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RECYCLED USED FLUORESCENT LIGHT TUBE SOLAR WATER HEATER

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Final Technical Report for Grant #DE-FG03-79SF10577: u-79-3

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CONTENTS

1. Summary for all work done
2. Progress toward program objectives
 - a. Theoretical studies
 - b. Experimental work and mechanical design
 - c. Theory of operation
 - d. Test procedures
 - e. Test results, drawings, charts, graphs, illustrations
3. List of test equipment
4. Conclusions
5. Recommendations
6. Financial report

1. Summary:

This project was to investigate methods that might be used to use old fluorescent light tubes as solar water heater components, then to produce a booklet of instructions for others to use to construct their own water heaters. I tried various methods of opening, cleaning and shaping the ends of the tubes. The reflective material needed inside some of the heaters was mylar and worked quite well but the B.T.U. gain was disappointing. There were problems with the cement used and epoxy resin was finally used. Two types of collectors using reflectors also used temperature differential thermostats and small pumps. One thermosyphon model used no reflectors nor tube length copper pipe. It produced more B.T.U.'s per day than either motorized model. The epoxy cement seemed best for its construction also. The whole program went nearly on schedule except for the test data and that was of course done last and is included in the appendix. There will be more data collected during the next year and materials will be tested more also. It was found that for Guam at least, the reflector type collectors I developed would not produce hot enough water for absorption type refrigeration.

2. Progress toward program objectives:

a. Studies were begun during the summer of 1979 to find ways that looked promising to utilize old fluorescent light tubes as heater components. Certain glass companies had all glass units which they claimed were very good and I suppose they were but the cost was very high. My goal was to produce collectors that would operate fairly efficiently and at the same time be buildable by an ordinary homeowner at a reasonable cost. I decided to work with copper and glass. Copper water carriers

and fluorescent light tube insulators. It was found that the white material that is used to coat the inside of fluorescent tubes, Calcium Halophosphate, should be easily dissolved by an acid. Dr. Levand, a chemistry professor at the University of Guam suggested hydrochloric acid. Since copper was to be used as the water carriers within the tubes studies were carried out to see how it could best be done. Drawings were made and after looking them over it seemed best to stay as simple as possible and to both enter and exit the tubes at the same end so that in case a tube should break it would be easy to replace the glass tube without dismantling the copper assembly. Two designs were chosen as most likely to succeed; they were a 5/16th inch loop and a 5/16th inch pipe within a 1/2 inch pipe. (Inside diameter measurements.)

If either of these assemblies were to be used alone they would present relatively small exposed surface area to the sun so a reflective surface would have to be provided. Theoretical methods were studied and drawings made. Exterior mirrors were ruled out since they would probably be dimmed very quickly due to rain and mildew. White paint on the outside of the tube would weather and besides its reflective ability was quite low. The shape of reflectors was also a consideration since I wanted the bank of collectors to be stationary. A vee-grooved interior reflector was considered but drawings showed that at certain angles many of the sun's rays would miss the copper pipes and when tested the aluminum I had to work with had a relatively low reflective ability also. It appeared to be best to place a reflector against the cylindrical surface of the glass tube. Again an outside reflector, stainless steel tape, was tried but again the amount of radiation reflected was low, about 30% at best. Also it would be exposed to the weather. Theoretically an

inside flexible reflector conforming to the curve of the cylinder seemed best.

The next consideration was the location of the pipes within the glass tubes. Sketches were studied and it was evident that if the pipes were touching the center of the reflector no light could be reflected back out of the glass tube once it entered. On the other hand if the pipes touched the reflector there should be heat loss by conduction through the glass. It was best then to place the pipes close to but not touching the "bottom" of the glass tubes. To keep the pipes in the right location within each tube some device or devices would have to be constructed to do it.

The soldering or brazing material also had to be decided upon. If the sun's rays are concentrated, very high temperatures are created, so theoretically any connections made on the copper pipes within the glass tubes would have to withstand temperatures in excess of some critical temperature. Silver brazing was decided upon since it would stand temperatures over 1000° and also it would provide greater strength than lead/tin solder.

Since silver required higher temperatures to braze, either an acetylene torch or an electric torch would be needed. I decided to try both.

The method of returning the water that would enter the tube through another pipe had to be considered. It would have to be a very "tight" turn since the inside of a glass tube is less than 1½ inches. I knew of no fittings to do the job so after considering several methods it was decided to use copper pipe caps.

The method of connecting the glass tubes to the copper assembly was considered carefully, however no cement experts were available on Guam

so since this was to be a project to use off the shelf materials as much as possible I tried all cements available but it was felt that since the pieces being joined would be small the amount of expansion would be small and therefore might not be of so great importance.

The next consideration was the method of drilling the holes in the headers and plate so that a strong bond could be made when soldered or brazed. The choices were ordinary drilling, punching, and the use of a tee-extractor. Theoretically a tee-extractor would furnish the most accurate and strongest method.

It was reasoned that if a vacuum could be created within the tubes after the tube was cemented to the copper plate the efficiency would be increased considerably over just air in the tube. A small pipe would need to be brazed in the plate to extract the air so as to provide better insulation and also eliminate the problem of condensed water on the inside of the tube. The problem seemed to be to adequately seal the tube-plate connection and also to have absolutely non-porous copper pipe and brazed connections. As no collectors had been made this way before to my knowledge I would just have to try the idea and see how well it worked.

Vacuum pumps are not available to everyone except by buying them and that seemed too expensive so I checked with various air-conditioner repairmen and found how they sometimes handled the problem. All parts were available so I decided to try the idea myself and if it worked out ok include it in my booklet.

A properly insulated storage tank was a must since solar heat must be stored at least overnight. Both the actual insulation had to be investigated and the method of bringing water into the tank and taking water out of the tank. No tanks made specifically for solar usage were available

so I would have to develop methods to use tanks that were manufactured for the use of electricity or gas. I reasoned that since gas heaters were built with a flue through the middle that I would work only with the electric heaters. The entry and exit problems would be magnified since the tank would both look better and be less vulnerable to storms if it were layed down. Of course if the present water heater in a house were used and left in place then a device would be developed to make this possible with as little trouble and expense as possible.

On paper it all looked possible so the next step was to actually build and try the theoretical concepts.

b. The experimental work actually went along with much of the theoretical planning and the mechanical design.

The first work was with the tube preparation and I knew the problems, at least some of them, when I started. The end of each tube had to be opened so my helper and I tried several methods. If only one end had to be removed, and it did, which one would be best? After trying first one and then the other it was evident that if the vacuum were broken first, which could only be done from the end with a "nub", when the end was broken out with a small screw driver the other end would be safe but if the end were broken first it would fly through the tube and break out the other end like a bullet. By noting the placement of the printed label on the tube it was found that in nearly all cases the end with the printing was the end with the nub and that was the end to take the outer cap from and break the seal, then break out the end. There is a very small amount of mercury vapor in the tube so we worked out in the open air.

Fusing the broken edges required much experimentation before we stopped ruining whole tubes. It was found that a propane torch could be

used if it had a broad flame and was used to slowly heat the whole end before coming in close with the flame to heat the broken edges white hot. When this process was worked out it was easy to place the end of the tube over a mandrel and smooth out the inner edge and also enlarge the end any desired amount.

A little research revealed that the tubes were coated on the inside with a white substance called Calcium Halo Phosphate. Upon the recommendation of Dr. Levand, hydrochloric acid was used to remove it. By mixing the acid with at least as much water the dilute acid could be handled quite easily, in fact both my helper and I used our bare hands to cover the end of the tube while sloshing the liquid back and forth although I suggested using rubber gloves in my instructions for others to follow. It was found that the tubes remained crystal clear after being rinsed with plenty of clear water. We did not experiment with ways to reduce spotting but I expect an additive would have helped.

The experimental work needed for a successful used fluorescent light tube collector cover was minimal. Actually once the tube cleaning and firing methods had been developed there only remained the methods of forming the tubes into a bank solid enough to do the job. My first idea was to make a frame to hold the tubes together. The frame was used also to attach the cover to the collector. Once the frame held the cleaned tubes it only remained necessary to seal the cracks between the tubes and to seal the ends of the tubes. Caulking compound worked ok for the ends but was hard to use for the cracks. Alkyd paint poured into the cracks sealed them ok but dripped through and was hard to clean up from the bottom side. It developed that if the bank were elevated on one end and exterior vinyl acrylic paint poured into each crack at the top end the

seal was formed easily and with very little clean up mess except at the bottom of the run where the surplus made quite a puddle. After several months use it was found that the tubes' open ends should be at the bottom end of the tank so that any condensation inside the tubes could drain back out.

Later, after experimenting with epoxy cement, it was decided that the tubes could be cemented directly to the collector and by using a turkey baster closed down to 1/16th inch at the point the epoxy could also be quite easily be used to seal the cracks between the tubes. Another common cement showed a great deal of promise but has not been tried enough yet and that was mastic for fastening panels to the wall.

Collector type I: We found that straight hard copper pipe was best to use for the copper heater inserts but it was necessary to heat the top several inches to remove the hardness so the pipes could be easily bent about 180° without kinking. After trying several methods of changing the liquid flow 180° within a little less than a 1 1/2 inch glass tube, in fact it was necessary to use half of the tube's diameter or 3/4 inch, for the heater that used two 5/16th inch I.D. pipes which are nearly 3/8th inch O.D. this required a direct turn around. We found that copper pipe caps made for 1/2 inch water pipe were just 5/8th inch in diameter inside therefore they could be made to do the job. I constructed a "plug" or form from 2 pieces of 3/8th inch rod welded together parallel for about 1 inch. The plug was made about 2 inches long. By flattening the cap a little the plug could be started into it then after a tap or two with a hammer on the plug and the cap base on an anvil the cap started to take the form of a 180° turn around. Laying the side of the partially flattened cap on the anvil with the plug still in, a center punch was used to force

the edge of the cap into the groove between the pieces of rod in the plug. The other side was treated the same and the turn around was finished. It was then found that the two pipes tended to warp if soldered or brazed together to keep them lined up side by side properly so wire loops were tried but didn't look nice so finally 1/8th inch pieces of 5/8th inch I.D. copper pipe were cut and formed over the plug and then slipped over the 2 parallel pipes. When placed properly the center punch was used to crimp the little rings down in between the 2 pipes on both sides and the unit was ready to have the turn around brazed in place. These rings also served to keep the lower pipe from touching the glass. Of course the rings did but these were only small heat leaks compared to the whole length of pipe.

There remained the problem of holding the "loop" in place in the tube and the question of whether to use discs of copper brazed on the pipes to fasten the glass tubes to or to use a strip. By trying various methods it seemed best to braze a piece of very soft copper wire in the form of a 1/2 inch coil to the turn around located so as to keep the loop hard against the center of the reflector once the loop was inserted into the tube. The strip was used since the loops could be oriented easily so as to take advantage of the best "aim" for any particular latitude and or roof slant or lack of it. Holes were placed in the strip on oblique lines running at an angle of 77° from the edge of the strip since our latitude is 13° and I wanted the collector to be mounted on a flat roof with no pitch.

There was some experimentation on how to best fasten the twin pipes through the copper strip. Ordinary 3/8th inch holes could be drilled but it was found that since the strip was made of very thin material and

the drill was fairly large it was difficult to drill smooth holes. It also was hard to hold as I found out by cutting a finger quite deeply so it required stitches. The answer was to use tee-extractors and a uni-drill. It took quite a bit of modification to produce a tool which would work well on a flat surface of thin material but since the original tool is made to extract tee's from pipes it was a great help. Also the holes were to be close together with only about 1/8th inch between the outer edges. It was found that by placing a steel washer between the extractor clamp and the 3/8th inch extractor then grinding the outer edge of the washer to fit the recessed groove made for a 1/2 inch extractor, a regular extractor clamp could be used. The hole in the washer had to fit snugly over the 3/8th inch extractor cylindrical body. This still did not help the extractor operate well on a flat surface so another steel washer was used on the other side of the extractor flange and a nut drilled to the same size as the inside of the extractor extrusion inner surface was welded to the washer, then one side of the nut was sawed off to leave a wall only 1/8th inch thick. Three 1/8th inch by half inch long pins were set in holes in the washer and welded securely to the washer equally spaced around the nut but near the outer perimeter of the washer. The pins and nut were then ground off a bit so they all stood out the same distance from the washer. Two holes were drilled through the three parts and the whole assembly bolted together to form a modified tee-extractor. To hold the bottom of the material to be extracted another piece was needed. A piece of 1/2 inch steel pipe 3 inches long was welded to a washer with a 3/4th inch center hole. The washer was welded to the pipe at the pipe's center, that is the outer edge of the washer was about 5/8th inch from each end of the pipe. A 1/2 inch hole was then drilled

through one wall of the pipe in the center of the hole in the washer. This produced a flexible lower anvil so that the clamp could hold the extractor on one side of the thin strip and the anvil on the other to keep the strip rigid during the tee-extraction. For one collector only I would suggest drilling only but if many are to be made the tee-extractor modification will be of value.

After the 3/8th inch pipes were brazed to the strip and 1 inch sections of capillary tube were also brazed in place through small holes drilled near the 3/8th inch holes the 3/8th inch pipes were spread apart so that the headers could be brazed to them. It was found that the pipes could be bent quite nicely after the strip was brazed in place since they got hot enough to soften them thoroughly.

The tee-extractor with no modification was found to be best to prepare the headers. We found that 3/4th inch copper pipe was about right for a heater no more than 4 feet wide. Larger pipe would be better for wider collectors. There was no experimenting needed to braze the small loop pipes to the headers, it went along easily and the headers were about 1 inch apart when finished. Water should enter cold to the bottom header from one side and exit hotter from the top header from the other side to equalize flow through all the heaters.

Heater type II: They Type I heater was pretty tedious to build so another way of circulating water into and out of a glass tube was considered. This one, we hoped, would be a little simpler. We decided to see if we could take cold water to the back end of the tube through a 5/16th inch pipe and bring it back out hotter through a 1/2 inch pipe by placing the small one inside the larger one. We found that by placing a copper cap over the end of the 1/2 inch pipe and not allowing the 5/16th

inch pipe to extent quite to the end of the cap it would be possible to provide for the 180° turn around within the required boundaries with no trouble at all. In fact the whole heater assembly would be only 3/4th inch in diameter at the bottom end. The copper placement spring was again used that we had previously experimented with and found satisfactory. One or two small bands also provided the very small air space between heater and reflector.

The header assembly was also simplified since only one hole for the heater assembly would be required through the thin strip to which the glass tubes would be cemented later, and the actual headers could be placed next to each other and separated from each other by any desired amount with no difficulty. The header to take hot water away was prepared using a 5/8th inch tee-extractor on one side and the 3/8th inch tee-extractor on the other side directly in line with the holes placed in the 2 inch copper strip the same way. (No modifications were needed for the top of the strip but the anvil lower part was needed for the holes in the 2 inch strip.) The two pipes entered this header but only the 5/16th inch pipe exited the back side. The 1/2 inch pipe was cut just long enough to accomplish this of course. The second header, the one to bring cold water to the heater, had 3/8th inch tee-extracted holes also placed at proper intervals along one wall of its length. The small pipes were brazed into these holes and the copper unit was finished. Opposite ends of the 2 headers were capped so that again water would enter from one side and leave from the other to equalize flow through the heaters.

Fastening glass tubes to the copper strips would have been a simple task if a proper cement were known. The cement needed to be a little flexible, able to bond readily to both copper and glass, and not be

affected by either hot water nor sunlight. After experimenting with all available on Guam an epoxy was chosen. It is not known yet how long it will stand up under actual working conditions but at this writing it appears to be holding up quite well although I have had some trouble maintaining a high vacuum in the tubes. Whether this is a problem with the cement or a problem with copper being too porous I don't know.

I have not been entirely satisfied with the use of Mylar reflectors either. The company claims seem to be too high. More experimentation will be done to determine the best material for the job, but on Guam even this material is hard to find. I tried white paint and was not happy with the results at all.

I'm sure that a selective coating on the pipes could be found in the states that would improve the collecting performance considerably but the best I found on Guam was Rustoleum Barbeque black spray paint although other paints were tried. We sent for some sodium chlorite but when it was discovered that air delivery would cost \$45 per pound I cancelled the order since cost effectiveness was important to the success of the units.

Heater type III: One of our professors, Dr. Rhoads, has been wanting to try a hose or system of pipes layed in the sun trailing down across his back yard which slopes down from his house. He thought a single connection from this to his drain valve on his heater would work. There were some things about the idea that seemed reasonable so I started experimenting with the glass tubes with only an entry hole and an exit hole at one end of the tubes. A copper disc was cut two 3/8th inch holes made in it, into which two 2 inch by 5/16th inch pipes were soldered. The disc was cemented to the opened end of a tube and two 3/8th inch

rubber tubes connected these tubes to two pipes soldered in the side of a gallon can. The glass tube was painted black and the system filled with water and set in the sun with the tube slanted 13° from the horizontal. Convection started immediately and even though there was no wind protection the gallon was soon quite hot. This was the start of a thermosyphon collector which so far seems to be the most efficient I've worked with. It is not a super hot system but produces more stored B.T.U.s than any of the others. I only see one problem that may turn up and that is with the cement.

I constructed a unit made up of ten, 4 ft. old fluorescent tubes. This is a bit less than 5 square feet of collector surface. I used an insulated box with a cover made from more fluorescent tubes. I have 15 gallons of water in the collector and in the storage tank. With partly cloudy skies the whole 15 gallons of water reaches 115° to 135° in about 3 hours then stays there until late afternoon. I have tested the cement connection under 70 lb. per sq. inch water pressure with no breakage nor separation. If the cement does not break down it looks like a great system that can be built for very little money.

In summing up the experimentation there are two areas that I see as needing more testing or perhaps more researched information or both, the reflective material and the cement. I am sure very good materials are already available somewhere but so far I've only found a limited supply of different kinds on Guam. It will be necessary to ship them in and furnish them to the home water heater builder as special materials if any are found superior to the ones I've tried.

c. The theory of operation for the collectors with the copper pipes and the reflectors was that they would operate both on direct sunlight

and on diffused light to some extent. Since the reflectors would only be effective for direct sunlight these heaters might not be too effective on Guam, however during much of the day there is a lot of diffused light which would be picked up by the black painted pipes directly. By using collectors with a relatively small amount of water contained within them they should heat quickly and then if a control sensed this heat the heated water could quickly be pumped into an insulated storage. Since the direct sunlight is very intermittent on Guam a control that could be adjusted to a small temperature differential "on" position should be needed. We tried controls with a 20° temperature differential and found them not acceptable so Natural Power inc. controls were ordered with a differential range of 0° to 25°. We set them at 10° "on" which has been quite satisfactory but will try them at 5° later.

For the thermosyphon model we provided a slope of 13° for the tubes and let the convection process handle the hot water transfer to an insulated storage tank. Since the water movement force was very low we provided 3/4th inch hoses and pipes between collector and tank. The tank bottom was placed well above the top of the collector to prevent any reverse flow at night or during cool spells.

d. The tests were performed as follows. Two variable controls were used with two Teel 200 gallon per hour booster pumps to circulate water from the two copper loop collectors to two styrofoam used fish shipping containers. The containers were sealed with paint and epoxy cement. The controls were set to turn the pumps on when the collectors reached a temperature of 10° more than the bottom of the storage tanks and off at 5° difference. They were later tried at 5° difference on and 0° difference off. The data were recorded most of the time every hour on the hour.

The thermosyphon model was set up on the same slant of 13° from horizontal facing south. As is usual there were periods of rain and wind and much cloudiness. The thermosyphon system also used a used fish shipping tank. The first two units were "filled" with 12 gallons of water while the thermosyphon system contained 16 gallons since its collector required nearly 4 gallons. Each collector provided a little less than 5 square feet of exposed area, i.e., exposed to the sky.

The test results will actually continue to come in for the next several years. At this time actual B.T.U. collection data can be and has been recorded. The results have been reduced to a graph for each unit with a comparison of all three on another graph. These graphs follow.

3. A List of All Test Equipment Used:

1. Two Natural Power inc. Series S25 Differential Thermostats
2. One United Electric 650 Temperature Recorder
3. One pressure gauge
4. One glass thermometer
5. One bimetal circular dial thermometer
6. One Delta T, Model DTT Differential Thermostat
7. Two Teel magnetic drive pumps, 200 gal/hr. no load
8. One Vacuum pump and gauge
9. Tire pump

4. My first conclusion is that Guam is a poor place to depend on direct sunshine to make the two concentrating collectors really affective. There is enough diffused lighting and direct lighting together to make the ther-

mosyphon model work very well though. It is too soon to tell whether the cement used will stand up under long term use however at this writing it looks good with no failures. The use of Mylar may be as good a reflector as can be found but I do not know at this time. It was the best one I tried, but my resources were limited by little flexible reflective material being available on Guam. Used fluorescent light tubes can be successfully used for solar water heater components.

5. I recommend that the three models be further tested but that even at this time the public should be made aware of their potential especially the thermosyphon model which can be produced at a lower cost than any water heater I have ever worked on. Of course they break easily which may be too big a problem for some areas, but replacement of the parts is cheap and quite easy to do.

End of Report

Frank M. Jaquette

Final financial report as of August 31, 1980

This report does not include the 5% still to be paid for printing the booklets if they are ok'd.

	Spent	Budgeted
Materials purchased to date	\$ 853.25	\$ 900.00
Supplies	310.88	320.00
Equipment	761.20	800.00
Salary, Director	4,000.00	4,000.00
Wages, Helpers	1,000.00	1,000.00
Travel, Material procurement	100.00	100.00
Printing	35.00	200.00
Consultants	00.00	200.00
Cash and checks on hand	(83.67)	
5% of \$7520 not received yet.	376.00	
Totals	<u>7,520.00</u>	<u>7,520.00</u>

Appendix A.

The temperature testing started late since the process depended upon delivery of the motor control units and the fact that I was called upon to teach summer courses at the University leaving little time. The storage tanks were styrofoam shipping boxes with 1 inch thick walls. The insulation proved to be less than needed but comparisons were made between the three collectors anyway. It was clear that the concentrating collectors were much less efficient as tested than the thermosyphon model.

There appears to be an error in the concentrating collectors' data. The dip shown on both graphs must have been caused by sunlight touching the temperature sensors located on the east end of the storage tanks. This kept the pump turned off early in the day yet recorded high temperatures. Then at 11:00 the sensor was shaded and the pump started. This has not been checked out yet but it will be corrected in later testing.

CONCENTRATING COLLECTOR Type I with
5/8 inch I.D. Loops.

Average Temperatures Reached

Collector 5 sq ft storage 12 gallons

CONCENTRATING COLLECTOR TYPE II WITH
a 5/16 inch pipe WITHIN a 1/2 inch pipe
Average Temperature Reached

COLLECTOR 5 sq ft Storage 2 gallons

Type Three; Thermosyphon Model

Average Temperature Reached

COLLECTOR 5 sq ft STORAGE AVERAGE 15 gals.

CONCENTRATING COLLECTORS I, II, &

THERMOSYPHON MODEL III

Average Temperature Reached