Feasibility Study – Using a Solar Evaporator to Reduce the Metalworking Fluid (MWF) Waste Stream

Federal Manufacturing & Technologies

L. J. Lazarus

KCP-613-8522

Published September 2008

Final Report

Approved for public release; distribution is unlimited.

Prepared under prime contract DE-ACO4-01AL66850 for the
United States Department of Energy

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process or service by trade names, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

All data prepared, analyzed and presented has been developed in a specific context of work and was prepared for internal evaluation and use pursuant to that work authorized under the reference contract. Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation or favoring by the United States Government, any agency thereof or Honeywell Federal Manufacturing & Technologies, LLC.

Printed in the United States of America.

This report has been reproduced from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, Tennessee 37831; prices available from (865) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal, Rd., Springfield, Virginia 22161, (703) 487-4650.

KCP-613-xxxx
Distribution Category UC-xx

Approved for public release; distribution is unlimited.

FEASIBILITY STUDY – USING A SOLAR EVAPORATOR TO REDUCE THE METALWORKING FLUID (MWF) WASTE STREAM

L. J. Lazarus

KCP-613-8522

Published September 2008

Final Report

Project Team:

D. L. Brown, SE2

E. E. Vance, SE2

B. Reed, SE2

K. Klein, 821

R. Griffith, 821

Contents

<i>Section</i>	<i>Page</i>
Abstract	9
Summary	9
Discussion	10
Scope and Purpose	10
Design Factors	10
Opportunities.....	14
Results.....	19
Conclusions and Recommendations	25
Appendix	
Observation Sheets	28

Illustrations

<i>Figure</i>	<i>Page</i>
1 Evaporator with rain shield installed, after 4 inch rain.....	10
2 Copper manifold – Streams distribution fluid over evaporator surface.....	11
3 First attempt of shield to prevent mist drifting outside tank boundary.....	11
4 Evaporator system setup in barrel lot.....	12
5 System pump.....	12
6 Evaporator - oil skimmer components.....	13
7 Specifications for Oakton Datalogger.....	13
8 J. C. Whitney Gas Gauge sensor and gauge	14
9 Polypropylene filter screen	15
10 Bag filter installed on system pump.....	15
11 Manifold modifications.....	15
12 Shield to protect bung on 5-gallon waste container.....	16
13 Ultrasonic liquid level sensor and specifications.....	16
14 Collector extensions installed	17
15 Instrument modifications	17
16 Magnetic thermocouple mount under the end of the collector extension.....	18
17 Solar powered fan installed in rain shield.....	18
18 Acid split of MWF for runs 1 and 2.....	19

Tables

<i>Number</i>		<i>Page</i>
1	Run 1 - Height Change	20
2	Run 2 - Height Change vs. Time	21
3	Run 3 - Height Change vs. Time	22
4	Run 3 - Light Intensity Measurement vs. Time	23
5	Run 3 - Temperature Profile Across Collector vs. Time	23
6	One Month of Temperature Cycles.....	24
7	Temperature - Humidity Extremes During Run 3	25

Abstract

A solar evaporator was designed, built, and operated to reduce the water-based metalworking fluid waste stream. The evaporator was setup in Waste Management's barrel lot inside one of the confinement areas.

The unit processed three batches of waste fluid during the prototype testing. Initial tests removed 13% of the fluid waste stream. Subsequent modifications to the collector improved the rate to almost 20% per week.

Evaluation of the risk during operation showed that even a small spill when associated with precipitation, and the unit placement within a confinement area, gave it the potential to contaminate more fluid than what it could save.

Summary

A solar evaporator was designed, built, and operated to reduce the water-based metalworking fluid waste stream. The design was intentionally kept as simple as possible. The evaporator was built on an aluminum frame and was sized on the largest available stock tank that could be purchased. Liquid wastes are collected in pails (5 gallon), barrels (55 gallons) and carboys (250 gallons). This combination worked out well because we could process one carboy at a time. The evaporator was setup in Waste Management's barrel lot inside one of the confinement areas. Instrumentation was kept simple and later expanded as more questions were asked. The fluid height sensor failed because of corrosion and had to be replaced with an ultrasonic monitor.

The unit processed three batches of waste fluid during the prototype testing. Initial tests removed 13% of the fluid waste stream. Subsequent modifications to the collector improved the rate to almost 20% per week by the third run. A number of shields were added to prevent any contamination from escaping the confines of the stock tank. Also many problems were encountered with the delivery manifold. Hole size was modified four times and finally a filter had to be added to the input of the system pump to prevent debris from plugging the manifold.

Evaluation of the risk during operation showed that even a small spill when associated with precipitation, and the unit placement within a confinement area, gave it the potential to contaminate more fluid than what it could save. A number of risk factors, suggestions, and conclusions can be found in the conclusions and recommendation section of this report.

Discussion

Scope and Purpose

Used and/or spoiled metalworking fluids represents one of the largest waste streams for the Kansas City Plant operation. Two types of metalworking fluids are used in FM&T operations: water-based and oil-based fluids. Water-based fluids are a mix of an oil concentrate and from 90 to 95% water. It costs FM&T \$0.52 per gallon to get this waste fluid removed from the site, properly treated per state and federal regulations, and discarded. The object of this study was to build a small solar evaporator to evaporate part of the water portion of the water-based fluid to reduce the quantity of the waste stream.

Design Factors

Research was begun on various solar evaporators. A design was proposed and built based on the largest oval stock tank available, manufactured by McMaster-Carr with a capacity of 330 gallons of fluid in a galvanized tank 96 inches long x 36 inches wide x 24 inches deep (*see* Figure 1). This tank matched well with the 250-gallon capacity waste carboys used by the waste management organization to remove liquid wastes.

**Figure 1. Evaporator with rain shield installed, after 4 inch rain
(The inside of the stock tank was dry; note the depth of rain accumulation.)**

The evaporator element (*see* Figure 2) was made from corrugated galvanized sheet that was powder coated black to absorb as much of the sun's energy as possible. The corrugations were 1.25 horizontal pitch with 0.25 height. The collector was 31 inches wide by 5 feet in length. There were 25 channels along its width. The corrugated sheet was set on a frame with a 5 degree slope. A copper manifold (*see* Figure 2) was mounted along the evaporator width at the top end. The manifold had 0.028 inch holes along its length at 1.25 inch intervals so that the fluid could be distributed along the top end of the galvanized sheet.

Figure 2. Copper manifold – streams distribution fluid over evaporator surface

Figure 3. First attempt of shield to prevent mist drifting outside tank boundary

A rain shield (*see* Figure 1) was designed to prevent rain from mixing with the Metalworking Fluid (MWF) being evaporated. The rain shield built was a 4 foot by 9 foot, 0.125 thick Plexiglas sheet supported by an aluminum angle iron frame. The rain shield had a 3.5 degree slope. A Plexiglas piece 6 inches wide sloping in the opposite direction was placed on the underside. This piece directed the flow back into the tank and prevented any condensate that formed over night to spill out of the system. The gap at the manifold end (head) of the unit was 12 inches above the tank and 6 inches above the collector. The gap at the foot end was 6 inches above the tank. On the rear end of the rain shield, where the gap was largest above the tank, a 4 inch side shield was installed to prevent wind from blowing the fluid out of the unit.

The evaporator was installed in the waste management barrel lot (*see* Figures 1 and 4) This lot is regulated by federal and state pollution prevention departments and monitored by the FM&T Environmental Operations department. Since the evaporator unit sat at a low point in a confinement area, any overflow or spray from the evaporator system had the potential to contaminate any rain water that collected and turn it into treatable waste. To prevent this, the drain valve for the area was closed if threatening weather was observed. Any accumulated rain water is inspected for cloudiness or oil floating on the surface. If no contamination is found, the accumulation is released into a storm drain. These concerns resulted in extremely tight operating parameters since a small release from the evaporation unit could result in the generation of hundreds of gallons of treatable waste.

Figure 4. Evaporator system setup in barrel lot

The system was circulated using a UL listed, Little Giant Model 4E-34NR 1/12HP submersible pump (*see* Figure 5). The pump was capable of pumping 810 gallons per hour at one foot, or raising the fluid 24.5 feet. The pump runs on 110 VAC with a low power requirement. Similar pumps have been successfully used with other MWF applications.

Figure 5. System pump

A Zebra Sidewinder Tube Skimmer (*see* Figure 6) was also attached to remove way oil (oil residue found in carboys and separated oil from spoiled fluid). This skimmer removes oil at a maximum rate of 1 quart/hour. The skimmer was mounted on top of a diverter. The lock jaw mounting plate was bolted to the bottom of the diverter. The whole assembly was then clamped to the top lip of the tank. This unit also runs on 110 VAC power. The oil side of the diverter was connected to a tube that ends in a 5-gallon waste oil container with a waste management designation of Oil L2, a non-hazardous waste oil container. The oil container was set in a separate confinement tank to prevent spills in handling the catch can from contaminating the area. The water side of the diverter returned the water-based component back to the stock tank. The waste oil can be fuel blended. If the MWF has over 10% oil it is considered hazardous waste which requires a much higher cost per gallon disposal cost.

Figure 6. Evaporator - oil skimmer components

A minimal amount of instrumentation was incorporated to track the evaporator operation. An Oakton Temperature/Humidity Datalogger (*see* Figure 7) was used to track the environment around the evaporator. This instrument was attached to a 0 to 10 VDC device to interface a fuel gauge from J C. Whitney (*see* Figure 8) to track fluid level. This proved unsuccessful because components of the float system were made of iron and quickly rusted to failure (first two weeks of operation) in the water-based environment. The fluid level was tracked by reading a 24-inch steel machinist scale that was clamped to one of the collector's legs that sat inside the stock tank. We did use the datalogger to track changes within the evaporator environment.

OAKTON[®] Temperature/Humidity Dataloggers

[click to enlarge](#)

R-35710-10
Oakton[®] RH/TempLog
Temperature/ Humidity
Datalogger

Qty: [Add to Cart](#)

\$160.00 / each (USD) In stock.

Product Rating ★★★★★ (2 Ratings) [Write a Review](#)
[Read 2 Reviews](#)

- Compact, rugged housing guarantees operation in busy areas, laboratories, cold rooms, and more
- Sample from once per 10 seconds to once per 2 hours—built-in clock and calendar track your data in real time
- Quickly document min/max values with optional IR printer
- Built-in clock and calendar track your data in real time

These loggers store up to 16,000 measurements, allowing you to track important temperature and humidity data for months. The two-digit LCD shows current conditions—minimum and maximum readings are available at the touch of a button. If set limits are passed, the built-in alarm flickers the display and must be manually reset. Use the external sensor input to add one additional sensor (sold separately) to your datalogger.

Model 35710-00 records temperature and features a water-resistant IP65-rated housing. Model 35710-10 records temperature and humidity and features a dustproof IP60-rated housing. Datalogger kits include datalogger, software and cable.

35710-00 & 35710-10 Loggers require 35710-50 software/cable if not used with 35710-20 cradle & 35710-25 receiver

Specifications	
RH range	0 to 100% RH
RH resolution	0.5% RH
RH accuracy	±3% RH from 0 to 90% RH ±6 RH from 90 to 100% RH
Temp range	-30 to 50°C (-22 to 122°F)
Temp resolution	0.5°C (1.0°F)
Temp accuracy	±0.6°C (±1.1°F)
Battery life	Approx. 2 years
Display	Two digit LCD display, 3/8"H
Output	Infrared: IRDA interface to printer or computer with IRDA port RS-232: cable connection to your computer (order cable/software package separately)
Sampling rate	Selectable via software from once per 10 seconds to once per two hours
Memory	16,000 data points
Housing	IP60 rated
Power	3.6 V lithium battery
Manufacturer number	EC650

Figure 7. Specifications for Oakton Datalogger

Figure 8. J. C. Whitney Gas Gauge sensor and gauge

Opportunities

Numerous problems and changes were required during the first run. These are noted in the daily logs. The first problem to be addressed was the prevention of any leaks that might contaminate the area. A number of changes involved the supply manifold. As the MWF flowed through the small holes at low pressure, buildup occurs, eventually clogging the holes in the manifold. Also, the fluid used for this process was waste fluid containing a lot of debris. As the debris builds up in the holes, the pressure in the manifold builds up and instead of streaming on the collector the fluid sprays out the holes. This creates a problem at the ends of the manifold where the spray can spill out of the stock tank onto the ground. Many variations of shield were tried to prevent this. The final design included a one foot long, 90 degree angle that was formed out of sheet metal starting at the manifold. A piece of vinyl strip door material was attached to the outside of the sheet metal, containing the spray at the end of the manifold.

Another problem discovered was seepage at the bottom seam of the tank caused by a small dent from handling damage. This seepage combined with the accumulated dirt that was carried into this area due to the slope of the ground which held the fluid, allowed water to wick under the stock tank. After the first rain and the obvious oil film around the base of the tank it was evident that more waste was being created than saved by evaporation. This seepage was controlled by using RTV on the outside seam. The inside seam was also covered with RTV between the first and second runs.

The third batch of fluid processed in the evaporator was fluid residue from chips sent for disposal. Even with holes enlarged five times from the initial 0.028 diameter to over 0.063 inch diameter, there was so much debris the manifold would clog in minutes. The rough polypropylene filter screen (*see* Figure 9) was not adequate for handling this combination of slug and debris.

Clogged screen and new screen

Detail of clog

Figure 9. Polypropylene filter screen

The screen was replaced with a trade size 9, 100/200 micron felt filter bag that was 5.5 inch diameter and 32 inches long. Rings were fitted to the inside of the bag to keep its shape and the end was tied to a piece of $\frac{3}{4}$ schedule 40 pipe connected to the input to the pump (*see* Figure 10).

Figure 10. Bag filter installed on system pump

The combination of filter bag and hole size solved the manifold plugging problem. The other modification made to the manifold was the installation of valves in the supply line (to regulate flow) and a tee (for the addition of a branch line) (*see* Figure 11). An $\frac{1}{8}$ inch branch line was installed in the stock tank and used as a fountain. This also set up a flow on the top surface around the inside edge of the stock tank and brought the oil floating on the top to the skimmer.

Manifold Modification

Underside of collector w/fountain on left side
and skimmer tube on right side

Figure 11. Manifold modifications

To prevent rain from entering the 5-gallon oil waste can, a shield was fabricated (*see* Figure 12) from a funnel over the open bung on the can.

Figure 12. Shield to protect bung on 5-gallon waste container

Another modification was the replacement of the fluid height measuring device (*see* Figure 13). This was the most costly of all the modifications. An ultrasonic liquid level height indicator was purchased from Omega Engineering Co. (*see* specifications below). the combination power supply and controller was also purchased for future applications such as the ability to remotely monitor the fluid level.

- 8" Beam Allows Application in Restricted Environments
- All Plastic Construction
- LED Digital Display Indicates Level in Inches or Centimeters
- Push Button Calibration For All User Set Points
- Built-in 10A Relay May Be Configured For Alarm or Automatic Fill/Empty Operations
- Fail-Safe Relay Logic Provides Echo and Power Loss Safety
- Sanitary Model Available

[View related products - Level Measurement](#)

SPECIFICATIONS

Range: 0.5 to 24.5 feet
Accuracy: $\pm 0.25\%$ of span
Resolution: 0.125" (3 mm)
Frequency: 50 kHz
Pulse rate: 8 pulses/second
Blocking distance: 6" minimum
Display type: 4 segment LED
Display units: Inch / cm
Supply voltage: 14-36 Vdc
Consumption: 200 mA
Current flow: Source / sink
Signal output: 4-20 mA, 12-36 Vdc
Signal averaging: Fast / slow
Calibration: Push button
Relay current: 10 amp
Relay output: 250 VAC, 10A, 1/2 hp, SPDT
Relay indication: ON / OFF status
Contact resistance: 30 milliohms
Fail-safe diagnostic: Relay reverts to safe position
Temperature rating: -40 to 60°C, (-40 to 140°F)
Temp. compensation: Automatic over entire range
Pressure rating: 30 psi @ 25 °C., derated @1.667 psi per °C. above 25 °C.
Enclosure rating: NEMA 4X / IP65
Enclosure material: Polypropylene
Transducer material: PVDF
Mounting threads: 2" NPT (4" female with "-S" option)

\$ 425.00 LVCN-51

- Universal Proportional Controller with Adjustable Setpoints
- Numerical Display and Bar Graph Assists in Programming
- Excellent Choice for Use with Continuous Ultrasonic and RF Capacitance
- Isolated 4 to 20 mA Proportional Output Reversible
- Time Delay Feature Dampens Alarm Chatter
- Auto Fill or Empty Capability with Independent Alarm
- Scaleable in Engineering Units

[View related products - Level Measurement](#)

Figure 13. Ultrasonic liquid level sensor and specifications

It was observed that readings taken from the steel rule were affected by temperature. Since the sensor device is mounted to the rain shield and senses the fluid level in a steel tank, the combined effects of thermal expansion of aluminum, Plexiglas, steel, and water affected the readings. Day to day readings taken at the same time of day at approximately the same temperature can be compared. This provides an explanation of why no changes in height are noticed during the heat of the afternoon but there are from 0.1 to 0.2 inch change in fluid height in the morning when everything has stabilized at the same temperature.

Collector extensions, painted black to absorb heat, were also added to the side walls of the stock tank. These extensions were flat with a small lip on the outside edges. It was observed that the fluid absorbs more heat on the flat section than the corrugated section of the extensions. To absorb more heat to warm the fluid, the stock tank was also painted flat black (*see* Figure 14).

Figure 14. Collector extensions installed

The collection of additional data began during the second run. Thermocouple readings were added along the evaporator surface at the head end, the end of the collector (or tail end), and at the end of the extensions. An additional data point was provided using a meter that measured light intensity in foot candle (*see* Figure 15).

Light intensity meter and thermocouple readout

Magnetic thermocouple mounts

Figure 15. Instrument modifications

Later, thermocouples in spring-loaded magnetic mounts were added. The end mount was mounted upside down (*see* Figure 16) under the end of the extension so that the temperature of the fluid leaving the collector could be measured. The two magnetic sensors were mounted under the fluid surface so that the fluid temperatures at the head and tail ends could be measured. Using these mounts with connectors allowed the thermocouples to be plugged into the readout to quickly obtain temperature readings.

Figure 16. Magnetic thermocouple mount under the end of the collector extension

Another modification made during the second run was the addition a solar-powered fan (*see* Figure 17) to each side of the underside of the rain shield to draw humid air from above the collector out from under the rain shield into the atmosphere and increase the evaporation rate. However, these fans did not generate very much volume and were not effective.

Figure 17. Solar powered fan installed in rain shield

Fluid stability was monitored for the first two runs. Because the fluid was being constantly circulated, no deterioration of the fluid was observed. As expected, acid splits showed the emulsified oil percentage increase during the run.

Figure 18. Acid split of MWF for runs 1 and 2

Acid split from the third run was zero because the emulsifier had been destroyed by bacteria.

Results

The first run of the evaporator system was loaded with a charge of MWF from the quick cleaning process in D/25. The MWF was a 2% solution of TrimSol heavily dosed with CimClean 30 and Kathon. This solution was used to break up deposits in the MWF system including the sump and to sterilize the surfaces. The fluid had no odor because bacteria and mold counts were zero. There was approximately 5 gallons of oil skimmed off the surface. The fluid level table shows a fairly constant slope. Loss rate was approximately 2 inches per week or approximately 13% per week.

There was a significant learning curve for the first run. The reason the initial slope (*see* Table 1) was steeper was because of the skimmer removing oil from the top surface at its maximum rate for hours. Also affecting the slope was the spray mist that was drifting out of the unit. After this problem was solved with installation of the shield, the slope remained fairly constant.

Table 1. Run 1 - Height Change

The second run was with another load of D/25 quick clean fluid.

Table 2. Run 2 - Height Change vs. Time

A decision was made not to run the system for a period of days due to modifications that had occurred. Conditions during the next three days of the run were raining with cloud cover. The confinement area filled with water and was not drained so the air around the evaporator was saturated. After conditions cleared and the confinement drained, fluid started to evaporate. The first week resulted in only a 5% evaporation rate (*see* Table 2). The effect of the evaporator extension is evident during the second week when the evaporation was almost 17%. For the 18 day run 30.7% of the fluid volume or approximately 0.19 inches per day was lost.

The third run was from the chip mill area of waste management. All the chip barrels are drained before the chips are processed. This drainage is accumulated in a carboy. The liquid is a mix of every fluid found in the plant along with any other materials that might be tossed into a chip barrel. The fluid was covered by a lot of oil and had spoiled. During spoilage the bacteria attack the emulsifiers in the water-based metalworking fluid and break the solution apart. The pH of the fluid when checked was 7.1. A typical water-based fluid is alkaline and has a pH from 8.6 to 9.1 in normal operation. When bacteria attack a fluid their waste is acidic. This fluid had been sitting around so long that the batch of approximately 200 gallons was almost neutral.

The fluid had a strong odor to it. In order to not violate area permits, permission was obtained by waste management to add one pound of sodium hydroxide to the fluid to bring it up into the normal alkaline range and slow down the corrosion effects and to add four ounces of odorant to control the odor.

During the third run, the skimmer removed over 22 gallons of oil floating on the top surface of the fluid. That accounted for the stair-step shape of Table 3. The weather during this run included two partial days of rain and overcast skies.

Table 3. Run 3 - Height Change vs. Time

During the 10 days since the run was started (*see* Table 3), 25% of the initial charge or approximately 2.5% per day had been removed. Ten percent of this total was due to the oil that was skimmed off the top surface during the first week. During the last five days approximately 0.2 inches of fluid height per day was removed due to evaporation.

Although the odor from this run got gradually stronger, there were no complaints from personnel in the area.

The light intensity measurements (*see* Table 4) show the effects of weather conditions. The slight change in slope of the fluid height is evident in this table. The impact from the light intensity had a striking effect on the temperatures taken along the evaporator surface and the fluid temperatures in the stock tank.

Table 4. Run 3 - Light Intensity Measurement vs. Time

The temperature of the evaporator stayed nearly constant during the daytime on the days with rain and significant cloud cover (*see* Table 5).

Table 5. Run 3 - Temperature Profile Across Collector vs. Time

The daily temperature and humidity excursions plotted on top of each other (*see* Table 6) shows some definite trends. To increase efficiency, the system pump should be shut down from midnight to 8:00 AM. During this period the evaporator acts like a condenser because the temperature extremes flip and the fluid cools as it flows down the surface.

Table 6. One Month of Temperature Cycles

When the data is spread out (*see* Table 7), it is evident that on certain days nothing significant occurred due to inclement weather and precipitation.

Table 7. Temperature – Humidity Extremes During Run 3

Conclusions and Recommendations

Following are conclusions about the feasibility of using an evaporator to reduce the water-based metalworking fluid waste stream.

The evaporator can reduce the metalworking fluid waste stream. Testing has shown that the potential is available in the summer and early fall time frame. However, in dealing with water – based material there is the potential for freezing. If the unit is to be run into late fall, the system pump must be run full time to prevent freezing.

The evaporator needs to be checked periodically during the day. It cannot be left unattended as currently designed and instrumented. This is especially true when the unit is first charged and the amount of oil that the skimmer can pick up may exceed the waste oil reservoir capacity. Also there is potential for leaks, manifold plugging, and wind gusts catching and moving the rain shield.

If the evaporator leaks and/or spills, there is potential for creating more waste than the evaporator can save. This is especially true if precipitation is involved because of the evaporator location in a confinement area of the barrel lot.

If the evaporator unit was longer, it would have the potential to evaporate more fluid, as proved by adding the extensions and verifying the loss rate rose.

If the evaporator tank had its own confinement tank, the potential for spill contamination would be greatly reduced. All oil waste containers need to be inside the confinement area. All components need to be under a rain shield. Precipitation could easily fill an uncovered confinement tank.

To operate the unit unattended, additional instrumentation has to be added to the installation and an annunciator panel installed in the waste management area so that personnel could quickly check on the unit.

Potential exists for making the evaporator unit more efficient. There is capacity in the pump to add a third fluid stream through a solar water heater. This would increase the fluid temperature and will affect the evaporation rate. Another suggestion is to add air flow under the rain shield to carry away part of the saturated air. Care must be taken in the unit design to prevent condensed droplets of MWF being released when warm humid air hits the cooler atmosphere. However, since the fluid is water based, no spill hazards are anticipated. Timers could also be added to shut the system down about three hours after sundown and activate the system after sunrise. This would prevent the evaporator from turning into a collector during early morning hours when the evaporator is cooling the fluid and removing air from its surroundings.

Future design must consider the effects of differential expansion on the instrumentation of the evaporator. As long as comparisons are made during the morning the data is valid. Differential expansion increases the measurement error during the day. Since the tank is painted black and the instrumentation is under the rain shield it is affected by the heating of the components. The data logger is within 3 inches of the tank wall and in the afternoon can read almost 30 degrees above ambient temperature. The rain shield, only partially blocked on one side, created its own environment. The location of the unit minimized air flow. This had a negative impact on the evaporation rate but did serve to protect from possible spills due to high wind.

This project contained many unexpected variables. A primary concern is that one spill and the associated contamination could create more waste than the potential benefit of the evaporator. This makes future application doubtful. These risks can be overcome but will increase the unit initial cost and monitoring costs. It would require a substantial amount of evaporation to pay for the expense of the system at an MWF removal rate of \$0.52/gallon, rendering the system non cost effective at this time.

Appendix

Observation Sheets

	A	B	C	D	E	F	G	H	I	J	K	L
1	Date	Time	Temperature	Humidity	Depth	Gage	Refractomete	pH	Oil Skim	Add Fluid	Acid	Comment
2	Run one Page 1				in	Position	Reading		Level	(lbs)	Split	
3	7/7/08	2:18	106	28	14.9	1716 lb of fluid			Sample	1716	3.5	Started-need to make h
4		3:00	Sunny	hot		Full	2	9.22	A			bigger. Started skimmer
5		3:42	104	30	14.9	Holes enlarged in manifold to 0.032 in						oil covered
6		Bright, cloudy			Adjusted flow rate, skimmer working, took sample							
7												
8	7/8/08	7:16	81	66	14.5	5/8						skimmer started, RS
9			Partly cloudy				Cloudiness increasing					
10	7/8/08	12:50	98	36	14.3	5/8	Added wear tensions, sphoned to remove oil from end of tank					
11		2:15	76	97	Started to rain, unplugged skimmer							
12				Confinement had 2 inches of water this morning								started skimmer
13	7/9/08	7:10	73	28	14.3	Fuel gage stopped working during the night, will check when confinement is dry						
14		12:35	95	46	14.2	Added sheild at right side at of main tank						
15												
16		1:30	97	42	14.15	Added shield to right side , moved manifold to right side						
17					Stopped pump at 3:00							
18		3:50	104	33	14.1	Restarted pump						
19												
20	7/10/08	7:20	74	88	13.95	Water condensed on inside of rain shield						
21						Added new splash shield, right side						
22		11:42	93	44	13.9							
23		1:50	100	36	13.8	Lowered Flow						
24		2:24	102	33	Ran skimmer from 2:30 - 3:30							
25	7/11/08	7:14	75	84	13.7	Had rain @ 5:30 , for 15 min - some MWF pulling out of hoe 50:1						
26						tank is sitting, no oil slick on top of water in confinement						
27					Retractometer very hard to read in sun, started skimmer							
28		11:56	93	47	13.6+	Starting to rain again - turned off oil skimmer						
29		2:07	90	56	13.6							
30	A -sample 263.85, ph 9.22 - ref 2.0, Hardness 250 ppm nitrate 10 ppm nitrate 0.3-1.0 ppm Alkalinite 20 drops, acid split-3.5%											
31		12:58	95F	46RH	13.5							
32												

	A	B	C	D	E	F	G	H	I	J	K	L
1	Date	Time	Temperature	Humidity	Depth	Gage	Refractometer	pH	Oil Skim	Add Fluid	Acid	Comment
2	Run 1 Page 2				in	Position	Reading		Level	(lbs)	Split	
3	7/11/08	2:07	90	56	13.6							
4	7/12/08	9:05am	82	69	13.4		Drops on sidewalk					Cloudy-Drizzel
5	7/13/08	8:43	79	55	13.2		Rained on and off all day Front thru					Rain shed covered with water
6		about 2-3 PM temp and humidity dropped. At 5:45 AM this morning driving east on 95th										
7		there was a fog cloud over Blue River and the Complex. Now it is cool and sunny rainshield										
8		covered. Confinement full of water, no slick open valve to drain. No coolant										
9		leaching out from dirt underneath tank. Let drain. Wiped rainshield.										
10		Condensate was on the bottom side of rain shield, removed as much as										
11		I could. Turned skimmer on while working on unit.										
12		9:05	86	44	Still draining confinement							
13		9:10	86		Finally saw white seepage from under tank and used pigmat							
14				44	to gather							
15		9:12	Stopped draining and closed confinement and valve, pig mat in TPH-2 can									
16			Still some condensate on bottom of rain shield, turned off skimmer									
17		9:48	88	36	Went inside and got wegy - now saw white seepage from underneath							
18			tank. Drugged up with pig mat									
19	7/13/08	Sample weight 249.27gm, ph 9.25, ref 2.0, hardness 250 - 425, Nitrate 10-20, Titration 21-22 drops, acid split										
20	7/14/08	7:06	68	74	13	Tool sample to check concentration in 200ml						
21		9:46	93F	33%	12.95							
22		11:54	100F	23%	12.94							
23		2:49	104	24%	12.9							
24	7/15/08	6:07	68F	77%	12.8		No morning Dew - did not reach dew point					
25		7:09	70	73%	12.8	Added dye supplied with 97022509 to darken fluid added 4 bottles						
26		10:00	95F	33%	12.7		enough for 4 drums					
27		12:48	95F	40%	12.6+	Dye allowed us to find leak in bottom seam. Use pig putty to						
28						fill gap						
29		1:05				Installed 2 black painted stainless steel fins						
30	7/16/08	7:35	72	75%	12.5	Dye makes fluid dark pink						
31		9:06	86	48%	12.5							
32		9:05	93	39	12.45							
33												

	A	B	C	D	E	F	G	H	I	J	K	L	
1	Date	Time	Temperature	Humidity	Depth	Gage	Refractometer	pH	Oil Skim	Add Fluid	Acid	Comment	
2	Run 1 Page 3				in	Position	Reading		Level	(lbs)	Split		
3	7/16/08	9:54	93	39%	12.45	Noticed additional leaks added pig putty to joint							
4						on both sides extend 5" right 4 in left. Also noticed							
5						shield dropped into tank tape got lose. C-clamped							
6						shield in place, should hold. Spray had been							
7						leaking down side of tank, wiped up.							
8		12:41	95	39	12.35	Leaks Fixed!!!							
9		11:30	100	39	12.3+	Rain shield installed on line from skimmer to oil							
10		2:45	97	35	12.3	L-1	container, Drilled out holes, moved scale						
11						to left side and remeasured. 12.35							
12					12.35								
13	7/17/08	6:40	72	75	12	No leaks Turn on skimmer							
14		9:14	91	41	12	Important to keep holes in manifold open to so mat. Fluid covers evaporate							
15		1:24	102	33%	12								
16	7/18	6:44	77	73	11.85	Skimmer off, no oil on top			Took sample**				
17		11:00	95	41	11.8	Sky is overcast							
18		12:08	86	53	11.75	Starting to drizzel							
19		1:37	84	58	11.75	Drilled holes in manifold. Had been raining, water on top							
20						of rain shield cloudy							
21	7/19/08	2:45	104	30%	11.5	oil coming to top			Partly cloudy				
22		2:55	111	26%	11.45	Turned skimmer on and brought up some oil				Bright sun			
23	7/20/08	--- no data Hot& Dry over 100F											
24	7/21/08	6:52	79	72%	11	two small leaks, notice could have been from wind					cleaned and washed down		
25						on north end. More oil turned skimmer on					with Windex		
26						took sample							
27		11:53	102	34%	10.9	Took Data from Data Logger							
28													
29	Sample data ph 9.24, Ref 2.2, Hardness 425, Acid Split 4.8%, Total Debris 0.4%, Nitrate 20, Nitrite 1.5												
30													
31	End of 1st Run												

	A	B	C	D	E	F	G	H	I	J	K	L
1	Date	Time	Temperature	Humidity	Depth	Gage	Refractometer	pH	Oil Skim	Add Fluid	Acid	Comment
2	Run 2 Page 1			in	Position	Reading			Level	(lbs)	Split	
3	7/24/08	11:00	97	43%	10.9							Begin 2nd Batch
4												u1003785.47 1331lbs
5												u1013872.5 for skimmer
6		1240	100	37%	10.9							
7		1420	107	33%	10.9							
8	7/25/08	7:20	75	27%	10.6							
9		9:09	75	27%	10.6							Sun coming out
10		12:20	95	53	10.5		Side Shield installed					Drain containment
11		1:15	100	43	10.5							Run skimmer .25 hours
12		4:06	104	38	10.5							Pump off for weekend
13												
14	7/28/08	6:36	75	69%	10.5							Overcast sky, drain water
15												from containment unit
16												plugged in skimmer
17		8:26	75F	72%	10.5							Unplugged skimmer
18		10:36	73	76%	10.5							Overcast Been raining
19		1:22	81	64	10.5							
20			77	83	10.3							
21		8:40	82	76%	10.3							overcast
22		12:36	86	63%	10.3							overcast sprinkles
23	7/30/08	Rain all night and most of the day. Unit not accessible in containment area										
24		Pumped down rain water from region										
25	7/31/08	7:15	72	99%	10.3							
26		12:53	86	97%	10.3			Covered with condensate lower side rain shield				
27	8/1/08	7:25	75	87%	10.3	Found one extension missing - installed 2 for a total of 5						
28		7:45	77	86	10.3	Side shields too long adjusted flow too high. Noticed hanging						
29						from manifold						
30		12:46	106	38%	10.3							
31												

	A	B	C	D	E	F	G	H	I	J	K	L
1	Date	Time	Temperature	Humidity	Depth	Gage	Refractomete	pH	Oil Skim	Add Fluid	Acid	Comment
2	Run 2 Page 2				in	Position	Reading		Level	(lbs)	Split	
3	8/1/08	12:53	106	38%		Sun out Turned on skimmer, oil seperating						
4		2:04	107	36	10.4	Partly cloudy, Turned on skimmer taking lot of oil off surface						
5	8/2/08	3:25	118	31	10.25	Hot and Humid, ran of fall flow for remain to clean manifold nozzels						
6	8/2/08	3:45	113	35%	10.25		Turned skimmer off			Clear 90		
7	8/4/08	7:01	81	67%	9.65	Turned on skimmer, installed outside thermo and humid						82.2 and 63%
8		9:20	95	43%	9.6	Skimmer pulling of oil						94F and 95%
9		2:04	113	30%	9.5	Skimmer still removing oil					Clear 90	
10		3:05	115	28	9.4+	Skiller separator leaking at filling, dropped into confinement						
11						Air temp 100 90 at Head End 102.5 at End Evap End Ext 105						
12											Clear 85	
13	8/5/08	7:50	86	60	9.3	Turn on skimmer						
14		8:20	88	58	9.3	Turn off,skimmer tighten outside air temp 85.5F, 90.9 hood, 82.5 end, 87 ext						
15		8:45	90	53%		filling and restarted lost 3 oz fluid during repair, clean up with pig mat						
16						cleaned under confinement tank						
17		10:55	100	40	9.2	fixed plugged holes				temp 90.4, 90.1, 89.5 90.9		
18						Removed side panel opposite skimmer					90.0 N 90.1 S	
19		0.234	118	25%	9.1	Top 99.0, Bot 101.0, End 103.5, @ Pump fluid 102.0, End 102.6						
20			79			Turned off skimmer						
21	8/6/08	7:16		67	8.9+	Turned on skimmer - Unstalled first solar fan						
22						Ambient 75.6, Head End 88.7, Tail 87.6, Ext End 88.1, Fluid South 88.5, Fluid North 88.5						
23		8:30	Installed 2 solar fans on to rain shield, sound extension - now have 6 extensions installed									
24			modified funnel over 5 gallon oil can, easier to adjust oil skimmer									
25			Fans had enough light around to drive fan.							Partly cloudy morning, cloudy afternoon		
26		9:43	86	60%	8.9						threat of rain	
27						Ambient 80.4, Head End 89.2,, Tail 89.0, End 87.3, South 88.6, North 89.0						
28		2:06	104	35%		8.8	Amb 91.5, Head 93, Foot 96, End 98.2, South 95.7, North 94.7					
29		2:45	96	41		8.8	Amb 89.7, Head 92.8, Foot 94, End 92.0, South 95.7, North 94.7, Turned skimmer off					
30						Changed battery and down loaded file						
31	8/7/08	7:22	73	74%	8.65	No oil turned on skimmer			Under side of rain shield 60% condensate covered			
32						2nd thermometer on top of rain shield						
33						76.8, 65%				Clear 90		

	A	B	C	D	E	F	G	H	I	J	K	L	
1	Date	Time	Temperature	Humidity	Depth	Gage	Refractometer	pH	Oil Skim	Add Fluid	Acid	Comment	
2	Run 2 Page 3				in	Position	Reading		Level	(lbs)	Split		
3	3/20/00	9:42	96.6	39%	8.6	E	Amb 77.0, Head 81.8, Tail 82.9, End 83.3, S 83, N 82.8						
4						K	Amb 76.7, Head 77.7, Tail 79.1, End 79.1, South 78.5, North 78.6						
5			New oil container started										
6		1:09	102	27%	8.5+		<95.7 and 31 thermometer in shade					partly cloudy 80	
7							EB Amb 89, Head 86.8, Tail 91.7, End 93.8, South 90.5, North 90.3						
8							KB Amb 83.2, Head 83.5, Tail 85.1, End 87.2, South 85.4, North 84.7						
9			As fluid heats up more oil appears on surface 4.3 and 5.4 okfc										
10							EB Amb 69.9, Head 81.3, Tail 79.9, End 80.8, South 81.1, North 81.4						
11							KB Amb 70.6, Head 81.5, Tail 81.3, End 81.0, South 81.0, North 81.3						
12		Inside of rain shield cover, covered with condensate, 80% coverage wiped off Sun touching top of rain cover with side											
13		at 7:45 AM - 1:15 at rain shield level, solar fans not running, condensation recovered solar cells											
14		No oil on surface											
15			F F	F F									
16		10:05	93 86.7	40 40%	8.3	Full sun 6.20 kfc							
17							EB Amb 84.4, Head 84.1, Tail 85.0, End 85.4, South 84.1, North 84.2						
18							KB Amb 84.4, Head 80.2, Tail 80.6, End 82.4, South 80.7, North 80.6						
19		12:37	98 94.8	32 32%	8.25	EB Amb 89.1, Head 91.5, Tail 94.0, End 95.0, South 91.6, North 90.9							
20							KB Amb 81.5, Head 86.0, Tail 86.8, End 87.6, South 86.3, North 85.9						
21				Saw oil turned skimmer on									
22		2:36	106 98.81	26 31%	8.25	Partly cloudy - shade 1.85 kfc							
23		Going in and out of sun					EB 88.5, Head 92.7, Tail 93.7, End 93.6, South 94.3, North 94.4						
24							KB Amb 92.0, Head 92.2, Tail 91.2, End 90.9, South 91.2, North 90.9						
25	8/9/08		Rained in the morning, cloudy all day High 75,										
26	8/10/08		Cleaning sunny afternoon High 85										
27	8/11/08	6:58	70 71	78 70%	7.75	0.243kfc	EB 69.1, Head 81.3, Tail 80.0, End 79.2, South 81.1, North 81.3						
28							KB 67.4, Head 81.3, Tail 81.1, End 80.0, South 80.4, North 81.4						
29		Dew inside rain shield, 30% covered at manifold and at south end at 7:14 .31 RFC											
30		Solar fans not running Residual water in bottom of oil skimmer confinement tote pan											
31			Top of TPH Debris 1 barrel and storage tote pan, no water on ground										
32													

	A	B	C	D	E	F	G	H	I	J	K	L	
1	Date	Time	Temperature	Humidity	Depth	Gage	Refractometer	pH	Oil Skim	Add Fluid	Acid	Comment	
2	Run 2 Page 4												
3	8/11/08	10:36	86 88.7	50 42%	7.65	Partial Cloudy, Power 3.6 to 5.6 KFC						Slight oil turned on, 10% skimmer	
4				EB 78.3 Amb Head 83.0, Tail 84.3, End 84.4, South 83.1, North 82.7									
5				KB 75.3, Amb Head 80.7, Tail 81.5, End 81.9, South 80.7, North 80.3									
6				Power at end 7.65 Sun out									
7		1:30	98 96.4	36 36%	7.6	Came out started taking measurements 2.44 kfc for Eb , cloudy							
8				EB Amb, 84.7, Head 89.9, Tail 90.0, End 89.3, South 89.3, North 89.4, 10.64 kfc for KB , Sun went back to cloudy									
9		60% - 70%		KB Amb 87.1, Head 87.0, tail 88.7, End 91.9, South 86.9, North 86.4									
10		cloud cover											
11													
12		2:50	106 107.4	26 28	7.55	Sun going in and out 8.78 - 10.16 kfc							
13		High Cirrus		Eb Amb 84.5, Head 86.0, Tail 92.3, End 95.9, South 93.0, North 91.5									
14		w/cumulus clouds		Kb Amb 81.8, Head 86.5, Tail 87.7, End 88.6, South 85.7, North 80.8									
15		50% - 70%											
16				Turned off skimmer									
17													
18	8/12/08	10:12	86%	57%	7.55	Turned off system and pumped to							
19													
20			Completion of run 2										
21													
22													
23													

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q		
1	Date	Time	Temperature	Humidity	Depth	Light Lvl	Head	End	Tail	TITk	HdTk	Refractometer	pH	Oil Skin	Add Fluid	Acid	Comment		
2					in	K ft-candk	Temp	Temp	Temp	Temp	Temp	Reading		Level	(lbs)	Split			
3	Run 3	Page 1																	
4		Before system turned on							Added fluid in confinement skimmer										
5																			
6	9/18	12:44	98	27	13.6	8.2/10.3	95	96	98	72.1	71.5		7.56				Ambient 83.5		
7			Turned on at 12:55 Added 215 naOH, 202 Oclesout, 202 dye , electronic 20.7																
8			Drill holes to .063 dia after manifold plugged 8.00 Having problem plugging manifold																
9			Put pump on top of one gallon pail. Pump still submerged																
10		Carbon from chip drain. Has a lot of debris in it including pig mat fiber																	
11				24	13.5	86.3	86.3	87.1	81.7	85.5	85.1			Electronic 20.2	Ambient 83.5F				
12	9/19	7:15	Left skimmer on all night and overflowed 5 gallon oil , 2 container got new Est. 3 gallons																
13			container , cleaned up mess. Started new oil. L2 container. Took one at Mic 100/200																
14			Micron Bag filters from FMS and Modified to fit 3/4 inch schedule 40 pipe																
15			and installed on pump. Pump prefilters were plugged. After installing filter																
16			unplugged manifold and readjusted. Seems to be working. At 9:00 added 2 oz of																
17			orderant ph of fluid 8.93																
18		9:00	70	71	13	2.8k	74.7	75	74	75.6	74.4		8.93	Took sample	Ambient 68.9				
19		12:45	93	35	13.3	6.35k	81.3	83.8	90.2	84.7	80.5			21.4 Ebc	Ambient 79.2				
20		1:14	97	31			85.8	86	87.1	86.1	84.4				21	Ambient 84.7			
21		3:37	107	21	12.9	5.8k	88	89	89.4	89.5	87	Turned off oil skimmer			21.3				
22	9/20	6:10	61	84	12.85	0.026	76.8	76.6	76.5	77	76.9	Turned on oil skimmer			21.3	Ambient 60.3			
23					Changed out oil L2 can - Evaporator covered with dew														
24		10:33	84	49	12.65	6.01	74.2	77.8	77.7	77.3	74				21.3	Ambient 78.9			
25		2:53	95	32	12.55	13.4/4.37	84.3	85.1	86.1	85.1	83.9				21.4	Ambient 87.8			
26		Debris under oil skimmer tube scraper, not all oil being removed - removed chips. Poured contents of 2nd oil L2 can																	
27		into 1st Removed 5 gallon of oil since yesterday																	
28	9/21	5:50	61	88	12.45	.022k	76.6	76	76	76.7	76.9	Covered without dew insk			21.4	Ambient 61.0			
29		9:15	73	70	12.25	3.34k	75.2	75.3	75.3	75.4	74.9	Covered w/50% dew			21.7	Ambient 70.8			
30		12:5	97	36	12.2	8.6k	83.1	84.3	85	83.9	83.2				22.2	Ambient 79.1			
31		3:30	97	32	12.15	6.1k	86.6	86.9	87.7	87.6	86.6				22.4	Ambient 81.0			
32		4:41	97	31	12.1	Changed out 5 gallon oil can and let runover night										22.3			
33																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Date	Time	Temperature	Humidity	Depth	Light Lvl	Head	End	Tail	TITk	HdTk	Refractomete	pH	Oil Skin	Add Fluid	Acid	Comment
2					in	K ft-candle	Temp	Temp	Temp	Temp	Temp	Reading		Level	(lbs)	Split	
3	Run 3		page 2														
4																	
5	9/22	6:40	64	83	11.7	.047k	77	76.6	76.3	76.7	77.2						22 Ambient 65.4
6			Decanted oil can Mat. Ran oil night, turned in 2 oil L2 5 gallon cans														
7		10:14	81	87	11.6	5.60k	76.5	77.7	78.6	77.8	75.5						22.3 Ambient 76.0
8		2:27	82/102	29	11.05	7.2k	88.7	89.7	91.6	89.3	87.3						22.4 Ambient 82
9		4:00	Turned off skimmer Top almost clear of oil														Ambient
10	9/23	6:55	66	81	11.55	.067k	73.9	74.6	73.8	74.2	74.2	Cover 10% widew					22.3 Ambient 65.9
11		10:47	88	46	11.4	4.9	77.4	80.6	79.3	79.7	76.7						22.7 Ambient 80.8
12		2:10	100	31	11.35	7.3	85.4	89	86.7	86.8	84.6						22.8 Ambient 84.9
13		4:55	98	34	11.15												23 Ambient
14	9/24	11:20	82	63	11.1	6.9	75.5	77.9	80.5	76.4	74.6	Rained 6:50 AM for 2 hours					22.6 Ambient 79.6
15		2:00	97	36	11	5.75	81.3	82.1	84.6	82.3	82						Ambient 82.9
16	9/25	7:05	61	87	10.85	0.61	74	73.8	73.8	74.2	74.2	a lot of condensate on inside of					22.8 Ambient 59.8 very little outside
17												rain shield - It was raining					
18		9:00	72	74	10.75	3.51	74.2	74.5	74.8	74.6	73.3	Removed dew inside - 80%					22.8 Ambient 68.0
19	9/26	6:45	63	86	10.8	0.04	75.4	74.9	74.6	75.5	75.3	Lots of condensate on bot of shield					23 60.1
20		7:56	63	87	10.6	0.74	74.5	74.9	74.6	75.5	74.9	Remov'd dew from underside of rain shield					22.9 64.5
21		11:00	88	44	10.65	5.5	77.2	78.4	80	78.5	76.6						23.5 83
22		2:45	104	27	10.6	6	87.3	89	90	84.1	86.7						23.5 87.6
23	9/27	8:50	66	76	10.4	2.7	72.7	72.8	73.2	73.2	72.3						23.3 67.8
24		12:50	100	31	10.35	7.65	82.8	83	85.2	84	82.5						23.7 83.7
25		4:16	107	22	10.3	3.97	88.7	89.5	90.5	89.6	88.6						23.7 87.5
26	9/28	8:44	98	32	10.05	7.8	83.2	84.2	87	84.5	83.9						24 89
27																	
28																	
29																	
30																	
31																	
32		4:41	97	31	12.1	Changed out 5 gallon oil can and let runover night										22.3	
33																	
34																	