To the Graduate Council:

I am submitting herewith a thesis written by David A. Turner entitled "The Utilization of Compost Heat in Small-Scale Aquaculture." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

J. Larry Wilson, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

THE UTILIZATION OF COMPOST HEAT IN SMALL-SCALE AQUACULTURE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

David A. Turner

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ABSTRACT

Heat generated from composting fresh animal manure was collected with steel and copper heat exchangers. Water was pumped through the heat exchangers at a constant flow of 2 L/minute. The effluent temperature showed an average increase (ΔT) of 5.7 C and 3.5 C for steel and copper, respectively. A volume of 5.9 m^3 of compost maintained these temperatures for an average of 15 days per run. In a series of tests, water flow rates of 1.0, 2.0, 3.0, and 4.0 L/minute experienced an average increase in temperatures of 8.1, 4.5, 3.2, and 3.2 C for steel and 5.9, 3.1, 1.9, and 1.6 C for copper, respectively. These tests were run for one 60-minute period on 6 consecutive days.

The application of this heat source in a recirculated system design showed an average increase in temperature of 4.8 C. It was observed that increased moisture of the composting material decreased the biological activity, i.e., heat generating capacity, of the compost heap. The technique showed potential for warming water when applied to small volume aquatic systems.

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INTRODUCTION

In recent years, warm water aquaculture has become a multi-million dollar industry in the southeastern United States. The principal species cultured by the industry is channel catfish (Ictalurus punctatus). During 1980, 46.5 million pounds of processed channel catfish were produced (USDA Economics and Statistics Service, 1981). The success of the industry in the southeast is due, in part, to the relatively long growing season with water temperatures above 15 C. This is the approximate minimum level necessary for channel catfish to metabolish food into flesh. Boyd and Lichkoppler (1979) emphasized the importance of increased water temperature for rapid growth of fish and fish food organisms that occur in temperate zones during cool winter months. Lovell and Skirul (1974) documented that channel catfish grown in the temperate regions do not feed as much or as consistently in the cool weather months as during the warm seasons. In Tennessee, a shorter growing season exists and requires that a larger fingerling (at an additional cost) be stocked to attain the desired harvestable size at the end of the season (T. K. Hill, personal communication).

In marginal areas such as Tennessee, the growing season is less than 150 to 160 days. In these areas, consideration has been given to methods which might increase the period of time that water temperatures are above 15 C. Conventional methods of heating water, such as direct heating of culture water with electric and gas heaters, have been considered (Martin 1967). Based on limited system capacity and market value of the fish produced, these attempts were uneconomical due to increasing energy costs and resulting minimum returns on the investment (TVA 1974).

Another more recent attempt to develop cost-effective methods of heating water for fish production has used solar energy (Harvey 1977). However, preliminary research determined that low-cost solar energy collectors had limited success in their application to aquatic systems. The main problem was the inability to maintain a suitable temperature regime for the aquatic culture organisms.

The purpose of this project was to develop and evaluate a practical method for using compost heat to warm water. Specifically, the objective was to determine if the heat generated by composting can be used to heat water in flow-through and recirculating systems. This method, if successful, may have potential for extending the growing season in small-scale aquacultural operations. "Against this background it is surprising that composting, so far, has not been used to any great extent in the United States. There is no doubt, however, that this method will become increasingly important in the future" (Schulze, 1962).

CHAPTER I

LITERATURE REVIEW

Composting is generally defined as an aerobic biological process in which organic wastes are converted into humus. This takes place through complex interactions of microorganisms such as bacteria, fungi, and protozoa (Dindal 1978). There are two thermal regimes produced by bacterial oxidation during the composting process (Poincelot 1974). The initial range of temperatures in composting is termed the mesophilic phase. This temperature regime is from the ambient temperature to 40 C. The second thermal regime of composting is the thermophilic phase in which temperatures range from 40 to 70 C (Poincelot 1974).

The process of composting has been utilized throughout recorded history. George Washington mentioned combinations of stable manure and soil in an entry in his diary dated April 14, 1760 (Poincelot 1974). It was not until the early 1930's, however, that a British agronomist, Sir Albert Howard, made important advances in the use of composting. His work was the first systemized approach and led to the organic gardening movement in 1942 by J. I. Rodale.

Much scientific research on the composting process has been completed during the past 50 years (Poincelot 1974). The aspect of composting on which this research was most concentrated involved the excellent potential of its thermal properties. The heat production potential of compost was determined by Wiley (1957) to be as high as 10,000 to 12,000 B.T.U. per pound of volatile solids decomposed into carbon dioxide and water. The temperatures in composting were found to be the result of processes that take place during the life cycle of indigenous bacteria and fungi (Poincelot 1974). During this cycle the heat increases as the biological oxidation of energy present within the compost heap is utilized. The thermal phases are named according to the associated bacteria and fungi present at particular temperatures. The thermophilic phase which exhibits temperatures from 40 to 70 C was the most important in the application of this research project.

No information on the documentation of utilization of compost heat to warm water was found in the literature. However, the utilization of this economical heat source was successfully used to heat a commercial greenhouse in Memphis, Tennessee (Plato Toulatous, personal communication).

CHAPTER II

METHODS

The research project was an applied study. The results are presented in two basic areas: developmental and experimental. Developmental results were obtained from qualitative observations and development of procedures which had an impact on the success of the heating systems. Experimental results were obtained from quantitative experiments. Both areas are addressed in the results and discussion chapter.

Compost heaps of fresh animal manure were constructed at the Holston Fisheries Facility during 1982. Large quantities of composting media were available on a regular basis from the Knoxville Zoological Park. Elephant manure was selected as the composting media because of its following characteristics: high hay content, high percentage of partially digested food, and 40-60 percent moisture content (Poincelot 1974). These characteristics resulted in an excellent biological heat energy source. Compost heaps were constructed for each experimental test during the study.

The compost heaps were constructed to maximize heat generation by maintaining aerobic conditions for as long as possible. They were also constructed to minimize heat loss through the use of insulation and a plastic cover. The following methods were employed in the construction of the compost heaps. A layer of brush approximately 30 cm thick was used as a foundation for the heap. It allowed an outside air source to circulate through the bottom of the compost heap. Day-old elephant manure was placed on the sides and the top of the brush. The finished compost heap had an overall width of 1.5 m, a height of 1.8 m, a length of 2.1 m, and a volume of 5.9 m^3. The dimensions of the heap included a minimum of 30 cm of insulation. The diagram of the compost heap and heat exchanger is shown in Figure 1.

A black polyethylene plastic cover of 4.0 mil thickness was placed over the top and sides of the completed heap and securely anchored. Temperatures of the compost heap were taken daily at a depth of approximately 15 cm from the top near the heat exchanger location.

The compost heap was allowed to mature to the mesophilic phase with temperatures attaining 40 C. When the compost heap temperature had risen above 40 C (thermophilic phase), the water warming phase of the experiment was initiated. The temperatures of the compost heap remained above 40 C during the thermophilic phase before return to ambient temperatures upon completion of the composting process.

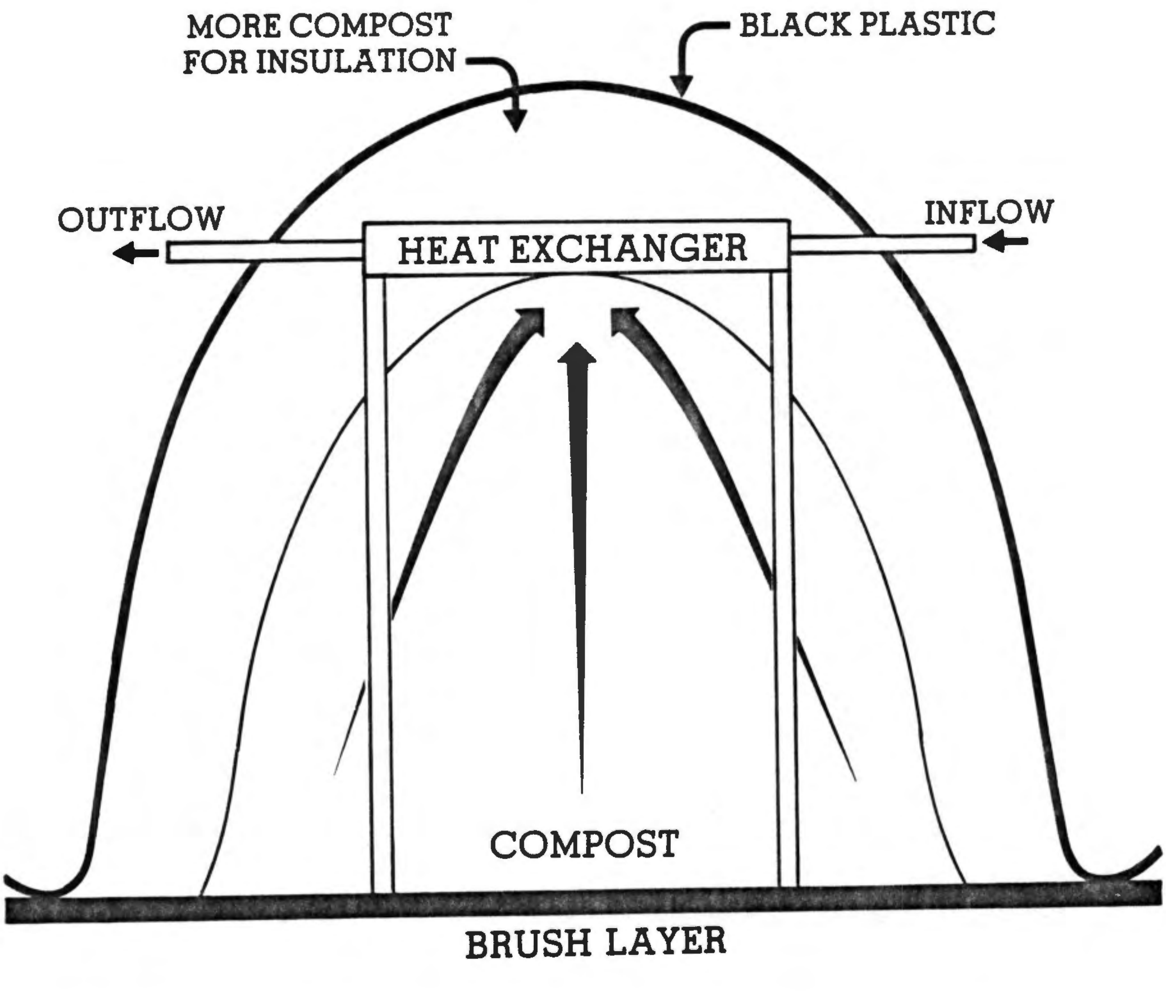


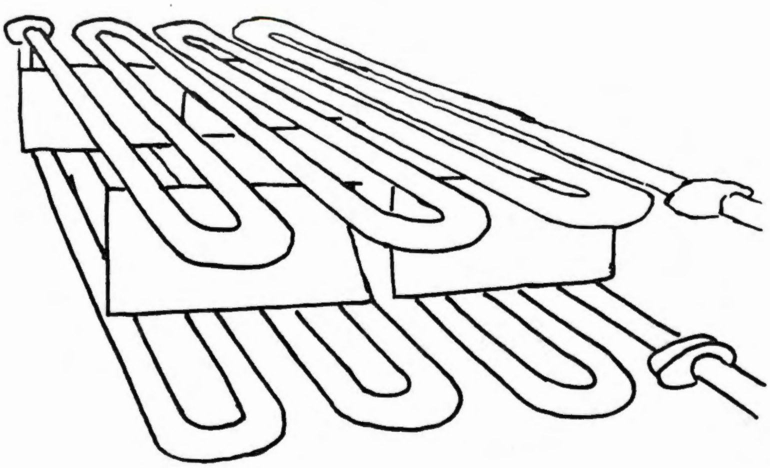
Figure 1. Diagram of the compost heap and heat exchanger configuration.

Heat Exchangers

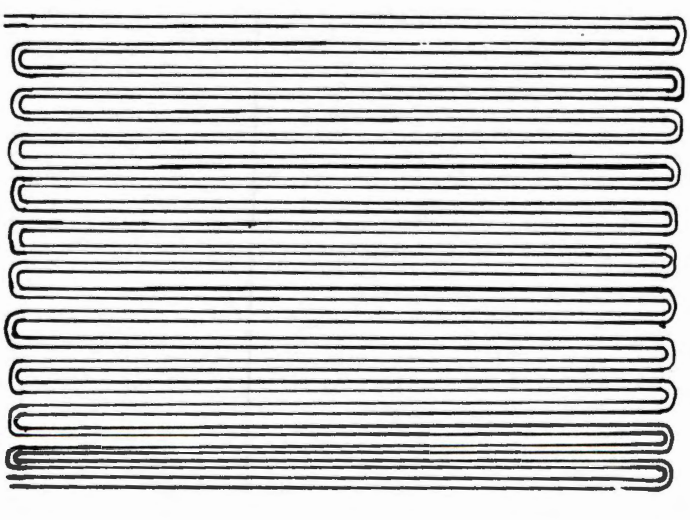
Heat exchangers of steel and copper were used to transfer heat produced during composting. The physical composition, configuration, and dimensions differed between the heat exchanger units. The steel unit employed was a shelf refrigeration unit from a dairy operation's storage cooler. It was composed of two layers of pipes (3.2 cm diameter) with a total length of 29.1 m and a surface area of 5.7 m^2. Each layer had seven pipes 210.8 cm in length which were joined by a 15.2 cm connector pipe as illustrated in Figure 2.

The copper heat exchanger was assembled with 1.3 cm diameter copper pipe. The copper pipe was cut into 22 length of 205.7 cm. One 45° angle street-L was soldered to each length using a portable gas torch. The lengths were soldered together to complete a continuous unit. The copper unit had total length of 44.6 m, a surface area of 3.5 m^2, and a thickness of 3.2 m. The copper heat exchanger was constructed in only one layer.

Two heat exchanger positions within the compost heap were tested in an attempt to maximize the compost heat transfer to the circulated water. A direct transfer method was tested by imbedding the heat exchanger in the compost heap. From a related study with wood chips as a media, Zoch (1982) found much higher temperatures near the apex of chip piles. Thus an indirect transfer of heat



(A)



(B)

Figure 2. The steel heat exchanger (A) diagram and the copper heat exchanger (B) diagram as used in the project. No scale is expressed in the drawings.

was employed using the same concept by positioning the heat exchangers above the compost heap. A wood stand was used to position the exchangers in the desired location in the compost heap.

Water Supply

The water supply for the research project was from a municipal source. During preliminary tests, a well water source from a well 76.2 m in depth with a flow rate of 18.9 L/min was utilized. The well water was abandoned due to a low volume output and inconsistent pressures (surges) ranging from .5 to 4 L/min. It was determined that a more consistent water flow was necessary to test the system. A flow rate of 2 L/min was used during subsequent tests. The water temperature was monitored daily throughout the experimental period.

Flow Rates

Three different experiments were conducted to examine various parameters associated with the use of compost heaps to raise the temperature of the water flowing through heat exchangers. In the first experiment, a constant volume of 2 L/min was circulated in a flow-through system design. The temperatures of the water and the compost heap were monitored daily with a hand-held thermometer. Six discrete tests of the experiment were completed during the spring, summer, and fall of 1982.

The time for each test varied and was dependent upon the rate of decomposition of the composting manure. The tests were terminated when the water and compost temperatures showed a decline (less than 40 C) compared to the initial temperatures. The steel heat exchanger was used on all of the trials, and the copper heat exchanger was used only twice.

In the second experiment, the effect of flow rate on change in temperature (ΔT) was evaluated. Flow rates of 1.0, 2.0, 3.0, and 4.0 L/min were supplied to the heat exchangers. A constant flow of water was established through the system with the water and compost heap temperatures monitored on 5-minute intervals for 60 minutes, six times during 6 days when the compost heap was in the thermophilic phase. Each discrete volume was circulated through the heat exchangers until the effluent water temperature remained stable with no change in the compost heap temperature. The temperatures were recorded to the nearest 0.5 C with a hand-held thermometer. The third experiment was to assess the effects of the compost heat in a recirculating or closed system design. A low head submersible pump (Little Giant No. 1P3212E-N) was used to pump a constant volume of water of 2 L/min through the heat exchanger and then to a receiving tank (1359 L). The temperatures of the effluent water, the receiving tank, and ambient control tank were recorded daily for the duration of the trial. These parameters were recorded to document the application of compost heat in a recirculated system.

CHAPTER III

RESULTS AND DISCUSSION

As stated earlier, the research project was an applied study. The results of the research project were divided into two general areas (developmental and experimental). The developmental areas include qualitative observations and the development of procedures. These will be presented in order of imporatance prior to specific discussion of each experimental test.

Developmental Results

The position of the heat exchanger units was very important to the success of the project. The first method of positioning was imbedding the exchanger pipes within the compost heap. This method had a negative effect on the biological activity of the composting media. It was determined when the heat exchanger units were positioned above the active compost heap an adequate heat transfer occurred. This method did not have any effect on the biological activity of the compost heap.

The insulation of the compost heap was a necessary addition to prevent severe temperature fluctuations in the compost heap and heat exchanger area. In preliminary experimental tests without insulation, the heat transfer was not adequate to effectively warm water to provide an optimal environment for aquaculture.

The short duration of the mesophilic phase of approximately 3 days per compost heap was noted. The duration of the thermophilic phase varied but on the average was 15 days per compost heap.

<u>First Experimental Test</u>

The first investigation concerned the application of the compost heat to a constant flow in an open or flow-through system. The 2 L/min flow was used and this was determined by the size or the capacity of the system. The flow of 2 L/min would displace 2.1 times the volume in the receiving tank during a 24 hour period. This flow rate would effectively maintain adequate water quality potential for production of warm water culture (T. K. Hill, personal communication).

The water passed through the heat exchanger units and returned to a receiving tank. A total of six test runs were completed using the steel heat exchanger and two test runs were completed using the copper heat exchanger. The results indicated in Table 1 document an average net change in temperature of 5.7 C for water in the steel heat exchanger and an average change in temperature of 3.5 C for water flowing through the copper heat exchanger. The longest period of composting was

Table 1. Weekly average of the net temperature change (C) of effluent water from steel and copper heat exchanger units with constant flow of 2 L/minute.[1]

Trial	Steel	Copper
1	2.5	4.0
2	5.9	2.9
3	5.9	
4	4.7	Mean 3.5
5	4.9	
6	10.3	
	Mean 5.7	

[1]This data is condensed from the raw data in Tables 2 through 7 (Appendix).

26 days, and the shortest period was 5 days with an average of 15 days. Each compost heap required an average of 10 man-hours for construction and was not turned after construction. The water temperature produced during six test trials using a constant flow of 2 L/min (2880 L/day) are desirable temperatures for production conditions for small-scale aquaculture systems.

The capacity of the receiving tank was approximately 1360 L, and the tank water was displaced 2.1 times during a 24-hour period at a flow rate of 2 L/min.

To this point, the discussion of the effluent water temperature data has been concerned with the net change in temperature. However, the effluent water temperature for six test trials averaged 26.7 C for the steel heat exchanger and 22.1 C for the copper heat exchanger.

As illustrated in Figure 3, the temperatures of the compost heat system demonstrated minor daily fluctuations. However, one temperature change did occur and was due to accidental removal of the plastic covering on day 9. This allowed the heated air space to cool rapidly which subsequently decreased the heat transfer to the heat exchangers. However, the heat transfer did increase after replacing the outer plastic cover as shown on day 10. The sensitivity of the biological system in compost is demonstrated by this temperature decline. The resultant rise or recovery in temperatures was caused by the restoration of thermophilic composting conditions which was assisted by the plastic cover.

As previously stated, the compost heaps demonstrated variability in the duration of the heat generating capacity. The variability was attributed to a higher than desirable moisture content (> 60 percent) of the composting media (Poincelot 1974) and an apparent texture change. The composition of the manure varied from that of predominantly hay to that of a finely textured material that resulted from a diet of a commercially prepared feed. In three of the test runs (Tables 3, 4, and 6 in the Appendix),

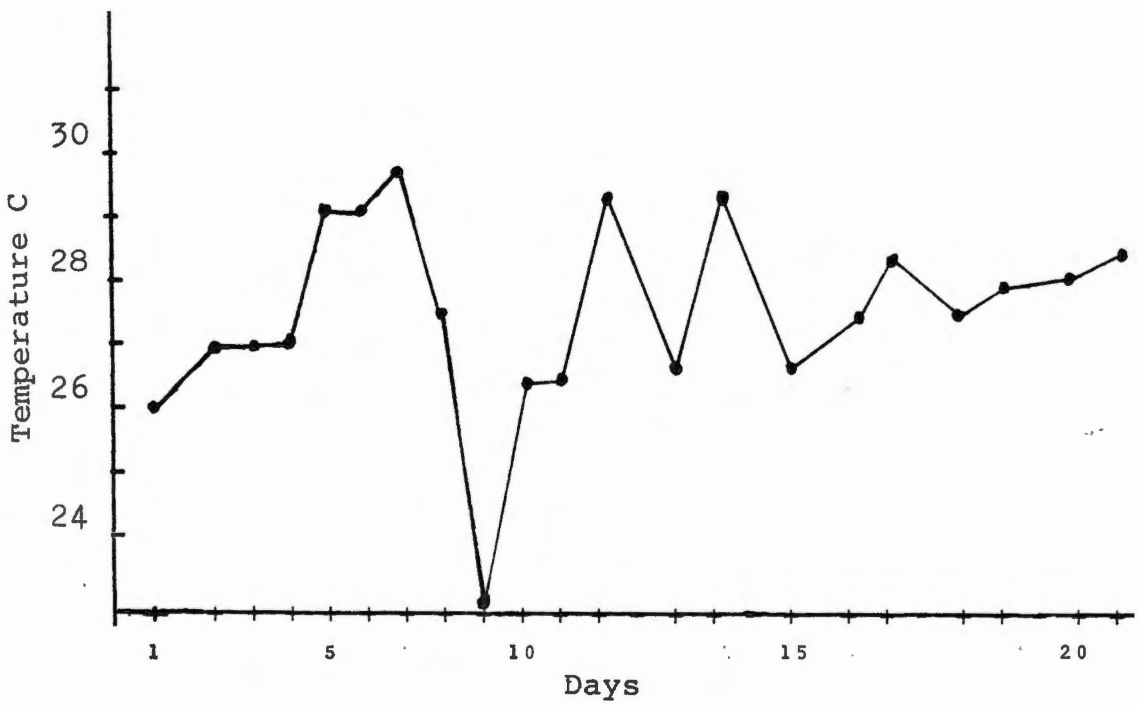


Figure 3. The first test of a constant flow of 2 L/min indicated a temperature fluctuation of the effluent water. The incoming water had a temperature of 17 C (Table 2, Appendix).

the duration of the tests were reduced due to the above-mentioned problem. The plastic cover and the insulation layer are necessary to maintain an adequate temperature for the heat transfer from the compost to the water in the heat exchangers. It was found here that the plastic cover also prevented atmospheric moisture from effecting the desired moisture level in the compost heap.

The data from this experiment showed that the effluent water that passed through the steel heat exchanger showed higher temperatures than that which passed through the copper heat exchanger unit. As mentioned earlier, major physical differences existed between the steel and the copper heat exchanger units. The most obvious difference was that the steel exchanger had two layers, and the copper had one layer to transfer heat. The two layers and a much larger pipe diameter created a longer retention time for the water within the steel heat exchanger. The fact that the steel heat exchanger was more efficient at heat transfer than the copper was based on the greater volume of the steel. Assuming that both heat exchangers were filled to capacity during the tests, the volume of the steel heat exchanger was 23.4 L, and the volume of the copper heat exchanger was 5.7 L. Thus, the steel heat exchanger retained four times the volume of water than was retained in the copper heat exchanger.

The caloric value of the heat energy produced by the steel and copper heat exchangers indicated that more energy was absorbed by the steel than the copper. The average caloric value produced by the net temperature change of the effluent water through the steel during the 2 L/min test was 12.08 kilocalories/min as compared to 6.04 kilocalories/min with the copper.

Second Experimental Test

The second experimental investigation involved the quantification of the heat energy produced in the compost heap and the heat transfer to the heat exchanger units at four discrete flow rates. During this phase, the compost heap had an average temperature of 44.0 C (thermophilic phase), and the water supply had an initial temperature of 8.0 C. The flow rates were tested at volumes of 1.0, 2.0, 3.0, and 4.0 L/min for 60 minutes each for six days, respectively (see Table 8, Appendix). The flow rate of 1.0 L/min had the most increase with an average temperature of 16.1 C or a net change (ΔT) of 8.0 C produced from the steel heat exchanger unit. The copper heat exchanger unit at 1.0 L/min flow rate had an average temperature of 13.9 C or a net change (ΔT) of 5.9 C. The net caloric change at this flow was 8.0 kilocalories/min for the steel heat exchanger and 5.9 kilocalories/min for the copper heat exchanger.

The second flow tested was a volume of 2.0 L/min during which both heat exchanger units experienced an increase in effluent water temperature over the incoming water. The water in the steel heat exchanger was reduced as compared to the 1.0 L/min flow to an average temperature of 12.5 C or net change (ΔT) of 4.5 C, but the energy extracted increased to 9.0 kilocalories/min for the steel heat exchanger as compared to the 1.0 L/min flow. The water from the copper heat exchanger unit also experienced a drop in temperature to an average of 11.1 C or a net change (ΔT) of 3.1 C. The energy extracted by the copper heat exchanger had an increase to 6.2 kilocalories/min.

The third flow rate tested was 3.0 L/min and exhibited only a slight increase in effluent water temperature from both heat exchanger units. The effluent water from the steel heat exchanger had an average of 11.2 C or a net change (ΔT) of 3.2 C. The effluent water from the copper heat exchanger had an average temperature of 9.9 C or a net change (ΔT) of 1.9 C. Both units experienced an increase of caloric value of 9.6 kilocalories/min for the steel and 5.7 kilocalories/min for the copper heat exchanger as compared to 2.0 L/min flow.

The fourth flow rate was 4.0 L/min. The data from this flow indicated minimal fluctuation in the effluent water temperature. The effluent water temperature from the steel heat exchanger was 11.2 C which was the same as the 3.0 L/min flow rate temperature. The caloric value had an increase to 12.8 kilocalories/min. The effluent water temperature from the copper heat exchanger experienced a slight decrease to 9.6 C or a net change (ΔT) of 1.6 C. The caloric value had a slight increase to 6.4 kilocalories/min.

The overall results of the quantitative testing of the discrete flow rates and the effluent water temperature relationships is shown in Figure 4. The decline in effluent water temperatures and net change in temperatures as the flow rates increased was an expected result. The calories of the heat energy extracted from the compost heap was greater for the steel heat exchanger than for the copper heat exchanger. This was due to the higher effluent temperatures for the steel which was explained by volume and retention time.

On comparing the 2.0 L/min flow rates of the second experimental test to the first test, the average net temperature changes (ΔT) were 4.5 C and 5.7 C for the steel heat exchanger, respectively. A similar comparison of the copper heat exchanger indicated average net temperature changes (ΔT) of 3.1 C and 3.5 C, respectively. The energy values for the steel heat exchanger for the 2.0 L/min flow rate was 11.4 kilocalories/min for the first experiment and 9.0 kilocalories/min for the second experiment. A similar comparison for the copper heat

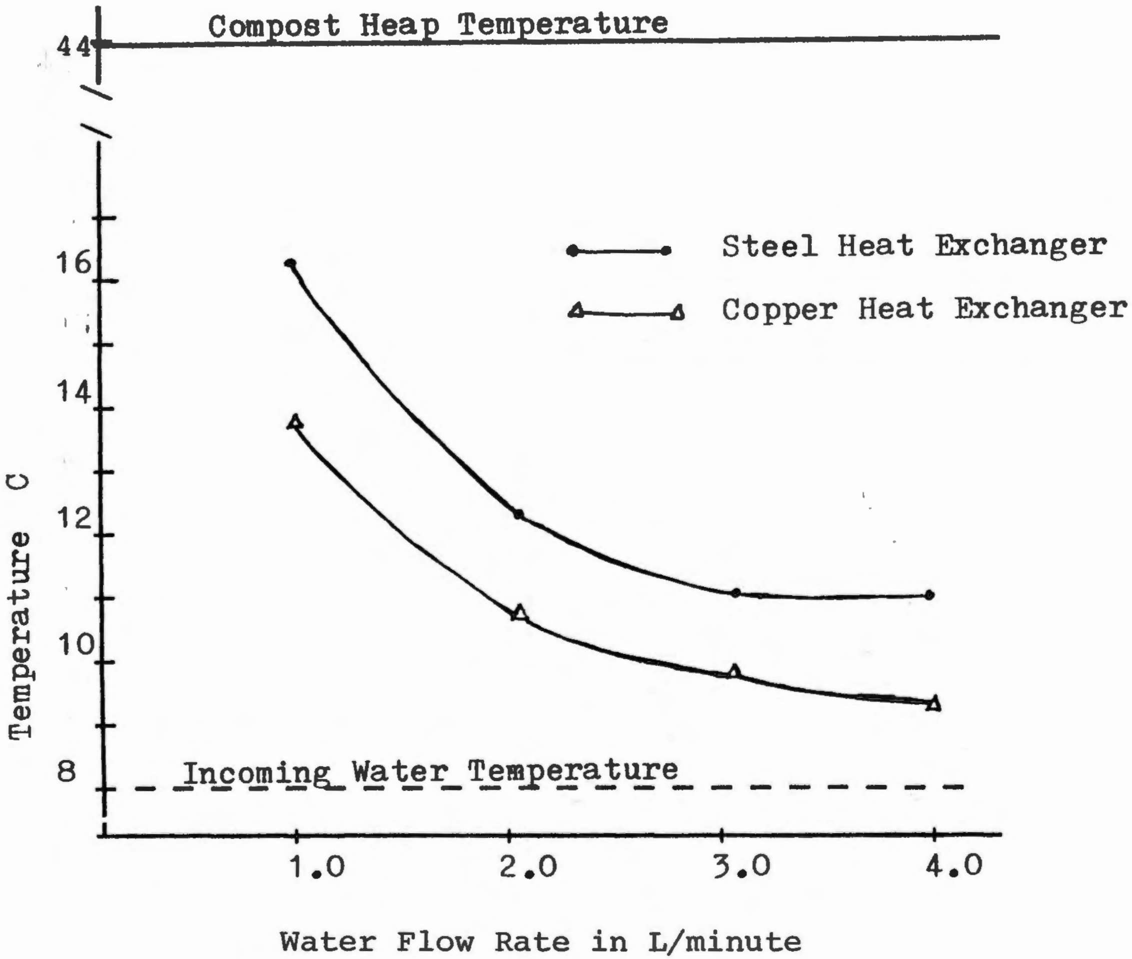


Figure 4. Average effluent water temperatures extracted from steel and copper heat exchanger units at four discrete flow rates over 60 minutes on 6 consecutive days.

exchanger was 7.0 kilocalories/min for the first experiment and 6.2 kilocalories/min for the second experiment. Even though the length of the second experiment was much shorter than the first experiment, the results were similar.

Third Experimental Test

The final application of the compost heat utilization was tested in a closed or recirculating system. A low head submersible pump (Little Giant No. 1P3212E-N) was used to pump the water at 2.0 L/min through the steel heat exchanger. The water was returned by gravity to the receiving tank. Temperatures of the effluent water, the receiving tank, and the inside water (unheated) were recorded daily. The data, as illustrated in Table 9 (Appendix) demonstrated the temperature differentials between an inside (unheated) tank and the recirculated (heated) tank. On two separate days, temperature declines occurred. These declines were caused by the wind removing the plastic covering from the compost heap. On all but one day, the recirculated tank temperature exceeded the unheated tank temperature. An average temperature difference between the heated and unheated tank was 4.8 C. From these results, one might expect to obtain higher temperatures in the recirculating system than in the flow-through system. This would be due to an increase in the incoming water temperature.

CHAPTER IV

CONCLUSIONS

Heat generated from composting fresh animal manure produced enough heat energy to warm water in an open or flow-through system and a closed or recirculated system. This study involved the development and testing of this in three separate experimental tests. From the study we concluded:

1. The position of the heat exchanger was most effective when located at the apex of the compost heap. Insulation of the compost heap with compost material and a plastic cover on the top and sides were found to maintain adequate temperatures for the heat transfer from the compost heap to the heat exchangers.

2. At 2 L/min, and under these experimental conditions, the steel heat exchanger extracted more heat energy from the compost heap than did the copper heat exchanger.

3. Net temperature changes at different flow rates (1.0, 2.0, 3.0, and 4.0 L/min) also indicated greater heat extraction by the steel exchanger. In addition, the flow/temperature change data could be used by fish culturists to regulate flow-through system temperatures by adjusting the flow to the desired temperature.

4. In recirculated systems, the net temperature change in incoming and effluent water is similar to changes in temperature in flow-through systems. However, the final effluent temperature may be higher due to the increased incoming water temperature in the recirculating system.

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APPENDIX

Table 2. First trial run with steel heat exchanger unit initiated April 29, 1982, with constant flow of 2 L/minute.

Date	Incoming Water Temperature (C)	Effluent Water Temperature (C)	ΔT (C)
April 29	17.0	26.0	9.0
April 30	17.0	27.0	10.0
May 1	17.0	27.0	10.0
May 2	17.0	27.0	10.0
May 3	17.0	29.0	12.0
May 4	17.0	29.0	12.0
May 5	17.0	29.5	12.5
May 6	18.0	27.5	9.5
May 7	17.0	23.0[a]	6.0
May 8	17.0	26.0	9.0
May 9	17.0	26.0	9.0
May 10	17.0	29.0	12.0
May 11	16.0	26.0	10.0
May 12	17.0	29.0	12.0
May 13	17.0	26.0	9.0
May 14	17.0	27.0	10.0
May 15	18.0	28.0	11.0
May 16	17.0	27.0	10.0
May 17	17.0	27.5	10.5
May 18	17.0	27.5	10.5
May 19	17.0	27.5	10.5
May 20	17.0	28.0	11.0
			Mean 10.25

[a]The plastic cover was accidentally removed from the compost heap.

The average energy extracted from the compost heap was 20.5 kilocalories/minute.

Table 3. Second trial run with steel heat exchanger unit initiated May 25, 1982, with constant flow of 2 L/minute.

Date	Incoming Water Temperature (C)	Effluent Water Temperature (C)	ΔT (C)
May 26	22.0	25.0	3.0
May 27	22.0	25.0	3.0
May 28	22.0	26.0	4.0
May 29	22.0	28.0	6.0
May 30	22.0	30.0	8.0
May 31	22.0	30.0	8.0
June 1	22.0	27.5	5.5
June 2	22.0	26.0	3.0
June 3	22.0	27.0	5.0
June 4	22.0	25.0	3.0
June 5	22.0	26.5	4.5
			Mean 4.82

The average energy extracted from the compost heap was 9.6 kilocalories/minute.

Table 4. Third trial run with steel heat exchanger unit initiated June 9, 1982, with constant flow of 2 L/minute.

Date	Incoming Water Temperature (C)	Effluent Water Temperature (C)	ΔT (C)
June 9	22.0	25.0	3.0
June 10	22.0	31.0	9.0
June 11	22.0	31.0	9.0
June 12	22.0	31.0	9.0
June 13	22.0	24.0	2.0
June 14	22.0	25.5	3.5
			Mean 5.91

The average energy extracted from the compost heap was 11.82 kilocalories/minute.

Table 5. Fourth trial run with steel heat exchanger unit initiated June 17, 1982, with constant flow of 2 L/minute.

Date	Incoming Water Temperature (C)	Effluent Water Temperature (C)	ΔT (C)
June 17	21.0	27.0	6.0
June 18	21.0	28.0	7.0
June 19	21.0	29.0	8.0
June 20	21.0	29.0	8.0
June 21	21.0	29.0	8.0
June 22	21.0	29.0	8.0
June 23	21.0	29.0	8.0
June 24	21.0	29.0	8.0
June 25	21.0	29.0	8.0
June 26	21.0	27.0	6.0
June 27	21.0	26.0	5.0
June 28	22.0	28.0	6.0
June 29	22.0	29.0	7.0
June 30	23.0	29.0	6.0
July 1	23.0	28.0	5.0
July 2	23.0	29.0	6.0
July 3	23.0	29.0	6.0
July 4	23.0	29.0	6.0
July 5	23.0	28.0	5.0
July 6	23.0	28.0	5.0
July 7	24.0	29.0	5.0
July 8	24.0	27.0	3.0
July 9	24.0	28.0	4.0
July 10	24.0	28.0	4.0
July 11	24.0	29.0	5.0
July 12	24.0	29.0	5.0
			Mean 6.1

The average energy extracted from the compost heap was 12.2 kilocalories/minute.

Table 6. Fifth trial run with steel and copper heat exchanger units initiated July 27, 1982, with constant flow of 2 L/minute.

	Water Temperature (C)				
		Effluent		ΔT	
Date	Incoming	Steel	Copper	Steel	Copper
July 27	25.0	2.0	4.0	27.0	29.0
July 28	25.0	2.0	3.5	27.0	28.5
July 29	25.0	2.0	2.0	27.0	27.0
July 30	25.0	2.5	2.0	27.5	27.0
July 31	25.0	3.0	2.0	28.0	27.0
August 1	25.0	4.0	2.0	29.0	27.0
August 2	25.0	4.0	3.0	29.0	28.0
August 3	25.0	3.0	2.0	28.0	27.0
August 4	25.0	2.0	2.0	27.0	27.0
	Mean	2.7	2.5		

The average energy extracted from the compost heap with the steel and copper exchangers was 5.4 and 5.0 kilocalories/minute, respectively.

Table 7. Sixth trial run with steel and copper heat exchanger units initiated November 9, 1982, with constant flow of 2 L/minute.

Date	Water Temperature (C)			ΔT	
		Effluent			
	Incoming	Steel	Copper	Steel	Copper
November 9	12.0	20.0	17.0	8.0	5.0
November 10	12.0	21.0	17.0	9.0	5.0
November 11	12.0	22.0	16.0	10.0	4.0
November 12	12.0	21.0	18.0	9.0	6.0
November 13	12.0	20.0	17.0	8.0	5.0
November 14	12.0	21.0	17.0	9.0	5.0
November 15	12.0	20.0	16.0	8.0	4.0
November 16	12.0	20.0	15.0	8.0	3.0
November 17	12.0	18.0	16.0	6.0	4.0
November 18	12.0	19.0	16.0	7.0	4.0
November 19	12.0	20.0	17.0	8.0	5.0
November 20	12.0	20.0	17.0	8.0	5.0
November 21	12.0	21.0	16.0	9.0	4.0
November 22	12.0	20.0	16.0	8.0	4.0
November 23	12.0	20.0	15.0	8.0	3.0
November 24	12.0	18.0	16.0	6.0	4.0
November 25	12.0	16.0	17.0	4.0	5.0
November 26	12.0	16.0	15.0	4.0	3.0
November 27	12.0	14.0	15.0	2.0	3.0
November 28	12.0	14.0	15.0	2.0	3.0
November 29	12.0	13.5	14.0	1.5	2.0
November 30	12.0	13.5	14.0	1.5	2.0
			Mean	6.5	3.5

The average energy extracted from the compost heat with the steel and copper exchangers was 13.0 and 7.0 kilocalories/minute, respectively.

Table 8. The effluent water temperatures of four discrete flow rates extracted from steel and copper heat exchangers during the second experimental test.

Time (min)	Flow Rate (L/min)	Water Temperature (C) Incoming	Effluent Steel	Effluent Copper	Net Energy (Kcal/min) Steel	Net Energy (Kcal/min) Copper
5	1	8.0	16.0	14.5	8.0	6.5
10	1	8.0	16.1	14.2	8.1	6.2
15	1	8.0	16.0	13.5	8.0	5.5
20	1	8.0	15.8	12.5	7.8	4.5
25	1	8.0	16.1	13.3	8.1	5.3
30	1	8.0	16.1	13.8	8.1	5.8
35	1	8.0	15.5	13.6	7.5	5.6
40	1	8.0	15.1	13.9	7.1	5.9
45	1	8.0	15.1	13.9	7.1	5.9
50	1	8.0	15.1	13.9	7.1	5.9
55	1	8.0	15.1	13.9	7.1	5.9
60	1	8.0	15.1	13.9	7.1	5.9
5	2	8.0	13.1	11.5	10.2	7.0
10	2	8.0	13.0	11.0	10.0	6.0
15	2	8.0	12.5	11.0	9.0	6.0
20	2	8.0	12.2	11.0	8.4	6.0
25	2	8.0	12.1	11.0	8.2	6.0
30	2	8.0	12.1	11.0	8.2	6.0
35	2	8.0	12.1	11.0	8.2	6.0
40	2	8.0	12.1	11.0	8.2	6.0
45	2	8.0	12.1	11.0	8.2	6.0
50	2	8.0	12.1	11.0	8.2	6.0

Table 8 (continued)

Time (min)	Flow Rate (L/min)	Water Temperature (C)			Net Energy (Kcal/min)	
			Effluent			
		Incoming	Steel	Copper	Steel	Copper
5	3	8.0	11.5	10.2	10.5	6.6
10	3	8.0	11.5	9.9	10.5	5.7
15	3	8.0	11.3	9.9	9.9	5.7
20	3	8.0	11.4	9.9	10.2	5.7
25	3	8.0	11.4	9.9	10.2	5.7
30	3	8.0	11.4	10.0	10.2	6.0
35	3	8.0	11.4	10.0	10.2	6.0
40	3	8.0	11.4	10.0	10.2	6.0
45	3	8.0	11.4	10.0	10.2	6.0
50	3	8.0	11.4	10.0	10.2	6.0
55	3	8.0	11.4	10.0	10.2	6.0
60	3	8.0	11.4	10.0	10.2	6.0
5	4	8.0	13.5	11.0	22.0	12.0
10	4	8.0	12.2	9.5	16.8	6.0
15	4	8.0	11.6	9.5	14.4	6.0
20	4	8.0	11.2	9.5	12.8	6.0
25	4	8.0	11.0	9.5	12.0	6.0
30	4	8.0	11.0	9.5	12.0	6.0
35	4	8.0	11.0	9.5	12.0	6.0
40	4	8.0	11.0	9.5	12.0	6.0
45	4	8.0	11.0	9.5	12.0	6.0
50	4	8.0	11.0	9.5	12.0	6.0

Table 9. First trial with a recirculated system design and the use of the steel heat exchanger with constant flow of 2 L/minute.

Date	Effluent Water Temperature (C)	ΔT	Effluent and Tank Temperature (C)	ΔT	Ambient Temperature
April 7	18.0	6.0	12.0	0.0	12.0
April 8	19.2	2.2	17.0	5.5	13.0
April 9	14.0	0.0	14.0	1.0	13.0
April 10	21.0	3.0	18.0	6.0	12.0
April 11	22.0	3.0	19.0	6.0	13.0
April 12	23.0	2.0	21.0	7.0	14.0
April 13	18.0	1.0	17.0	2.0	15.0
April 14	29.0	5.0	24.0	8.5	16.5
April 15	29.0	5.0	24.0	7.0	17.0
April 16	29.0	4.0	25.0	7.0	18.0
	Mean 22.2		Mean 19.1		Mean 14.3

VITA

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He enrolled in The University of Tennessee, Knoxville in 1970 and received his Bachelor of Arts degree in Biology in 1975. He was employed by the Tennessee Valley Authority for 6 years during which time he entered the Graduate School of The University of Tennessee, Knoxville, where he graduated in June 1983 with a Master of Science degree with a major in Wildlife and Fisheries Science.