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A study to investigate the energy expenditure of subjects while they were operating mechanical trenchers of different design

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A STUDY TO INVESTIGATE THE ENERGY EXPENDITURE OF SUBJECTS WHILE THEY WERE OPERATING MECHANICAL TRENCHERS OF DIFFERENT DESIGN

by

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CHAPTER I

THE PROBLEM AND RELATED LITERATURE[1]

The Problem

Statement of the Problem

The purpose of this study was to investigate the energy expenditure of subjects while they were operating mechanical trenchers of different design.

Significance of the Study

In the selection and use of any machine two groups of criteria need to be considered. The first group is mechanical criteria which are related to the ability of the machine to fulfill its function; while the second group of criteria is related to the characteristics of the machine which permit the operator to run the machine for a relatively long period of time without undue fatigue. The machine may meet one set of criteria and not the other; but ideally, it should meet both. This study will analyze the energy expenditure of operators while they are running different types of mechanical trenchers. This analysis belongs in the second group of criteria and should be of benefit in the selection and the design of the machines.

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[1]This study was completed under a cooperative agreement between the Montana State University Department of Health, Physical Education and Athletics and the Missoula Equipment Development Center of the United States Forest Service, Department of Agriculture.

Basic Assumptions

The following assumptions were made for this study.

1. It was assumed that the terrain conditions selected were adequate to produce characteristic energy expenditures while operating the trenchers. These conditions were established under the guidance of qualified Forest Service personnel.
2. It was assumed that the work period that subjects completed before the collection of test samples was sufficient to produce steady state metabolism, and the period during which test samples were taken was thereby a true test of the energy expenditure during trenching.
3. It was assumed that "since, in exercise of short duration, oxidation of proteins may be disregarded, the caloric value of 1 liter of oxygen will depend on the relative amounts of carbohydrate and fat used."[2]

Definition of Terms

Mechanical Trenchers. Machines used to build fire line.

Fire Line. A strip of ground from which all flammable material has been removed and the bare earth exposed. It is used to prevent the spreading of a fire.

Chain. A measure of distance which is equal to 66 feet.

Energy Expenditure. The number of calories produced by an

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[2]Peter V. Karpovich, *Physiology of Muscular Activity* (Philadelphia: W. B. Saunders Company, 1959), p. 81.

individual while performing a certain task under specified conditions.

Calorie. The amount of heat required to raise the temperature of a kilogram of water one degree Centigrade.

Indirect Method of Measurement. Determining the amount of energy used by calculating the amount of oxygen absorbed and carbon dioxide eliminated.

Limitations of the Study

1. Only skilled operators were used as subjects to prevent the occurrence of any variations in energy expenditure due to learning during the experimental periods.
2. Only a small group of subjects was used due to the time involved in completing the necessary number of trials and the availability of qualified subjects. This limited the application of statistical tests of significance and the level at which results could be tested.
3. The only analysis involved in this study was the energy expenditure of workers while operating the trenchers. No attempt was made to analyze the mechanical effectiveness of the machines in relation to the quality of trench dug or the mechanical durability of the machines.

Related Literature

The analysis of the energy expenditure while performing tasks involved in fighting forest fires has not been attempted prior to this time. Consequently, no directly related literature was available. Some work has been completed for the lumber industry, and this is briefly reviewed below.

Passmore and Durnin[3] have reviewed work done on energy expenditure by workers in the lumber industry. It is stated that perhaps the hardest physical work undertaken is lumbering. Studies reviewed by Passmore and Durnin of work done in lumber camps in Sweden showed an average production of 5,000 Calories per day and in some cases over 6,000 Calories per day. This study also showed that the mean caloric production per minute varied from 9.0 to 10.7 while felling trees during the winter. The mean caloric production per minute varied from 5.9 to 9.8 while cutting firewood during the summer. Passmore and Durnin also reviewed a study done by Kaminsky in which he measured the work done while transporting wood by sleigh uphill over snow during the German winter. This type of work showed a production of 10.5 Calories per minute. Another study was done by Glasar in which he measured energy expenditure while using an axe. During the perpendicular blows of the axe the range in Calories per minute was 6.9 to 24.1. For horizontal blows of the axe the range in Calories per minute was 12.0 to 13.2

Karvonen and Turpeinen[4] found that in lumberjacks who were working in competition in Finland, the mean caloric production per day varied from 4,120 calories to 7,210 calories. The analysis of this caloric production was accomplished in the following manner. The meals were planned before competition and the dishes were typical of Finnish home-cooked food which was familiar to the competitors. The amount of

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[3]R. Passmore and J.V.G.A. Durnin, "Human Energy Expenditure," Physiological Reviews, 35:823, October, 1955.

[4]M. J. Karvonen, Osmo Turpeinen, "Consumption and Selection of Food in Competitive Lumber Work," Journal of Applied Physiology, 6:603-612, 1954.

food taken by each competitor was measured before consumption. The liquid intake was measured by using the volume of a standard drinking glass. The composition of the foodstuffs was measured from values which were derived mostly from analyses made on foodstuffs actually used in Finland.

CHAPTER II

PROCEDURE OF THE STUDY

Subjects

Four male employees of the Missoula Equipment Development Center, United States Forest Service, Missoula, Montana, were used as subjects. The subjects were pre-trained in the operation of the trenchers. They were considered trained when they could anticipate the machine's movements and control its output.[1] Subjects were also given experience in using the air collection eouipment during the training period. Physical characteristics of the subjects are shown in Table I.

TABLE I

CHARACTERISTICS OF TEST SUBJECTS

Subjects	height centimeters	weight kilograms	surface area souare meters	age yrs.
R.A.	190.5	84.0	2.12	23
D.G.	173.0	75.5	1.89	29
D.C.	176.9	74.9	1.92	27
B.L.	179.0	88.2	2.08	28
MEAN	179.25	80.65	2.00	26.75

[1]United States Department of Agriculture, Fireline Trencher (Missoula Equipment Development Center, Forest Service, Missoula, Montana, Mimeographed Report, 1962), p. 16.

Equipment and Apparatus

Trenching Equipment

The trenchers used during the study were commercial products and will be referred to as Trencher A, Trencher B, and Trencher BH. Trencher B and Trencher BH are the same trencher except that the operator was attached to Trencher BH by a harness. The harness did not effect the mechanical performance of the machine in any way.

Trencher A (Figure 1) is called a flail-type trencher since it has chains which strike the ground removing the flammable material. The chains are attached to a motor-drive hub which can be made to revolve either right or left depending upon the location of the operator to the side hill. A sling, which fits over the operator's shoulder, helps support the machine in a working position. The trencher is powered by a small gasoline motor which is located on the rear of the machine.

FIGURE 1. TRENCHER A AND SUBJECT READY TO BEGIN TESTING

Trencher B (Figure 2) and Trencher BH (Figure 3, page 10) have two sets of oppositely helical blades which are 6 inches in diameter by 12 inches in length. These are mounted on a short shaft and are motor driven through a chain drive. They revolve at a rate of 500 revolutions per minute. The sets of blades dig into the earth, removing the flammable material and casting it to either side.

FIGURE 2. TRENCHER B

FIGURE 3. TRENCHER BH

Air Collection and Sampling Equipment

The open circuit method for the collection of expired air was selected because of its accuracy and adaptibility to the problem. A diagram of the air collection apparatus is shown in Figure 4. The subject wore a special face mask (F) which fit over his nose and mouth. An automatic one-way valve (V_1) was connected to the face mask so that the subject inhaled atmospheric air while his expired air went into a rubber tube (T). This rubber tube was in turn connected to a three-way valve (V_3) which was used to direct the air into one of two Douglas bags which were carried by an assistant. The opening into each Douglas bag had a manual valve (V_2). By manipulation of the valves, both bags could be filled and a subject could continue work even though he might expire more than the capacity of one bag during his work period.

After the expired air had been collected, the bag's contents were mixed by laying it on a flat surface and kneading it a few times. Samples of air were then taken from the Douglas bag into sampling tubes over mercury as the air was run through a dry gas meter for measurement of the volume.

Gas Analysis Equipment and Its Use

Scholander Gas Analyzer

The Scholander method of gas analysis was used to determine the percentage of oxygen and carbon dioxide in expired air samples. In this technioue, a 0.5 cubic centimeter air sample was introduced into a reaction chamber. During absorption of the gases, mercury

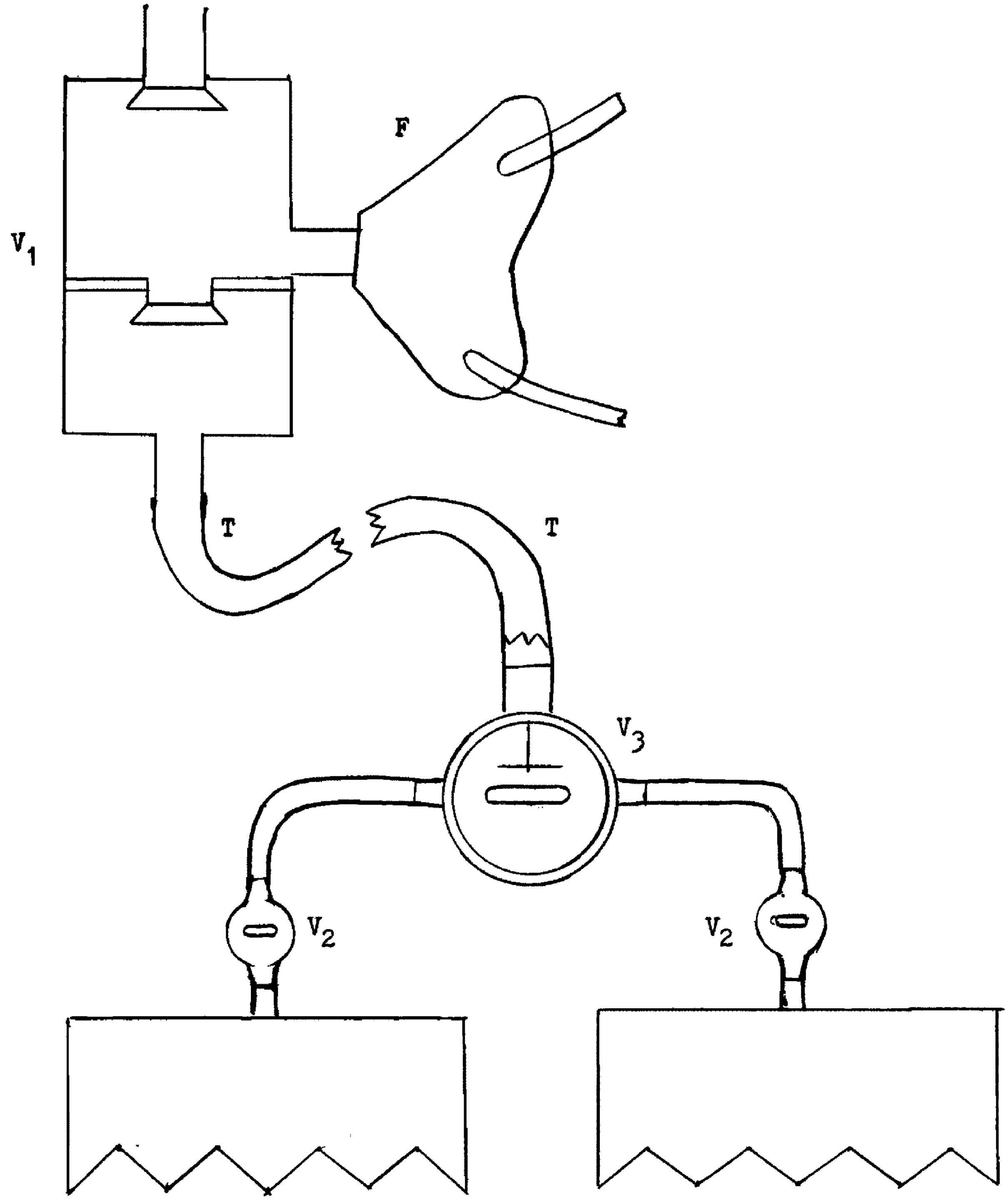

FIGURE 4. AIR COLLECTION APPARATUS. A, face mask; V_1, one-way valve; T, rubber tube; V_3, three-way valve; V_2, manual valve.

was delivered into the reaction chamber from a micrometer burette so as to maintain the balance of the gas against a compensating chamber. Volumes were read in terms of the micrometer divisions.[2]

The accuracy of the Scholander method was originally established by comparing results from its use with the results from the use of a Haldane apparatus. Expert analysts took samples of outdoor air and analyzed them by both the Scholander and Haldane methods. The two methods agreed within a 0.033 per cent accuracy.[3] Since the accuracy of the Scholander method favorably matches that of the traditional Haldane method, it can be used for all ordinary respiratory work.[4] As the gas analysis can be accomplished in less time by the Scholander apparatus, that method has an advantage over the Haldane method.

Transfer of gas sample

The technique of gas transfer used in this study is a modification of a technique described by Consolazio, Johnson, and Pecora.[5] The apparatus is shown diagramatically in Figure 5. The procedure is described below:

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[2]P. F. Scholander, "Analyzer For Accurate Estimation of Respiratory Gases in One-Half Cubic Centimeter Samples," *The Journal of Biological Chemistry*, 167:5-7, January, 1947.

[3]*Ibid.*

[4]*Ibid.*

[5]C. Frank Consolazio, Robert E. Johnson, Louis J. Pecora, *Physiological Measurements of Metabolic Functions in Man* (New York: McGraw-Hill Book Company, Inc., 1963), p. 81.

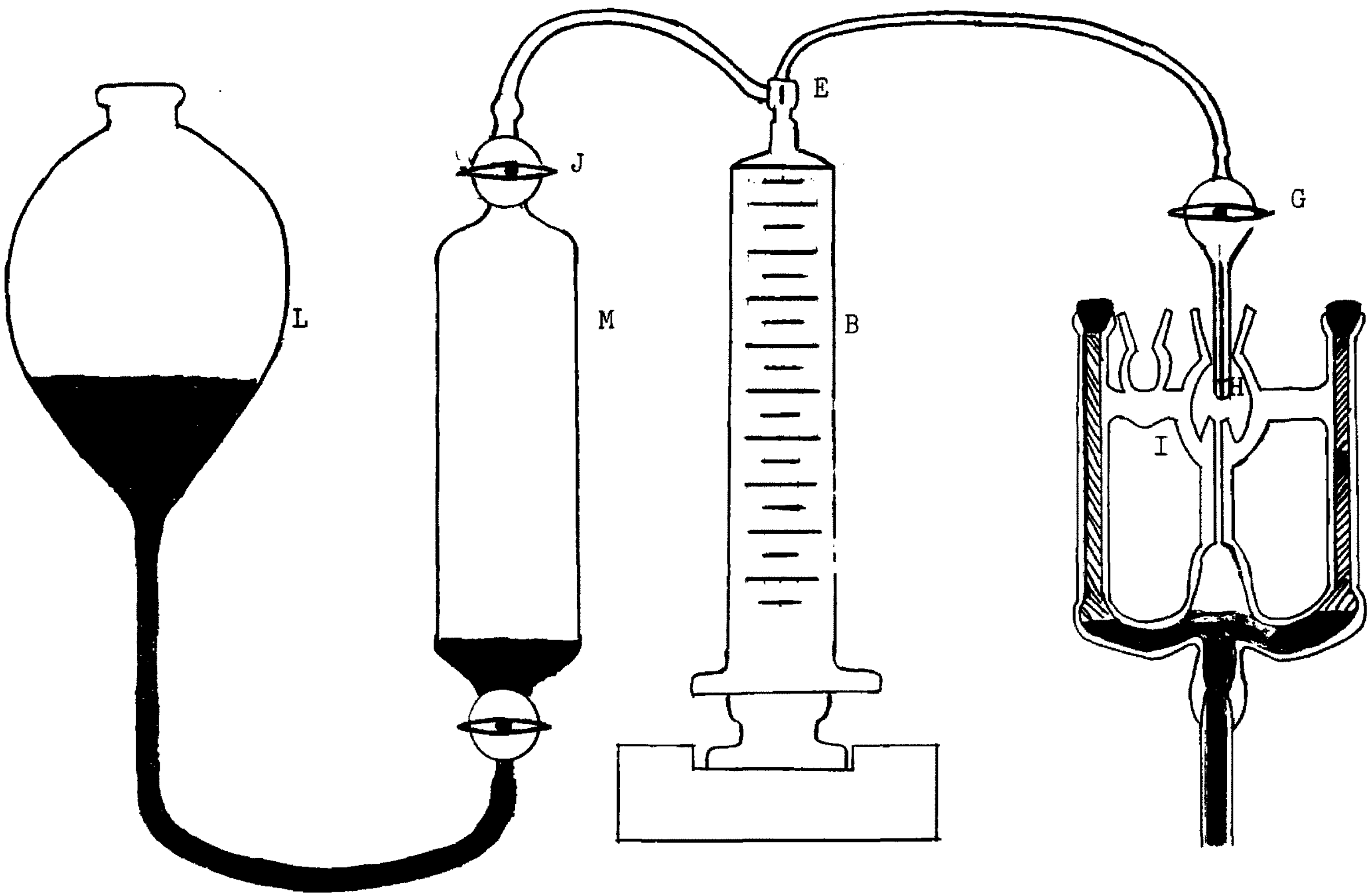

FIGURE 5. TRANSFER OF GAS SAMPLE. B, syringe; G, valve, H, rubber tip; E, valve; I, compensating chamber; J, valve; L, mercury reservoir; M, sampling tube.

Flushing:

1. Valve (J) was opened and valve (E) was set so that air passed only into the syringe (B). Mercury was run into the sampling tube (M) from the mercury reservoir (L) and 15 cubic centimeters of air forced into the syringe. Valve (J) was then closed.
2. Valve (G) was then opened and valve (E) turned to allow the air in the syringe to pass into the atmosphere. Valve (G) and valve (E) were then closed immediately.
3. The above procedure was repeated three times. On the fourth time the rubber tip (H) was seated on the compensating chamber (I) of the Micro-Scholander analyzer.
4. The alignment of the rubber tip (H) and the compensating chamber (I) was made exact so that the transfer of air was under pressure from the syringe (B) to prevent outside air from being sucked into the micrometer.

<u>Analyzing the sample</u>

The technique of gas analysis described by Scholander was used here. After the air sample had been transferred into the analyzer and all other adjustments completed, the total volume was read and recorded as (M_1). Carbon dioxide absorbent was then introduced and after all the carbon dioxide had been absorbed a second reading (M_2) was taken. Oxygen absorbent was next introduced into the reaction chamber and a third reading (M_3) taken after all the oxygen had been absorbed. The indicator drop was then sucked off and the micrometer screwed back to zero. All the precautions described by Scholander were taken to help insure the accuracy of the results.[6]

The per cent of carbon dioxide and oxygen in the sample was computed according to formulae presented by Scholander.[7] These are presented below:

$$\frac{M_1 - M_2}{M_1} = \text{per cent of carbon dioxide}$$

$$\frac{M_2 - M_3}{M_1} = \text{per cent of oxygen}$$

M_1 = volume of the air sample.

M_2 = volume of the air sample after absorption of carbon dioxide.

M_3 = volume of the air sample after absorption of carbon dioxide and oxygen.

Standards for acceptance

Before an analysis was considered acceptable it had to meet certain standards. First, the micrometer burette had to come with $\pm$ .005 millimeters of the machine zero at the end of the analysis. This level of accuracy was set by Scholander to allow for the elasticity of rubber stoppers in the side arms of the analyzer. Variations greater than this would indicate inconsistency of operation. Also, the per cent of carbon dioxide and oxygen on two successive analyses had to be within $\pm$ .05 per cent of each other for the analyses to be acceptable.

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[6]Scholander, op. cit., p. 10.

[7]Ibid.

Measurement of temperature and barometric pressure

The temperature during the test periods was taken in degrees Fahrenheit and later converted to degrees Centigrade by using a chart prepared by Consolazio, Johnson, and Pecora.[8]

An altimeter was used to measure the barometric pressure in inches. This was later converted to millimeters of mercury by multiplying it by a conversion factor obtained from Morehouse and Miller.[9]

Measurement of distance trenched

The distance trenched during the gas collection time of the experimental period was measured with a tape measure. Flags were used to mark the spot where trenching began, where gas collection began, and where trenching stopped. The distance trenched during gas collection was changed to chains by dividing the measured distance by 66 feet, the length of one chain.

Computation of Energy Expenditure

The following indirect method of measurement was employed in the computation of energy expenditure:

1. The volume of the gas collected during each experimental period was converted to Standard Temperature Pressure Dry (STPD), by multiplying the measured volume by a correction factor obtained from charts prepared by

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[8] Consolazio, *op. cit.*, p. 217.

[9] Laurence E. Morehouse, Augustus T. Miller, *Physiology of Exercise* (St. Louis: C. V. Mosby Company, 1959), p. 330.

Consolazio, Johnson, and Pecora.[10] The magnitude of the factor was dependent on the atmospheric pressure and the temperature of the gas at the time the gas volume was measured.

2. The per cent of nitrogen in the sample was obtained by adding the percent of carbon dioxide and oxygen together and then subtracting from one hundred per cent.

3. The true oxygen and the true carbon dioxide were computed according to the formulae from Consolazio, Johnson, and Pecora.[11] This was done to help figure the gas volume per unit of time. The gas volume per unit of time for oxygen was then used to figure the calories per kilogram of body weight per minute. The calories per kilogram of body weight per minute was used to figure the calories per kilogram of body weight per chain trenched.

true oxygen = $\%N_2$ in expired air x 0.265 - $\%O_2$ in expired air

true carbon dioxide = $\%CO_2$ in expired air - 0.03 ($\%CO_2$ in atmospheric air)

4. The respiratory quotient (R.Q.) was computed according to the formula of Consolazio, Johnson, and Pecora.[12]

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[10] Consolazio, loc. cit.

[11] Ibid., p. 8.

[12] Ibid., p. 9.

$$\text{R.Q.} = \frac{\%CO_2 \text{ in expired air} - 0.03\ (\%CO_2 \text{ in atmospheric air})}{\%N_2 \text{ in expired air} \times 0.265 - \%O_2 \text{ in expired air}}$$

5. The caloric equivalent of the respiratory quotient was obtained from a chart given by Dukes.[13]

6. Gas volume per unit of time ($\dot{V}$) was computed according to a formula presented by Consolazio, Johnson, and Pecora.[14]

$$\dot{V} \text{ gas} = \frac{\text{Volume collected (uncorrected)}}{\text{Gas collection time}} \times \text{STPD factor}$$

7. The volumes of oxygen and carbon dioxide per unit of time were computed according to formulae by Consolazio, Johnson, and Pecora.[15]

$$\dot{V}o_2 = \frac{\dot{V} \text{ gas}}{100} \times \text{true } O_2$$

8. The Calories per kilogram of body weight expended per minute were computed according to the following formula:

$$\text{Kcal/kilogram body weight/minute} = \frac{\text{Caloric equivalent} \times \dot{V}o_2}{\text{body weight in kilograms}}$$

9. The Calories per kilogram of body weight per chain expended during the gas collection period were computed by the following formula:

$$\text{Kcal/kilogram body weight/chain} = \frac{\text{Kcal/kilogram body weight/minute} \times \text{collection time}}{\text{chains trenched}}$$

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[13] H. H. Dukes, The Physiology of Domestic Animals (New York: Comstock Publishing Associates, 1955), p. 622.

[14] Consolazio, loc. cit.

[15] Ibid., p. 9.

Experimental Procedure

Selections of Experimental Conditions

The terrain features consisted of an ascending slope with a 30 per cent incline, and a contour slope. The soil conditions consisted of grass and weeds, with individual root systems, rocks from 2 inches to 6 inches in diameter, and sparsely populated with pine and fir trees. Subjects trenched on the contour with the top of the slope to the left of the subject, on the contour with the top of the slope to the right of the subject, and ascending the slope. The conditions were selected after consultation with Forest Service personnel who had been working with the trenchers. The terrain features previously described fit the experimental conditions selected.

The two contour conditions, contour uphill left and contour uphill right, were included in the study because the motor of Trencher A was always in a fixed position on the right side of the operator. The motors of Trencher B and Trencher BH were not in such a fixed position. Because of this factor the Forest Service felt two contour conditions would be a more efficient test of the subject using the machines.

Application of Experimental Conditions

The sequence of trencher use and the sequence of the application of experimental conditions was set up prior to the actual testing. These sequences were set up in such a manner that the trenchers were used in all possible combinations. Thus, for example, any benefit which might occur when using Trencher B before Trencher BH or some other order would be negated. The same is true for the order of experimental conditions.

Subjects were assigned to these sequences by lot. The fact that only four subjects were used did not permit the randomization desired for the study.

Each subject was tested while using Trencher A, Trencher B, and Trencher BH in each of the experimental conditions. Table II shows the sequences in which each subject used each trencher.

Table III shows the sequence of terrain conditions followed by each subject.

Example:

R.A. Trencher A, B, BH in that order on contour uphill right, then contour uphill left, and then ascending.

D.C. Trencher B, BH, A in that order on contour uphill left, then ascending, and then contour uphill right.

TABLE II

ORDER OF USING TRENCHERS

Subject	order of trencher use 1	2	3
R.A.	A*	B**	BH***
D.C.	B	BH	A
D.G.	BH	A	B
B.L.	B	A	BH

* Trencher A
** Trencher B (without harness)
*** Trencher BH (with harness)

TABLE III

ORDER OF EXPERIMENTAL TERRAIN CONDITIONS

Subject	order of terrain conditions 1	2	3
R.A.	CR*	CL**	A***
D.G.	CL	A	CR
D.C.	A	CR	CL
B.L.	CL	CR	A

* Contour
** Contour uphill left
*** Ascending

On the next to last day on which data was collected Trencher A got out of sequence with Trenchers BH and B due to mechanical failures of Trencher B, but Trencher BH and Trencher B were never out of sequence with each other. Table IV shows the final sequence in which the trenchers were used.

TABLE IV

SEQUENCE OF TRENCHER USE FOR LAST TWO DAYS OF TESTING

Subject	order of trencher use 1	2	3	4	5	6
D.C.	B	A	BH	A	B	BH
B.L.	B	A	A	BH	B	BH

Conduct of Experimental Trials

The subject was placed in a lying position prior to the test. His radial pulse was taken for 15 seconds at one minute intervals until it was the same for two consecutive times. When this condition was obtained, the subject began work immediately. For the first nine minutes of the working period the subject was not attached to the air collection apparatus.

At the conclusion of this nine minute working period the subject immediately put on the face mask which connected him to the air collection apparatus. He then resumed working. An assistant carried the air collection apparatus which consisted of the Douglas bags and a three-way valve. This gave the subject quite normal movement while he was working. Problems which might have arisen by having the subject carry the air collection apparatus were believed to have been eliminated by this procedure.

The dead air space of the apparatus was flushed with expired air while the subject worked for one more minute. At the end of this one minute period, the expired air was directed into a Douglas bag and the subject continued working for three more minutes. If his expired air filled the first Douglas bag before the end of the three minute period, the bag would be closed and the air directed into a second bag without interrupting his work. At the end of the three minute collection period the subject stopped work immediately and sat down, after which his pulse rate was taken for 15 seconds and then recorded.

The Douglas bag or bags was then disconnected from the air collection apparatus and a sample, which was later analyzed in the laboratory, was taken over mercury into a 125 or 250 milliliter sampling tube and labeled. The remainder was run through a dry gas meter to determine the total volume of expired air The Douglas bag was rolled up tightly to ensure that the entire sample had been measured. The temperature of the expired air was read from a thermometer in the dry gas meter after it had been measured.

CHAPTER III

ANALYSIS AND DISCUSSION OF RESULTS

Analysis of Results

Heart Rate

Table V shows the pre-exercise and post-exercise heart rates of subjects for each experimental period. The pre-work rate showed considerable variation. Subjects R.A. and D. C. showed the most variation whereby subject R. A. had a minimum resting rate of 48 beats per minute and a maximum of 76 beats per minute, while subject D.C. had a minimum rate of 48 beats per minute and a maximum rate of 88 beats per minute. Subject B.L. had the least variation with a minimum of 48 beats per minute and a maximum of 64 beats per minute. When the heart rates were further analyzed as to the sequence in which the trenchers were used in the experiments, no definite pattern was revealed, since the pulse rate from the first test of the day was not necessarily higher or lower than for the second test nor was the second test necessarily higher or lower than for the third test. These variations probably illustrate the difficulty of obtaining a true resting pulse rate for a base value in studies of this type.[1] Since variations in heart rate can be effected by so many factors, it was not possible to attribute the variation to any one factor in this study.

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[1]Peter V. Karpovich, *Physiology of Muscular Activity* (Philadelphia: W. B. Saunders Company, 1959), p. 204.

In every instance but two, the heart rate increase as measured between pre-work and post-work rates was less for subjects using Trencher A than for either Trencher B or BH. These two instances were for subject R.A., while ascending with Trencher A compared to Trencher BH; and for subject D.G. who showed no difference while contouring uphill left while using Trencher A and Trencher BH. Under ascending conditions, subjects using Trencher BH always showed a smaller increment than when using Trencher B. No other condition showed a definite pattern. The greatest difference in pre-work and post-work heart rates was 116 beats per minute for subject D.G. with Trencher B while ascending.

For the post-exercise heart rate, the smallest value was in subject D.G. with Trencher BH during the contour uphill left condition, where he had a pulse rate of 64 beats per minute at the end of the work period. The same subject also had the highest post-exercise rate when he was operating Trencher B under ascending conditions. His pulse attained a rate of 180 beats per minute at the end of the work period. It should be noted that this post-exercise rate of 180 beats per minute is at the value considered to be the maximal for aerobic performance by some authors and above the maximal rate of 160 beats per minute as given by a few authors.[2] This may indicate that this was not steady state work but that an oxygen debt was building during ascending conditions. However, many authors feel that a value of 180 beats per minute is too low, and top heart

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[2]Bruno Balke, Science and Medicine of Exercise and Sports (New York: Harper and Brothers, 1960), p. 342.

rates above this value have been found frequently.[3] It is felt that the assumption of a steady state under these conditions has not been invalidated by this single high post-exercise rate and the procedure of collecting air for a three-minute work period was still an acceptable technique.

TABLE V

PRE-WORK AND POST-WORK HEART RATES

Subject	Trencher A			Trencher B			Trencher BH		
	Pre*	Post**	Diff***	Pre	Post	Diff	Pre	Post	Diff
				Ascending					
R.A.	60	156	96	72	172	100	68	128	60
D.G.	68	124	56	64	180	116	60	156	96
D.C.	88	148	60	64	160	96	68	160	92
B.L.	60	88	28	60	152	92	52	128	76
				Contour uphill right					
R.A.	48	68	20	72	124	52	56	100	44
D.G.	68	96	28	56	100	44	56	100	44
D.C.	72	104	32	48	140	72	68	144	76
B.L.	60	88	28	60	120	60	64	108	44
				Contour uphill left					
R.A.	76	84	8	68	140	72	60	116	56
D.G.	60	76	16	60	124	64	48	64	16
D.C.	68	88	20	72	116	44	72	136	64
B.L.	60	84	24	52	132	80	48	112	64

* Pre-heart rate per minute
** Post-heart rate per minute
*** Difference between pre-heart rate and post-heart rate

[3] Karpovich, *op. cit.*, p. 195.

Respiratory Quotient

The respiratory quotients for all subjects during all experimental conditions are shown in Table VI. The lowest respiratory quotient (.73) was exhibited by subject R.A. while using Trencher A under contour uphill left condition. The highest respiratory quotient (.97) was shown by subject D.G. under ascending condition with Trenchers B and BH. The respiratory quotient values are within those described by Karpovich for short periods of work, with the exception of the value of .73.[4] A respiratory quotient this low might be expected after a long work period, but in this instance it occurred during the first work period of the day. This small respiratory quotient for subject R.A. was produced while using Trencher A under contour uphill left condition. It should also be noted from Table V (page 25) that this subject had a very low heart rate increase in this instance as well as a very low energy expenditure as shown in Table IX (page 32). In all instances, these are the lowest values for the entire study.

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[4] *Ibid.*, p. 56.

TABLE VI

RESPIRATORY QUOTIENTS DURING TRENCHING

Subject	Trencher A*	Trencher B**	Trencher BH***
		Ascending	
R.A.	.89	.85	.86
D.G.	.91	.93	.94
D.C.	.87	.97	.97
B.L.	.88	.93	.91
		Contour uphill right	
R.A.	.82	.88	.89
D.G.	.80	.88	.89
D.C.	.86	.85	.96
B.L.	.83	.91	.87
		Contour uphill left	
R.A.	.73	.88	.83
D.G.	.87	.87	.91
D.C.	.84	.89	.86
B.L.	.86	.87	.87

* Trencher A
** Trencher B (without harness)
*** Trencher BH (with harness)

Energy Expenditure

Method of Analysis

With a sample of four subjects it is difficult to apply statistical tests of significance. The design of this study was such that nonparametric techniques were applicable. The Walsh test was selected as the test of statistical significance.[5]

[5] Sidney Siegel, Nonparametric Statistics (New York: McGraw-Hill Book Company, 1956), p. 83-87.

With this test, it must be realized that to say results have statistical significance has limited value since the highest level that can be tested with four subjects is the .125 level. This does not approximate the traditional .05 and .01 levels. Even at the high value of .125 level as a point for accepting or rejecting hypotheses, all cases must show either an increase or decrease for this value to be attained. However, this test was applied, and whenever a reference is made to statistical significance it is to this .125 level.

To analyze the energy expenditure while using different trenchers, comparisons were made between the number of Calories expended per kilogram of body weight per minute by each subject, while using each trencher in a specific experimental condition. Comparisons were also made between the Calories expended per kilogram of body weight per chain trenched by each subject. Separate comparisons were made for each of the three experimental conditions.

Ascending

Table VII shows the energy expenditure per kilogram of body weight per minute under ascending conditions. Subjects showed a significantly lower energy expenditure (.125 level) while using Trencher A than while using Trencher BH. No significant difference was shown between the energy expenditure while using Trencher B compared to Trencher BH or Trencher A compared to Trencher B.

TABLE VII

ENERGY EXPENDITURE IN CALORIES PER KILOGRAM OF BODY WEIGHT PER MINUTE WHILE ASCENDING

Subject	Trencher A	Trencher B	Trencher BH
R.A.	.180	.165	.206
D.G.	.158	.167	.186
D.C.	.166	.198	.199
B.L.	.129	.170	.157

Table VIII shows the energy expenditure per kilogram of body weight per chain trenched during the ascending condition. It was found that no differences of energy expenditure by the subjects were statistically significant when comparing the machines to one another.

TABLE VIII

ENERGY EXPENDITURE IN CALORIES PER KILOGRAM OF BODY WEIGHT PER CHAIN TRENCHED WHILE ASCENDING

Subject	Trencher A	Trencher B	Trencher BH
R.A.	.342	.409	.375
D.G.	.423	.309	.396
D.C.	.402	.606	.569
B.L.	.530	.405	.424

Contour uphill right

Table IX shows the subjects energy expenditure per kilogram of body weight per minute while trenching during the contour uphill right condition. Subjects showed a significantly lower energy expenditure (.125 level) using Trencher A than when using Trencher B. They also showed a significantly lower energy expenditure (.125 level) using Trencher BH than when using Trencher B. No significant difference was shown between energy expenditure when using Trencher A and Trencher BH.

TABLE IX

ENERGY EXPENDITURE IN CALORIES PER KILOGRAM OF BODY WEIGHT PER MINUTE WHILE CONTOURING UPHILL RIGHT

Subject	Trencher A	Trencher B	Trencher BH
R.A.	.138	.199	.180
D.G.	.090	.151	.080
D.C.	.098	.162	.143
B.L.	.088	.145	.136

Table X shows the subjects' energy expenditure per kilogram of body weight per chain trenched during the contour uphill right condition. Subjects showed a significantly lower energy expenditure (.125 level) using Trencher BH than when using Trencher B. No significant difference was shown between the energy expenditure while using Trencher A and Trencher B or Trencher A and Trencher BH.

TABLE X

ENERGY EXPENDITURE IN CALORIES PER KILOGRAM
OF BODY WEIGHT PER CHAIN TRENCHED
WHILE CONTOURING UPHILL RIGHT

subject	Trencher A	Trencher B	Trencher BH
R.A.	.436	.253	.229
D.G.	.176	.462	.176
D.C.	.173	.365	.338
B.L.	.330	.435	.300

Contour uphill left

Table XI shows the subjects' energy expenditure per kilogram of body weight per minute while trenching during the contour uphill left condition. Subjects showed a significantly lower energy expenditure (.125 level) using Trencher A compared to using either Trencher B or Trencher BH. No significant difference was shown between the energy expenditure when using Trencher B and Trencher BH.

TABLE XI

ENERGY EXPENDITURE IN CALORIES PER KILOGRAM OF BODY
WEIGHT PER MINUTE WHILE CONTOURING UPHILL LEFT

Subject	Trencher A	Trencher B	Trencher BH
R.A.	.065	.185	.119
D.G.	.073	.134	.186
D.C.	.103	.133	.132
B.L.	.077	.124	.146

Table XII shows the subjects' energy expenditure per kilogram of body weight per chain trenched while trenching during the contour uphill left condition. Subjects showed a significantly lower energy expenditure (.125 level) using Trencher A than while using Trencher BH. No significant difference was shown between energy expenditure when using Trencher B and Trencher BH or Trencher A and Trencher B.

TABLE XII

ENERGY EXPENDITURE IN CALORIES PER KILOGRAM
OF BODY WEIGHT PER CHAIN TRENCHED
WHILE CONTOURING UPHILL LEFT

Subject	Trencher A	Trencher B	Trencher BH
R.A.	.113	.325	.319
D.G.	.155	.490	.410
D.C.	.238	.225	.305
B.L.	.278	.293	.317

Although there was a difference in the position of the operator in relation to the machine with Trencher A when trenching under contour uphill right or contour uphill left conditions no statistically significant difference was shown between the energy expenditures under these conditions. However, Trencher B did show a difference which was significant at the .125 level when determining energy expenditure per kilogram of body weight. No other definite differences were shown. When comparing the energy expenditure of subjects in Calories per kilogram of body weight per chain trenched while contouring uphill left versus contouring uphill right, it was found that there was no comparable difference of energy expenditure of the subjects.

Discussion of Results

Subjects showed a significantly lower energy expenditure (.125 level) in Calories per kilogram of body weight while using Trencher A than while using Trencher BH during ascending and contour uphill left conditions. Subjects also showed a lower energy expenditure with Trencher A than with Trencher B on contour uphill right and contour uphill left conditions. In regard to the energy expenditure per kilogram of body weight per chain trenched, subjects using Trencher A showed a significantly lower expenditure (.125 level) than while using Trencher BH during contour uphill left conditions.

At no time did the subjects as a group show less energy expenditure while using Trencher B than while using Trencher A or Trencher BH, either in relation to energy expenditure per kilogram of body weight or in relation to the number of chains trenched. Within the limitations of this study, Trencher B was shown to be the most inefficient machine from the standpoint of the energy expenditure of the operator.

Subjects using Trencher BH showed a significantly lower energy expenditure (.125 level) in Calories per kilogram of body weight per minute than while using Trencher B during contour uphill right conditions. In Calories per kilogram of body weight per chains trenched, subjects using Trencher BH showed significantly lower energy expenditure (.125 level) than while using Trencher B during contour uphill right conditions. Although Trencher BH was shown superior to Trencher B in these two instances, at no time was it shown superior to Trencher A.

Only Trencher B showed a significant difference when comparing the energy expenditure per kilogram of body weight during trenching under contour uphill right versus contour uphill left conditions. This cannot be explained in terms of the operator's position in relation to the machine since the position is the same no matter whether the uphill side of the contour is to the right or to the left of the operator.

It should be noted, that the analysis of the operation of Trencher B was difficult since the nature of its construction permits many methods of operation. Consequently, subjects could assume various positions during operation of Trencher B, whereas there was one quite standard position with Trencher A. It is therefore felt that some of the variability in the results from Trencher B was due to different methods of operation. It was not felt that this variability was completely eliminated with the addition of the harness as was done with Trencher BH.

In summary, subjects in three instances showed less energy expenditure when using Trencher A than when using Trencher BH. In a similar comparison with Trencher B, subjects expended less energy in two instances. In three situations Trencher A was shown to have no advantage over Trencher B, and in four situations no advantage over Trencher BH. Trencher BH was shown to have an advantage over Trencher B in two instances and showed no advantage in four instances. At no time were Trencher B or Trencher BH shown to have an advantage over Trencher A.

CHAPTER IV

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Energy expenditure was measured while operating two mechanical trenchers of differenct design. These trenchers were designated Trencher A, Trencher BH, and Trencher B. Trencher B and Trencher BH were the same trencher except for a harness arrangement attached to Trencher BH. The harness did not effect the mechanical function of the machine in any way.

Four male subjects, who were employees of the Missoula Equipment Development Center, United States Forest Service, Missoula, Montana, were assigned at random to the sequence in which they would be tested while using each trencher. The sequence of terrain conditions was also assigned at random. Each subject was tested nine times. The subject worked for thirteen minutes on each test. During the last three minutes of each test expired air was collected. At the completion of each test period the expired air was measured by a dry gas meter and a sample taken over mercury into a 125 or 250 milliliter sampling tube. The air samples were taken to the research laboratory and analyzed with the Micro-Scholander Gas Analyzer. A comparison of the pre-heart rate, post-heart rate, and respiratory quotients for each subject while using each machine under each condition was also determined.

The Walsh test was selected as an applicable statistical test for analyzing the results. When using the Walsh test the highest level of statistical significance that could be tested with four subjects was the .125 level. All cases must show either an increase or decrease for this level of significance to be reached.

Energy expenditure was analyzed by comparisons between the subjects under each experimental condition in relation to the Calories expended per kilogram of body weight per minute and the Calories expended per kilogram of body weight per chain trenched.

For energy expenditure per kilogram of body weight per minute, a statistically significant lower energy expenditure (.125 level) was found under ascending conditions for subjects using Trencher A opposed to using Trencher BH; under contour uphill right condition for subjects using Trencher A opposed to using Trencher B and while using Trencher BH opposed to using Trencher B; and under contour uphill left condition for subjects using Trencher A opposed to using either Trencher B or Trencher BH.

For energy expenditure per kilogram of body weight per chain trenched, statistically significant lower energy expenditures (.125 level) were found when subjects used Trencher BH than when they used Trencher B during the contour uphill right condition; and under contour uphill left condition for subjects when they used Trencher A rather than Trencher B or Trencher BH.

Conclusions

The following conclusions were made within the limitations of this study.

1. In regard to energy expenditure, both in relation to Calories per kilogram of body weight and Calories per

body weight per chain trenched, Trencher A was a more efficient machine than either Trencher B or Trencher BH. Although no statistically significant difference was found between the trenchers in some situations, whenever a difference was found the energy expenditure during the operation of Trencher A was always less than during the operation of Trencher B or Trencher BH.

2. The addition of the harness to Trencher B (making Trencher BH) was apparently advantageous in terms of energy expenditure only in relation to the Calories expended per kilogram of body weight while trenching under contour uphill right conditions and contour uphill left conditions. No over-all advantage was shown with the addition of the harness to Trencher B.

Recommendations

In view of the findings of this study and the problems encountered during its completion, the following recommendations have been made:

1. Further research should be completed using more subjects. Due to the small sample, it was very difficult to assess the true variability encountered in the results.
2. Future studies should include additional tests to measure fatigue and physiological stress. Although it is important, energy expenditure cannot be regarded as a one true test of the effect a machine has on the operator.

3. Machine B should be studied to determine a standard operating technique. The variability in the manner subjects operated this machine may be the cause of some of the variability in the results.

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APPENDIX

APPENDIX A

SAMPLE OF SUBJECT'S RECORD SHEET

Subject______________________________ Date__________________

Weight in kilograms (nude)______________with clothes)______________

Experimental condition____

Heart rate: Pre-work_________________ Post-work__________________

Gas collection time___________ Temperature ambient________________ °C

Time of test_______Barometric reading______________________ mm Hg.

Temperature of sample______°C STPD factor________________________

Corrected volume STPD______liters. Total distance worked_____________

Total work time_______Distance worked during gas collection__________

Chains trenched________

% CO_2 (sample 1)_______________ % O_2 (sample 1)___________________

% CO_2 (sample 2)_______________ % O_2 (sample 2)___________________

% CO_2 _______________ % O_2 ___________________

% N_2 _______________

True O_2 = % N_2 in expired air x 0.265 - % O_2 in expired air.

True CO_2 = % CO_2 in expired air - 0.03 (% CO_2 in atmospheric air)

$$R.\ Q. = \frac{\%\ CO_2 \text{ in expired air} - 0.03}{\%\ N_2 \text{ in expired air} \times 0.265 - \%\ O_2 \text{ in expired air}} =$$

$$\frac{\_\_\_\_\_\_ - 0.03}{\_\_\_\_\_\_ \times 0.265 - \_\_\_\_\_\_} = \_\_\_\_\_\_\_\_\_\_$$

Caloric equivalent per liter = ________________

$$\dot{V}O_2 = \frac{\dot{V}\text{ gas}}{100} \times \text{true } O_2 = \frac{\_\_\_\_\_\_}{100} \times \_\_\_\_\_\_ = \_\_\_\_\_\_$$

APPENDIX A (continued)

$$\text{Kcal/kilogram body weight/minute} = \frac{\text{Caloric equivalent x } \dot{V}O_2}{\text{Body weight in kilograms}} =$$

$$\frac{\qquad \text{x} \qquad}{} = \underline{\qquad\qquad\qquad}$$

$$\text{Kcal/kilogram body weight/chain} = \frac{\text{Kcal/kilogram body weight/min x 3}}{\text{Chains trenched during gas collection}}$$

$$= \frac{\qquad \text{x 3} \qquad}{} = \underline{\qquad\qquad\qquad}$$