-2			0	169	72		5146
2-3			0	169	73		5067
3-4			0	169	73		5067
4-5			0	169	73		5067
5-6			0	168	73		5031
6-7			0	168	79		4560
7-8			0	168	86		4010
8-9			0	168	89	3672	3774
9-10			0	168	91	14256	3617
10-11			0	167	94	30240	3345
11-12			0	167	99	39312	2952
PM 12-1	171	185	18024	166	100	46440	5688
1-2	170	188	20277	166	101	46440	5651
2-3	170	190	22530	167	101	49896	5730
3-4	170	189	21403	167	100	39312	5808
4-5	170	181	12391	166	96	35640	5918
5-6			0	166	92	30240	3466
6-7			0	166	88	17928	3779
7-8			0	167	82	5400	4288
8-9			0	168	79		4560
9-10			0	169	76		4832
10-11			0	169	73		5067
11-12			0	169	72		5146
			94625	168	85	358,776	112,636

APPENDIX C

MONTHLY PERFORMANCE SUMMARY

June, 1981

LUBBOCK
MONTHLY SUMMARY
SOLAR TANK

Date	Tank Temp. Aug.-Midnight (F)-(F)		Ambient Air Temp. (F)	Solar Input Energy (BTU)	(Hr)	Auxil. Input Energy (BTU)	(Hr)	Energy Loss (BTU)	Solar Energy Available (Insolation)	Asph (Gal
1	156	155	64	44516	4.00	0	0	65174	390,000	4284
2	155	158	70	41595	5.75	0	0	60215	381888	
3	157	159	61	48745	6.00	65731	3.25	68007	358992	
4	160	160	59	15580	3.50	101,125	5.00	71549	257040	
5	157	155	60	0	0	0	0	68716	224972	
6	154	155	67	41595	5.75	0	0	61631	356748	
7	154	155	74	43403	6.00	0	0	56673	378382	
8	154	155	81	50331	6.75	0	0	51714	378382	
9	154	155	83	51833	6.75	0	0	50297	381888	
10	155	156	73	42068	5.25	0	0	58089	328320	
11	156	158	75	46742	6.00	0	0	57381	374494	
12	157	159	72	44071	5.50	0	0	60215	406728	
13	156	155	72	42847	5.50	0	0	59506	340799	
14	154	155	74	45295	5.50	0	0	56673	360504	
15	158	162	60	0	0	212363	10.50	69424	151632	
16	161	163	59	46519	5.50	40450	2.00	72258	428336	
17	160	161	67	40899	5.25	0	0	65882	415592	
18	159	161	75	42068	6.00	0	0	59506	396360	
19	159	161	78	44739	6.00	0	0	57381	390586	
20	159	160	79	45406	6.00	0	0	56673	392472	
21	157	159	79	46742	6.00	0	0	55256	390744	
22	157	159	77	44071	6.00	0	0	56673	371178	
23	157	158	74	45907	5.50	0	0	58798	397990	
24	156	157	74	43403	6.00	0	0	58089	392472	
25	155	156	75	43403	6.00	0	0	56673	383832	
26	155	156	73	41622	5.50	0	0	58089	358776	
27	155	156	73	37839	5.00	0	0	58089	364392	
28	155	155	71	55089	5.50	0	0	59506	343008	
29	154	155	70	36726	5.00	0	0	59506	310608	
30	151	147	71	31161	5.00	0	0	56673	304776	7454
31						0	0			
	4687	4716	2140	1,204,215	156.5	419,668	20.75	1804314	10711891	
	156	157	71	40141	5.22			60144	357063	