

CONSTRUCTION AND TESTING OF A RESPIRATORY
APPARATUS FOR EQUINE

by

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INTRODUCTION

Renewed interest in equine research appears to be paralleling a rise in the number of horses in the United States. The era of the horse seemed to be drawing to a close following the industrial revolution, when the equine was no longer needed as a means of transportation or as a beast of burden. The horse may no longer be necessary to us as a work animal, but millions of people are now enjoying the equine for pleasure, show, racing and a variety of other activities.

Scientific research is available for cattle, sheep, hogs, chickens and a wide variety of animals used for food production, however, this is not the primary purpose of the horse. Information is needed in regard to the nutritional requirements of the horse and the various feedstuffs which can be utilized to meet these requirements. Energy is one such nutrient.

Some energy values currently recommended for the horse are extrapolations of data from cattle and sheep and fail to recognize certain critical differences. When strenuously working horses are fed large quantities of grain to meet their energy requirement, colic and founder must be constantly guarded against.

Currently, there exists a competition for grains between man, and livestock used for production and recreational animals, such as the horse.

Fats supply 2.25 times more energy than an equal weight of carbohydrate. This concentrated energy source may be helpful to horse-men who find it necessary to feed large quantities of energy.

The respiratory quotient (RQ) is the molar ratio of carbon dioxide (CO_2) production to the corresponding oxygen (O_2) consumption. The normal range for RQ's is .7 to 1.0, depending upon whether fat, protein, carbohydrate or a combination of the above is being metabolized.

When O_2 consumption and CO_2 production are known, the RQ and subsequently energy expenditure can be calculated. In order to evaluate energy utilization in equine special equipment is needed to collect and sample respiratory gases. With this in mind, design of a suitable collection mask and sampling regime was initiated.

REVIEW OF LITERATURE

History of Calorimetry

The origin of the science of respiration can be traced to the work of Antoine Laurent Lavoisier (Culotta, 1972). Lavoisier in 1777 was the first to carry out respiration trials by measuring the amounts of O_2 consumed and/or CO_2 produced by an animal (Kleiber, 1975). Lavoisier introduced modern chemical nomenclature, especially as it relates to oxygen, and demonstrated that living involves oxidation.

At approximately the same time, 1778, Adam Crawford constructed a combustion calorimeter to measure the heat produced when O_2 and hydrogen are burned together in closed containers. Crawford measured the heat by the increase in temperature of a given amount of water (Kleiber, 1975).

The two primary methods of calorimetry, direct and indirect, were developed in 1777. Direct calorimetry is the measurement of heat loss from the animal's body, i.e., heat of radiation, conduction, convection and evaporation (Brody, 1974). Only a few of these chambers are in existence due to the cost of construction. Indirect calorimetry is the measurement of heat production indirectly based on the relationships between the amount of heat produced from oxidation of food or body constituents and the amounts of O_2 consumed and CO_2 produced (Blaxter, 1971).

Since the animal body ultimately derives all of its energy from oxidation, energy utilization can be estimated from the exchange of respiratory gases (Swenson, 1977). In general, there are two techniques available for the measurement of respiratory exchange in indirect calorimetry. Both seek to measure O_2 consumption and CO_2 production per unit of time. The closed circuit type, developed by Regnault and Reiset in 1849, involves recirculation of the same air after removal of CO_2 by a suitable absorbent and replacement of the consumed O_2 by an equal quantity of O_2 . The open circuit type, invented by Pettenkofer and Voit in 1862, involves the continuous passage of fresh air through the system (Brody, 1974).

The Respiratory Quotient

The metabolic respiratory quotient (RQ) as defined by Slonim and Hamilton (1976) is the molar ratio of CO_2 production to the corresponding O_2 consumption. During a steady state, this metabolic respiratory quotient can be calculated by dividing the CO_2 production by the O_2 consumption. The magnitude of the respiratory quotient depends on the nature of the substrate being oxidized. For carbohydrate oxidation the RQ is approximately 1. Fat contains relatively little O_2 ; thus additional O_2 must be obtained to oxidize the fat. The RQ for fat is approximately .7, while protein is intermediate with an RQ of .8.

Deviations from a normal RQ (.7 to 1) arise as a result of various factors. Respiratory quotients higher than 1 have been reported and are most logically explained by the synthesis of fat from carbohydrate (Paul, 1971; Cureton, 1948; Margaria et al., 1933). However, high RQ's

may also result from over-ventilation of the lungs in rapid breathing (Swift and French, 1954). Respiratory quotients below .7 may result from the synthesis of carbohydrate from fat.

Soskin (1941) reported the RQ of the whole body to be the composite of many different RQ's arising in the various organs and tissues of the organism. Rarely, if ever, does the entire body burn only one kind of fuel according to this author. Rather, a mixture of all three feedstuffs is metabolized, giving rise to a range of metabolic respiratory quotient values (Soskin, 1941; Slonim and Hamilton, 1976).

In man the resting RQ is normally within the range of .8 to .85 (Carlson et al., 1963; Cureton, 1948). In early exercise the proportion of carbohydrate burned increases. This is reflected in an increased RQ from the resting value up to values as high as 1.12 (Paul, 1971; Cureton, 1948; Margaria et al., 1933). After prolonged intense exercise, high proportions of fat are burned and a lower RQ results (Havel, 1971; Iliev and Kessev, 1970; Costill, 1970). A trend for the RQ to decrease with training and during long submaximal exercise was demonstrated in human athletes (Michael and Cureton, 1953; Costill, 1970). Astrand (1967) found that a subject in poor physical condition had a higher RQ at a specific load than a well trained subject with the same load.

Richardson (1929) warned against the use of the RQ without critical scrutiny. This is because the catabolism of substances other than carbohydrates, fats and proteins, can also

affect the RQ. This discrepancy is demonstrated by the catabolism of depot fat and by the observation that the metabolic CO_2 production may not be accurately reflected by exhaled CO_2 during short term analyses. The RQ can be used to determine caloric expenditure and preferred energy substrate (carbohydrate versus fat) if care is taken.

Soskin (1941) suggested that the classical and physiological interpretation of the RQ of the whole animal cannot be upheld; however, it might be valid if applied to individual organs or tissues. Werthessen as cited in Soskin (1941) found the RQ in individual rats ranged from extremely low to extremely high. When all animals in this experiment were considered the range was from .27 to 1.70.

Astrand (1967) supports the concept that the RQ can be used to estimate the proportional contribution from fat and carbohydrate in total energy yield. It was concluded from these studies in humans that the diet affects the participation of fat versus carbohydrate in work metabolism. Consumption of a diet which is rich in carbohydrates increases the RQ and also improves the capacity for prolonged exercise.

Caro (1966) found the RQ can vary when the body's stores of carbon dioxide are altered. The body stores of carbon dioxide equal three hours normal carbon dioxide production. The corresponding stores of oxygen equal only a few minutes. An extremely small change in the percentage of the carbon dioxide stored may, therefore, have a dramatic effect on the RQ.

Knehr et al. (1942) determined respiratory quotients in men walking 8 min at 5.6 km on an 8.6% grade. The men were divided into a control group (no exercise) and 2, 4 or 6 month exercise groups. Respiratory quotients determined for these groups were .94, .93, .92 and .92, respectively. There was an increased efficiency in the ability of these men to ascend an incline, accompanied by a decrease in heart rate as the subjects became conditioned.

Glickman et al. (1967) performed 10 experiments on male subjects seated in a cold room (-28.9C) for 4 hours. Mean heat production increased during each hour of exposure but individual values fluctuated. The average respiratory quotient showed a trend for depressed values during the exposure.

Yousef and Dill (1969) experimenting with two female burros found RQ to range from .77 to 1.1 at rest on an alfalfa hay diet. Mean values for the two animals were .88 and .96. During a fasting period lasting 48 h, mean RQ values for these burros dropped from .92 to .72. The author felt this decrease in RQ indicated transition to the metabolism of body fat stores.

Burke (1979), utilizing indirect open circuit calorimetry, reported RQ's ranging from .83 to 1.35 for ponies at rest. When respiratory quotients were determined during exercise, values of .56 to .90 were observed. Upon cardiac recovery from exercise, RQ's remained depressed, with a range of .55 to .77. This author also investigated various exercising regimes commonly used by horsemen today (walker, treadmill and riding). All horses carried 63.5 kg

of weight. He found oxygen consumption and energy expenditure rates were higher for the riding regime than for horses exercised on the walker or treadmill regimes. This effect could be due to the movements and stresses associated with a rider as compared to the sandbags. Respiratory quotients tended to decrease with training and during long submaximal exercise and remained low during recovery. When the animals in the above study were raced in a series of four consecutive races, the two year olds showed a more dramatic increase in RQ's than three year olds. This would suggest the three year olds were more metabolically stable than the younger horses.

Techniques of Calorimetry

Lavoisier's first experiment was conducted by placing a guinea pig, protected by cotton bedding in a chamber completely enclosed in ice. From this experiment it was concluded that the exhalation of a given quantity of CO_2 corresponded to the melting of a given weight of ice. Another method employed by this investigator was to surround the animal chamber with a known volume of water and to measure the rise in temperature of the water. The latter procedure is the basis for most modern methods of direct calorimetry (Brody, 1974).

The apparatus developed by Regnault and Reiset in 1849 consisted of a ventilating system which moved the air over a CO_2 absorbant. The oxygen consumed by the animal in a chamber was replaced by adding oxygen from a gas burette, so the pressure in the chamber remained constant. Here the air in the chamber maintained its original composition

and the volume of oxygen added was a direct measure of the animal's oxygen consumption (Kleiber, 1975).

Pettenkofer and Voit, in 1862, devised the open circuit method of calorimetry. In this system the subject was also placed in a chamber; but there was a continuous passage of air through the system (no recirculation). A pump drew air out of the chamber through a meter. The advantage of this system over the closed system of Regnault and Reiset was that an air tight system was not vital. As long as suction was maintained in the chamber and no chamber air was lost, it made no difference whether the air entered the chamber through leaks or through the proper inlet (Kleiber, 1975). In this device CO_2 was also determined by the absorption method.

Tigerstedt (1895) built an open-air circulatory apparatus with a chamber similar to that of Pettenkofer and Voit. However, his model collected a continuous sample of the outflowing air for gas analysis. With the introduction of the Tigerstedt apparatus it was now possible to measure O_2 consumption as well as CO_2 production (Kleiber, 1975).

The Pettenkofer and Voit apparatus was further modified by a number of early German researchers for equine use. Through a series of developmental changes, they eliminated the chamber and collected the expired air via a tracheal canulae, thus providing a portable device (Maynard and Loosli, 1962). The early German workers initiated the use of treadmills for controlled exercise in their research.

Flatt (1958) devised a lightweight portable, dry gas meter which attached to the animal's back. A tracheal canulae facilitated direct

measurement of expired air. This procedure allowed free, natural movement of the animal.

Blaxter and Joyce (1963) investigated the longevity and validity of the tracheotomized approach. These workers reported that oxygen consumption, measured from pulmonary exchange, was the same for tracheotomized sheep as that measured by confining the animal in a chamber. However, a large amount of methane and carbon dioxide was not measured by the tracheotomized technique because the gases are belched out by the sheep. These workers concluded that, except in those experiments where it is essential that the face and mouth not be obstructed, the use of a face mask is superior to tracheostomy.

Hornicke (1973) constructed a small face mask and recording device for use on an exercising riding horse. This system was based on telemetry and electronic data processing equipment.

Burke and Albert (1978), using open circuit, indirect calorimetry, measured physical fitness and energy expenditures in horses. These investigators used a mask which fit over the muzzle of the animal and allowed for inhalation of atmospheric air and collection of expired gases. Expired gases travelled through a dry-bellows flow meter and was collected in teflon gas bags for analysis of oxygen and carbon dioxide content.

Osuji (1974) reported that conventional estimates of the energy required for maintenance have been made with animals housed indoors or in respiration chambers. This researcher concluded that the extra muscular activities, over and above those observed indoors or in

chambers may increase the maintenance energy requirements of animals in range conditions by 25 to 50%.

Osuji et al. (1975) stated the energy cost of eating for sheep cannot be predicted accurately without taking into account the physical form of the diet. Diets examined by these workers were chopped dried grass (DGC), pelleted dried grass (DGP) and fresh grass (FG). Increases in heat production were 23 kcal/hr for DGC, 12 kcal/hr for FG and 6 kcal/hr for DGP. Conducting similar studies with cattle, Holmes et al. (1978) reported similar results. These workers concluded the energy expenditure due to eating can exert significant influences on the efficiency with which dietary energy is utilized. For the grazing animal, the rate at which metabolizable energy can be ingested is critical. The digestibility, yield and physical structure of the pasture forage offered to the animal are all likely to exert important effects on the rate of metabolizable energy intake and efficiency of energy utilization.

Energy Expenditure

The end result of energy metabolism, the production of ATP or energy, is not measurable except under special laboratory conditions. Therefore, it has become customary to measure processes which have been shown to be proportional to the production of ATP. Included in this category are the consumption of oxygen, the production of carbon dioxide, or the liberation of heat (McLean and Watts, 1976; Miller, 1968). Oxygen consumption is known to have a given caloric equivalent depending on the substrate being burned; this, coupled with the

resultant production of carbon dioxide, form the basis of indirect calorimetry.

Swift and French (1954) state that of the three determinations, oxygen consumption, carbon dioxide production and the respiratory quotient, only two are needed to compute the third and obtain the heat production.

When discussing heat production it is necessary to follow the breakdown of energy from gross energy to net energy (figure 1). Heat is produced by all the oxidations which take place in the body. All the energy that is used in maintaining the body is eventually changed to heat. This transformation of energy to heat maintains the body temperature (Morrison, 1936). The energy lost from the transformation of gross energy to apparent digestible energy is largely composed of undigested feed and is termed fecal energy. In the conversion of apparent digestible energy to metabolizable energy, losses in the urine and from gaseous products of digestion occur. These gaseous losses can be large in ruminants but are negligible in the monogastric. A large loss of heat occurs in the breakdown of feed, through the heat of fermentation and the heat increment. The remaining energy produced from the feed is termed net energy and will be utilized for maintenance. If the ration contains excess net energy, it will be used for productive purposes (Church and Pond, 1975).

McLean (1972) states that in open circuit calorimetry, heat production can be predicted with accuracy to within $\pm 2\%$, solely from the measurement of oxygen concentration and ventilation rate.

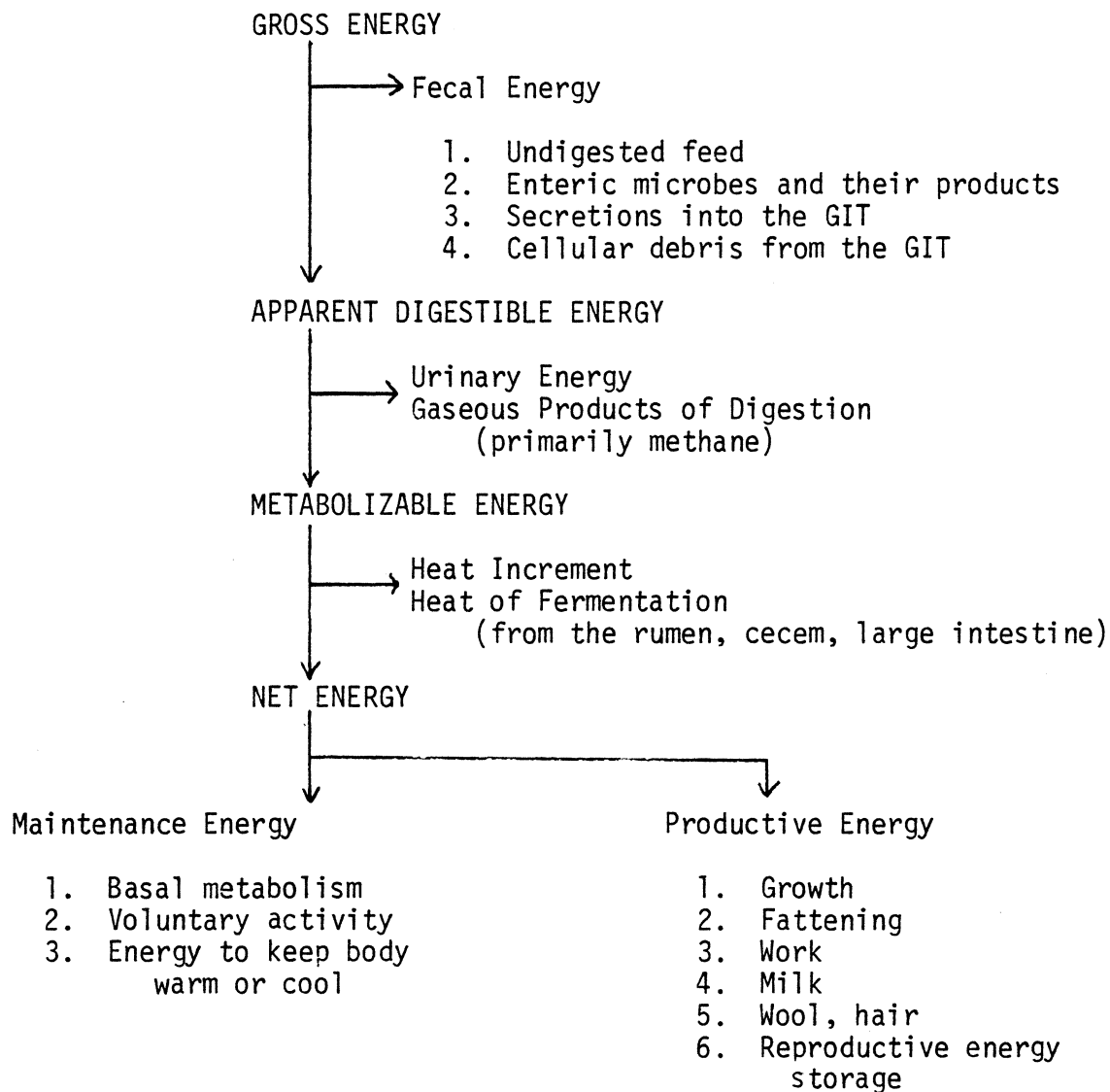


Figure 1. Energy breakdown scheme

Brockway (1978) states that any method of estimating energy expenditure in free ranging animals must meet certain requirements before it can be adopted for general use. The accuracy of the technique should be such that energy expenditure can be estimated to within $\pm 10\%$ and expenditure time should be measurable over periods of 1 h or less.

Yamamoto et al. (1979) estimated heat production from heart rate in cattle and obtained an accuracy of $\pm 10\%$ in all instances. However, differences between individual animals made separate calibration equations necessary for each animal.

Carlson and Hsieh (1970) reported that the quantity of heat produced can be calculated from any one of the following equations:

$$Q = VO_2 (3.9 + 1.1 R)$$

$$Q = 3.9 VO_2 + 1.1 VCO_2$$

$$Q = VE (1.046 - 5 FEO_2)$$

where Q = heat produced in kcal, VO_2 = oxygen consumption in liters, VE = volume of expired air, FEO_2 = fraction of oxygen in expired air, R = respiratory quotient.

Swift and French (1954) report that heat production can be calculated from the Tissot method.

$$X = (O_2L \times \%O_2) \times CRQ$$

where X = heat produced in kcal, O_2L = volume in liters at STPD, $\%O_2$ = % oxygen consumed by animal, CRQ = caloric value of oxygen at the respective respiratory quotient.

Osnes and Hermansen (1972) reported that an individual's maximal rate of oxygen transport sets an upper limit on the amount of energy which can be liberated (aerobically) during prolonged exercise (i.e., 10 min or more). During short term maximal effort in humans, anaerobic glycolysis plays the major role in energy supply. This preferential use of glycogen during short term intense exercise has been supported by Taylor et al. (1977) and Astrand (1967).

Magidov et al. (1962) showed oxygen consumption per unit of body weight was 12 to 18% less in 2 year old horses than in yearlings. These workers also showed walking increased oxygen consumption five-fold over resting and trotting increased it eight-fold. However, with a training period of 6 mo these values were reduced to a 3- to 5-fold increase at the walk and a 5- to 8-fold increase at the trot. These studies involved 44 animals in which resting heat production fell from 1 to 5 kcal/kg/hr in the first year of life to about 1 to 3 kcal/kg/hr in the second year of life. These workers also reported resting heat production was 40% higher in summer than in winter.

Nadal'jak (1962a) studied gaseous exchange in horses and determined energy expenditure at rest in the morning to be 132 kcal/100 kg/hr. Walking at 5 to 8 km/hr with a normal load (load that produced a drag of 15% of the horse's weight) energy expenditures rose to a mean value of 1198 kcal/100 kg/hr. Twice the normal load increased energy expenditure to a mean of 3079 kcal/100 kg/hr. It was determined that the most economical work was with half the normal load

drawn at the walk.

Nadal'jak (1962b), using 20 horses of heavy draft breeding with a mean weight of 747.5 kg, found that a normal load for large horses at a walk should be 150 kg. Further work by Nadal'jak (1962b) showed training had an effect on energy expenditure in horses by reducing oxygen debt.

Wooden et al. (1970) measured the effects of diet on gaseous exchange in horses. These workers determined energy utilization in a series of four balance trials. A face mask and an open circuit calorimetry apparatus was used to obtain the oxygen consumption and carbon dioxide production. Heat production on days 3 and 4 of the fasting period was approximately $93 \text{ kcal/W}_{\text{kg}}^{.75}$. This value is considerably higher than the interspecific value of $70 \text{ kcal/W}_{\text{kg}}^{.75}$ for basal heat production proposed by Kleiber (1932). The RQ's of the horses indicated that conditions for fasting were not met. Blaxter (1962) demonstrated that animals on a high plane of nutrition before fasting produce higher fasting heat production values than those animals which were consuming maintenance or sub-maintenance levels of energy before fasting.

Burke and Albert (1978) measured physical fitness and energy expenditure in horses. Standard metabolic rates determined by these workers averaged 1.11 kcal/hr/kg . This is greater than $.736 \text{ kcal/hr/kg}$ reported by Brody (1974), but approximates Winchester (1943) and Nadal'jak (1962c) who reported values of 1.20 and 1.32 kcal/hr/kg , respectively. Mean energy cost, while standing reported

by Burke and Albert (1978) was 1.66 kcal/hr/kg, which is in close agreement with an NRC (1978) value of 1.71 kcal/hr/kg. The increase in energy expenditure of walking over standing was 3.31 kcal/hr/kg (Burke and Albert, 1978), which is not in agreement with Hall and Brody (1934) who reported the increase over standing to be 1.70 kcal/hr/kg.

OBJECTIVES

The overall objective of this research was to develop an indirect open circuit calorimetry apparatus which could be utilized to sample and measure respiratory gases, specifically oxygen and carbon dioxide, in the equine.

The specific objectives were to:

1. Develop a face mask to fit over the muzzle of the animal, permitting the inhalation of atmospheric air and collection of expired gases.
2. Develop an apparatus to measure the volume of expired gases and sample the gas for analysis of oxygen and carbon dioxide content.
3. Determine RQ and heat production values for three test diets: alfalfa hay, cracked corn plus hay, and concentrate plus hay.

EXPERIMENTAL PROCEDURE

Mask Development

To obtain samples of CO₂ and O₂ needed to calculate respiratory quotients and heat production, a face mask was developed to channel the expired gases into the sampling apparatus. The design was based on the indirect open circuit method of calorimetry.

The face mask, made of light plexiglass, was a modified version of the design of Burke and Albert (1978). The mask fits over the muzzle of the animal and was secured to the horse in much the same manner as a feed bag. The mask was 1 cm thick, 36 cm in length and 20 cm in width (figure 2). Six one-way rubber inhalation valves with an inside diameter of 2 cm¹ were located along the lower portion of the mask (figure 3). These valves permitted a maximum inspiration of atmospheric air equal to three times the normal ventilation area of the horse's trachea. Four one-way rubber exhalation valves were situated in the false bottom of the mask. When the animal expired the inhalation valves were forced shut, and the exhalation valves were forced open, thus channeling the expired gas out of the mask (figure 4). These exhalation valves were 2 cm in diameter and allowed for twice the normal ventilation area of the horse's trachea.

The expired air then passed through two openings 4 cm in diameter located in the removable hose attachment plate (figure 2). At this

¹W. E. Collins, 220 Wood Road, Braintree, Mass. Catalog No. P-304-1.

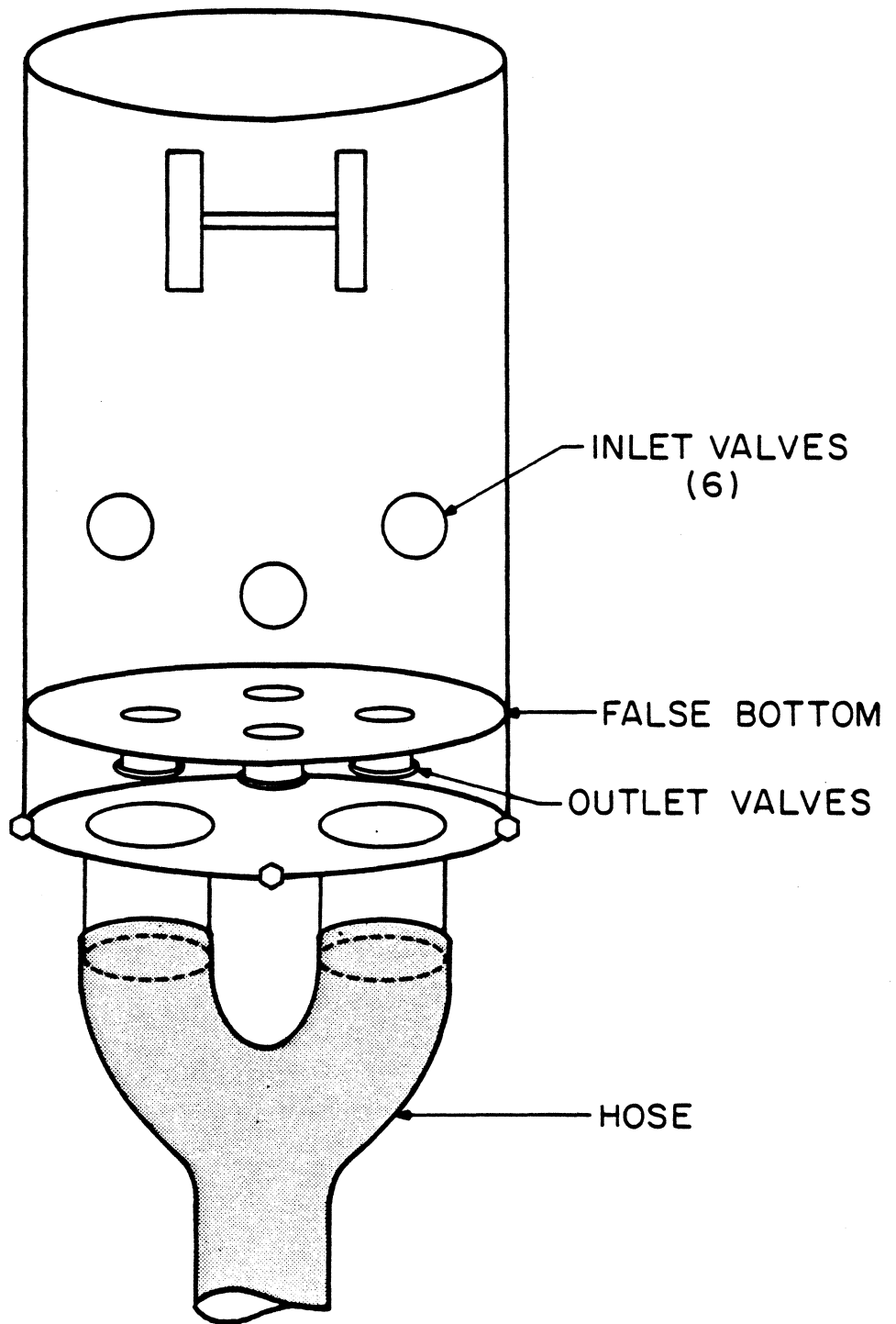


Figure 2. RESPIRATION MASK

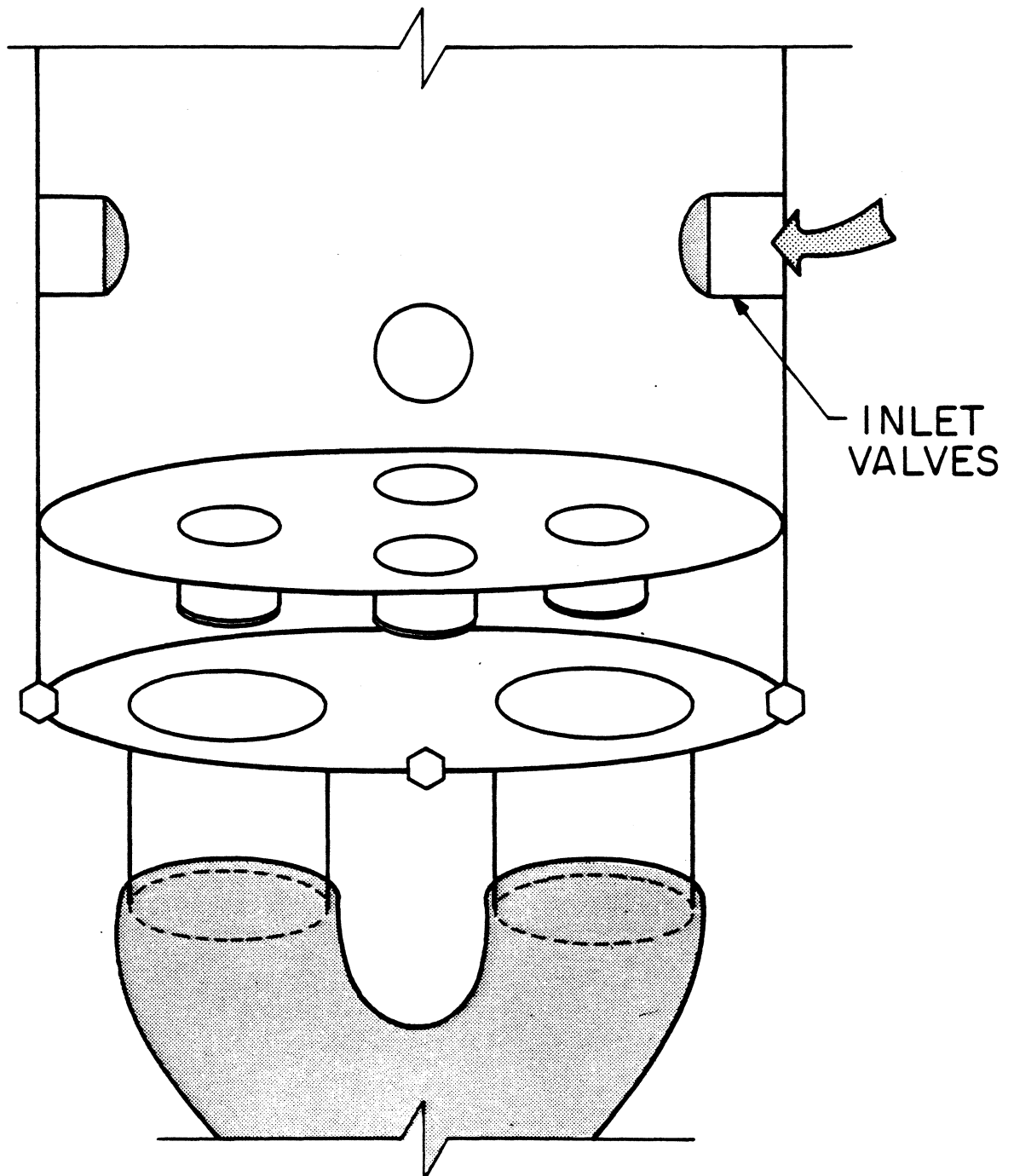


Figure 3. RESPIRATION MASK SHOWING INLET VALVES

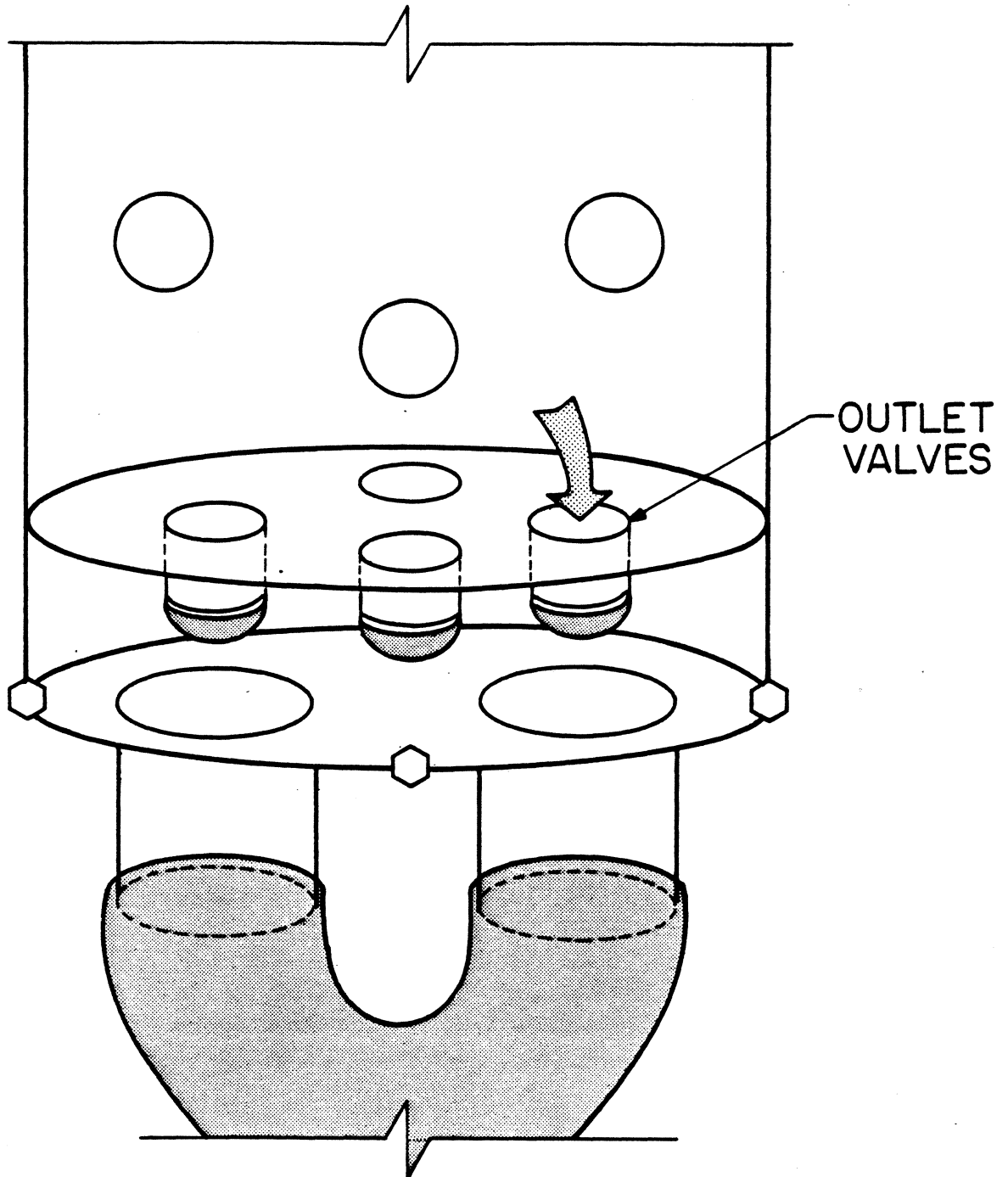


Figure 4. RESPIRATION MASK SHOWING OUTLET VALVES

point a Y-shaped corrugated rubber hose² was attached to the mask and channeled the gases into the measuring and sampling apparatus.

The top of the mask was lined with foam rubber 5 cm in thickness to minimize air leakage and allowed greater comfort to the animals. A rubber pad .25 cm in thickness was secured around the bottom edge of the mask to protect the mask from damage. An adaptation period of several weeks employing a dummy mask was essential to condition the animals to wearing the apparatus.

Protection of the fragile plexiglass mask was vital. During the sampling periods the animals were placed in a well-padded stock and a neck collar was attached to the animal to reduce excessive neck and head movement. Animals and equipment were allowed a 10 min equilibration period prior to sampling.

Development of Equipment for Measuring and Sampling Expired Gases

Expired air from the mask was pulled into the sampling apparatus by means of a variable speed vacuum pump (figure 5). A constant and accurate vacuum was essential to calibrate the rate of flow and to insure that a negative pressure could be maintained at all times to avoid backflow of gases into the mask.

A section of the hose, 4 cm in diameter and approximately 1 m in length leading from the mask to the pump, was submerged in an ice bath to condense the moisture. It became necessary to add the ice bath

²W. E. Collins, 220 Wood Road, Braintree, Mass. Catalog No. 22263.

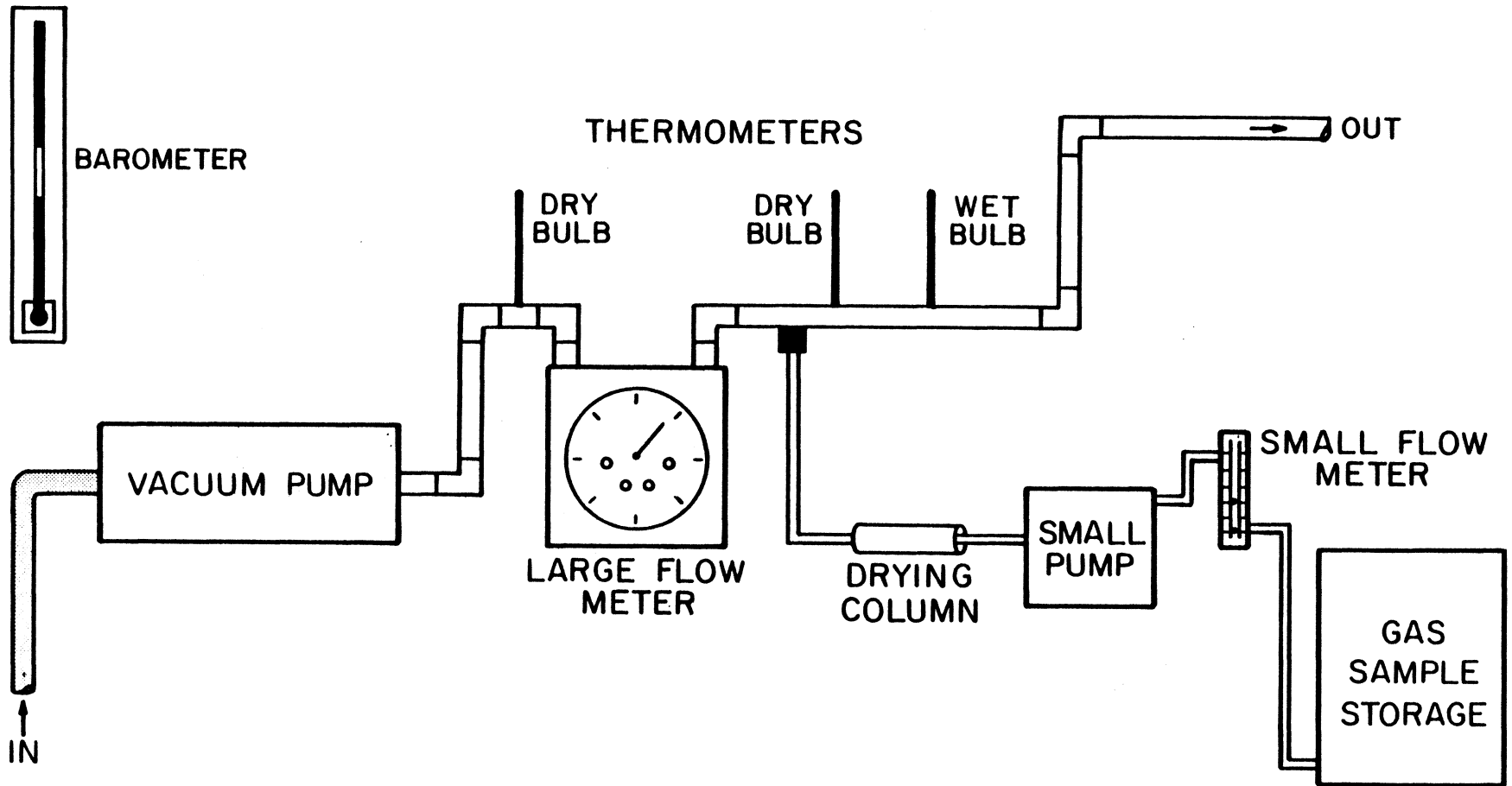


Figure 5. RESPIRATORY GAS MEASURING APPARATUS

to the unit when it was discovered that a large amount of moisture was accumulating in the system and affecting the wet and dry bulb thermometer readings.

The expired air was then passed through 5 cm iron pipe to a flow meter³. Immediately following the large flow meter, a polystaltic pump⁴ collected a continuous sample of gas, approximately 55 ml/min, from the exhaled gas. The sampled aliquot was drawn through a drying column packed with Dririte⁵. The small polystaltic pump then forced the expired sample through a small flow meter. The meter was a check to insure a continuous sample was being collected. The expired gas samples were then forced into 6 liter vitalometers⁶, that were modified to serve as storage containers. Sampling periods lasted 30 minutes. Approximately 1500 ml samples of the expired gases were collected. Before the mask was attached to the animal, samples of atmospheric air were obtained, using the same procedure as described above. After sampling, the expired air was passed out of the building and into the atmosphere.

The sampling equipment was routinely checked for leakage by removing the hoses from the base of the mask and sealing them. The vacuum pump was then turned on; if a leak was present the flow meter would be activated. However, if there was no leak the flow meter made no recording.

³American Meter Company, Model DTM-325.

⁴Neptune Dyna-Pump Model 2.

⁵Fisher Scientific Company, 711 Forbes Avenue, Pittsburgh, Pa.

⁶Collins Standard Vitalometer, Catalog No. P-800.

A barometer⁶, two dry bulb thermometers and a wet bulb thermometer were included in the system to allow conversion of gas volumes to standard temperature, pressure and density (STPD).

Gas Analysis

Triplicate subsamples of both atmospheric air and expired gases were drawn from the storage containers using 50 cc Pharmaseal Stylex syringes. The syringes were equipped with a three-way stopcock (Pharmaseal K-69) which eliminated contamination at subsampling. The stopcocks also facilitated smooth and rapid injection of the samples into the gas partitioner⁷. The samples were injected through a built-in gas sampling valve, with a calibrated sample loop of .5 ml. This injection procedure facilitated greater ease and replication.

Samples of expired gases and atmospheric air were analyzed for carbon dioxide (CO₂) and oxygen (O₂). The partitioner was connected to an automatic recorder and printout device⁸.

Basic operation of the partitioner consisted of introducing a mixture of gases into the instrument where it was passed through two chromatographic columns by a continuous flow of helium carrier gas. The first column was packed with Di-2-ethylhexylsebacate⁹ on 60 to 80

⁶Princo Barometer, Fisher Scientific Company, 711 Forbes Avenue, Pittsburgh, Pa.

⁷Fisher Hamilton Gas Partitioner, Fisher Scientific Company, 711 Forbes Avenue, Pittsburgh, Pa. Catalog No. 11-27.

⁸Omniscribe.

⁹Compounds available from Fisher Scientific Company, 711 Forbes Avenue, Pittsburgh, Pa.

mesh columpak (DEHS). The second column was packed with 42 to 60 mesh molecular sieve.

When the mixture of gases was introduced into the partitioner, all components of the sample, except CO₂ were swept quickly through the first column. As they emerged from the column their presence was recorded as a composite peak. As the CO₂ emerged from column one, it was recorded immediately after the composite (figure 6). The composite mixture and CO₂ were then passed into column 2, where the CO₂ was permanently absorbed and the components of the mixture were separated and appeared as individual peaks on the recorder. Prior to each sampling session, the partitioner was standardized, using a mixture of gases (O₂, CO₂, N and CH₄) of known concentrations.

To determine respiratory quotients and heat production, volumes of CO₂ produced and O₂ consumed were calculated using the following formulas. Oxygen consumption was determined as the difference in the oxygen content of the atmospheric air and the expired gas from the animal on a percentage basis. Carbon dioxide content was calculated by subtracting .033% CO₂ (CRC, 1980, value for CO₂ present in the atmosphere) from the percent CO₂ in expired air.

Respiratory quotient was calculated using the equation reported by Kleiber (1975).

$$RQ = \frac{\text{volume of CO}_2 \text{ produced}}{\text{volume of O}_2 \text{ consumed}}$$

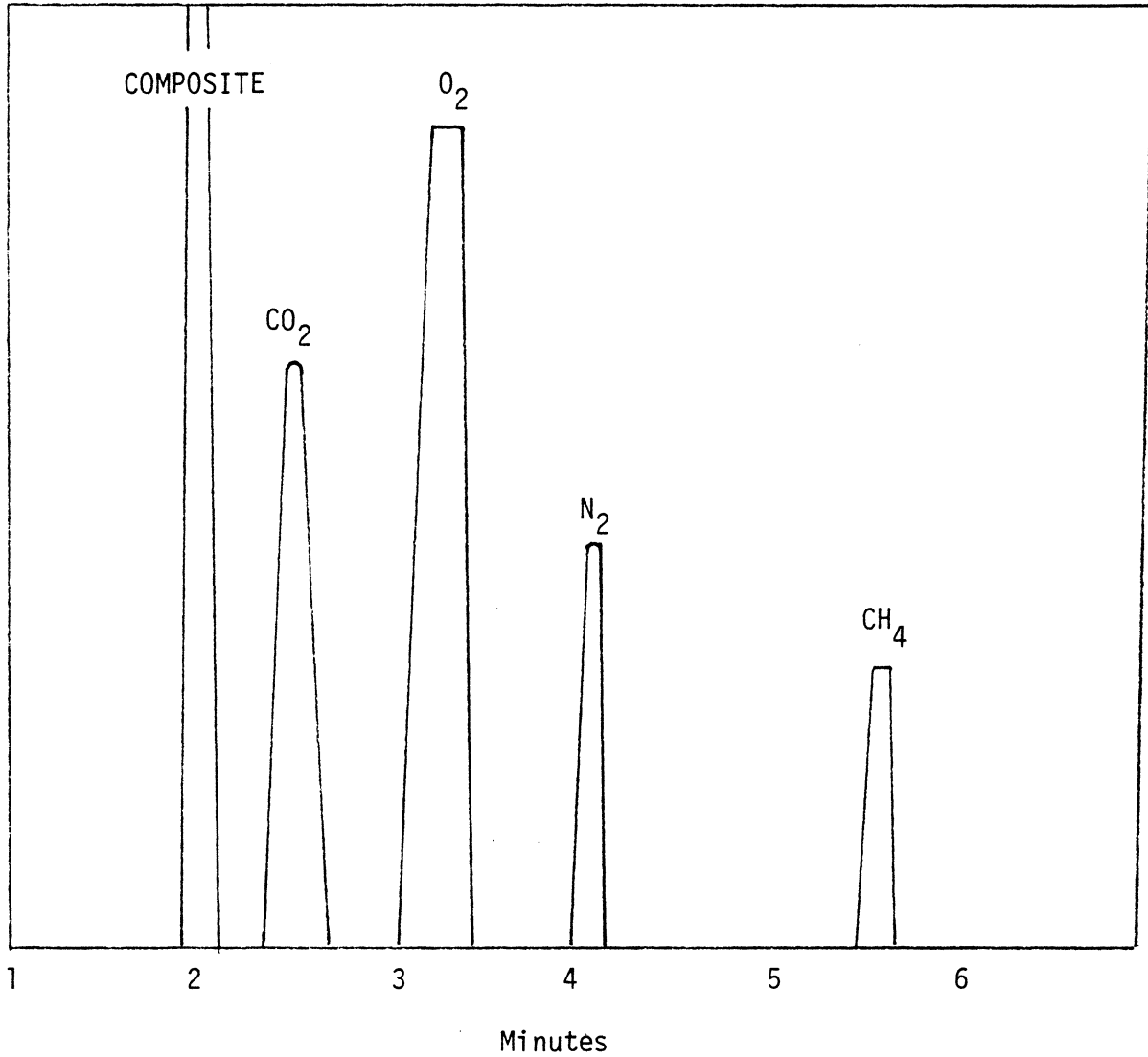


Figure 6. SAMPLE GAS ANALYSIS USING A FISHER HAMILTON GAS PARTITIONER

Heat production was calculated using the equation of Tissot cited in Swift and French (1954).

(heat produced in kcal) = ($O_2L \times \%O_2$) x CRQ, where

O_2L = volume in liters at STPD

$\%O_2$ = % oxygen consumed by the animal

CRQ = caloric value of O_2 at the respective
respiratory quotient

Implementation and Testing

Three grade ponies with an average weight of 260 kg, which had been on pasture, were selected. The ponies were individually housed in 2.9 x 1.4 m stalls equipped with automatic waters. The ponies were confined to these stalls except for a daily exercise period. The exercise consisted of a brisk walk for one hour on a variable speed hot walker, immediately following the sampling regime. The three ponies were fed each of the three diets (table 1) in three consecutive feeding periods.

The ponies were adapted to the face mask, confines of the stock and the sampling apparatus over a period of 4 weeks.

Diet 1

During the adaptation and collection periods all animals were fed alfalfa-grass hay at 1% of body weight. Composition of alfalfa-grass hay is shown in table 1. Ponies received one half of their ration in the morning and the remainder in the evening. All animals consumed their entire ration during this period.

TABLE 1. INGREDIENT COMPOSITION OF FEEDSTUFFS^a

Item	Diets		
	1 Alfalfa-grass hay ^b	2 Corn grain ^b	3 Grain mix ^c
Dry matter, %	89	88	18.2
Digestible energy (Mcal/kg)	2.11	3.87	--
Crude protein, %	12.55	10.9	--
Crude fiber, %	35.0	2	7.62
Fat, %	--	--	2.76
Calcium, %	.925	.05	.827
Phosphorus, %	.28	.60	.61

^aDry basis.

^bNRC (1978).

^c"Colt Maker" supplied by Southern States Cooperative, Richmond, Va.

Diet 2

The ponies were gradually switched to a diet of cracked corn and alfalfa-grass hay (table 1). This was done in an attempt to increase the respiratory quotient by supplying more energy in the diet. Feeding periods were staggered in the morning so that each animal received its portion of corn 2 h prior to the gas sampling regime. Hay was fed in the evening at the rate of 1.36 kg per animal. During this period one animal refused the corn portion of the ration and was subsequently switched to a commercial grain mix.

Diet 3

All animals during this period were offered a commercially prepared grain mix containing 18% protein (table 1) and alfalfa-grass hay. Feeding periods were staggered in the morning so that each animal received the grain mix 2 h prior to the gas sampling regime. Hay was fed in the evening at the rate of 1.36 kg per animal. This higher protein diet was offered to detect a decrease in the RQ.

RESULTS AND DISCUSSION

Initially all animals received alfalfa-grass hay (Diet 1) at 1% of body weight daily. Results are shown in table 2. Mean RQ's were .991 and .999, respectively, for ponies 29 and 30. Daily RQ's ranged from .724 to 1.11 for pony 29 and .754 to 1.13 for pony 30. These values agree closely with those of Yousef and Dill (1969) who reported RQ's for female burros at rest receiving an alfalfa hay diet to range from .77 to 1.1.

Results of feeding Diet 2 are shown in table 3. When animals consumed cracked corn, RQ's averaged 1.01, 1.05 and 1.19 for ponies 22, 29 and 30, respectively. Respiratory quotients increased as a result of adding grain to the diet. Mean values ranged from .779 to 1.19 for pony 22, .945 to 1.23 for animal 29 and .852 to 1.40 for animal 30. It should be noted that animal 30 was taken off trial early because of refusal to consume the grain portion of the diet.

RQ's higher than .7 to 1.0 were recorded for animal 30. Respiratory quotients higher than 1.0 have been reported and explained as the result of catabolism of depot fat to energy (Paul, 1971; Cureton, 1948; Margaria et al., 1933). In the case of No. 30 the grain refusal may have resulted in the body converting stored fat to meet the energy requirements for maintenance, this process producing an elevated RQ.

Table 4 shows the results of Diet 3, in which animals consumed a commercially prepared grain mixture containing 18.2% protein, in

TABLE 2. RESPIRATORY QUOTIENTS (RQ) OF PONIES FED DIET 1

Day	Pony no.	Alfalfa-grass hay consumed	RQ
		g	
1	29	1360.8	1.01
2	29	1360.8	.724
3	29	1360.8	1.22
4	29	1360.8	1.11
5	29	1360.8	.894
Mean \pm S.E.			.9916 \pm .083
1	30	1360.8	1.07
2	30	1360.8	.924
3	30	1360.8	.754
4	30	1360.8	1.12
5	30	1360.8	1.13
Mean \pm S.E.			.999 \pm .088

TABLE 3. RESPIRATORY QUOTIENTS (RQ) OF PONIES FED DIET 2

Day	Pony no.	Corn consumed ^a g	RQ
1	22	2270	.971
2	22	1260	1.15
3	22	1362	.779
4	22	1362	.992
5	22	1362	1.18
6	22	2200	.995
7	22	1970	1.04
8	22	1954	1.03
9	22	1443	1.00
Mean \pm S.E.			1.01 \pm .0381
1	29	1550	1.12
2	29	1435	1.08
3	29	205	.970
4	29	1362	1.06
5	29	1362	1.23
6	29	1816	1.11
7	29	1816	.945
8	29	1816	1.00
9	29	1816	.981
Mean \pm S.E.			1.05 \pm .030
1	30	185	1.35
2	30	210	1.40
3	30	160	1.15
4	30	173	.852
5	30	194	1.19
Mean \pm S.E.			1.19 \pm .0959

^aPonies received 1362 g of alfalfa-grass hay daily in addition to the cracked corn.

TABLE 4. RESPIRATORY QUOTIENTS (RQ) OF PONIES FED DIET 3

Day	Pony no.	Grain consumed ^a	RQ
		g	
1	22	1814	.978
2	22	1814	1.06
3	22	1814	.923
4	22	1814	.853
5	22	1814	.894
6	22	1814	.709
7	22	1814	.865
Mean \pm S.E.			.897 \pm .0412
1	29	1814	.995
2	29	1814	1.20
3	29	1814	1.08
4	29	1814	.911
5	29	1814	.902
6	29	1814	.772
7	29	1814	1.06
Mean \pm S.E.			.988 \pm .0530
1	30	1814	.796
2	30	1814	.883
3	30	1814	1.70
4	30	1814	.745
5	30	1814	.990
6	30	1814	.726
7	30	1814	1.04
Mean \pm S.E.			.983 \pm .1276

^aPonies received 1362 g of alfalfa-grass hay daily in addition to the grain mix.

addition to alfalfa-grass hay. Mean RQ's for ponies 22, 29 and 30 were .897, .988 and .984. On day 3 a RQ of 1.70 was recorded for 30. Omission of this value due to its high variation seemed appropriate. A corrected mean RQ of .863 for 30 appears more representative. Daily RQ's ranged from .709 to 1.06 for pony 22, .772 to 1.20 for pony 29 and .726 to 1.04 for pony 30.

Few respiratory quotients have been reported for the horse. Wooden et al. (1970) reported RQ values of .80 to .82 for two unconditioned horses at rest. These values are lower than the values recorded in this study. Burke (1980) recorded a mean RQ of 1.04 for horses at rest. This figure is slightly higher than the .956 determined in these studies.

Heat production values were calculated using the equation of Tissot cited in Swift and French (1954). Since protein metabolism represents only a small amount of heat loss it was not subtracted from the total heat production values.

Energy data for the alfalfa-grass hay diet is shown in table 5. Heat production values ranged from 1131 to 3629 kcal/kg intake/day (appendix tables 1 and 2), with means of 2318 and 1948 kcal/kg intake/day for ponies 29 and 30, respectively. An energy balance value was derived for each diet by subtracting the heat production from the respective metabolizable energy values. Energy balance for pony 29 was -158 and 213 kcal/kg intake/day for pony 30.

NRC (1978) estimates the metabolizable energy requirement for pony 29 to be 10.51 mcal of energy for maintenance. Due to an

TABLE 5. MEAN ENERGY DATA FOR DIET 1^a

	Pony no.	
	29	30
	-----kcal/kg intake/day-----	
Digestible energy ^b	2181	2181
Urinary energy ^c	20	20
Metabolizable energy	2161	2161
Heat production	2318 ± 389 ^d	1948 ± 339
Energy balance	- 158 ± 389	213 ± 339

^aAlfalfa-grass hay.

^bNRC (1978).

^cHintz and Schryver (1972).

^dMean ± S.E.

apparent palatability problem this animal would only consume 1% of its body weight in hay or ingest 5.89 mcal of energy per day. For this reason other animals were limited to 1% of body weight per day in hay. It is possible that this animal, which had a nervous temperament, was in negative energy balance.

Heat production and energy balance values for ponies fed a cracked corn and alfalfa-grass hay (Diet 2) are shown in table 6. Heat production values ranged from 1396 to 4114 kcal/kg intake/day (appendix tables 3, 4 and 5). Mean heat production was 1612, 2099 and 2658, respectively, for ponies 22, 29 and 30. Mean energy balance values are 1478, 902 and -312 kcal/kg intake/day. Number 30 was eventually removed from the trial because of refusal to consume the corn, and consuming only 1.36 kg of hay per day. It can be assumed this pony was approaching a fasting heat production state.

Table 7 shows the energy data for ponies fed a commercial grain mix and alfalfa-grass hay (Diet 3). Mean heat production values for ponies 22, 29 and 30 were 1856, 1699 and 1627 kcal/kg intake/day, respectively. Individual values for pony 30 ranged from a low of 852 to a high of 2791 kcal/kg intake/day, with the values for all other animals falling within this range (appendix tables 6, 7 and 8). Energy balance data for these ponies were 1267.75, 1424.12 and 1496.54 for animals 22, 29 and 30, respectively.

Mean digestible and metabolizable energy and heat production values for the three experimental diets are given in table 8.

TABLE 6. MEAN ENERGY DATA FOR DIET 2^a

	Pony no.		
	22	29	30
	-----kcal/kg intake/day-----		
Digestible energy ^b	3109 \pm 34 ^d	3021 \pm 79	2381 \pm 8
Urinary energy ^c	19 \pm 1	20 \pm 2	36 \pm .20
Metabolizable energy	3090 \pm 34	3001 \pm 81	2346 \pm 8
Heat production	1612 \pm 78	2099 \pm 271	2658 \pm 126
Energy balance	1478 \pm 106	902 \pm 348	- 312 \pm 133

^aCracked corn and alfalfa-grass hay.

^bNRC (1978).

^cHintz and Schryver (1972).

^dMean \pm S.E.

TABLE 7. MEAN ENERGY DATA FOR DIET 3

	Pony no.		
	22	29	30
	-----kcal/kg intake/day-----		
Digestible energy ^b	3141	3141	3141
Urinary energy ^c	18	18	18
Metabolizable energy	3123	3123	3123
Heat production	1856 \pm 126 ^d	1699 \pm 88	1627 \pm 228
Energy balance	1268 \pm 126	1424 \pm 88	1497 \pm 228

^aCommercial grain mix and alfalfa-grass hay.

^bNRC (1978).

^cHintz and Schryver (1972).

^dMean \pm S.E.

Metabolizable energy was highest for the diet containing the commercial grain mix, intermediate for the corn diet and lowest for the hay diet. Heat production was highest for the alfalfa-grass hay diet, followed by the cracked corn and then the commercial grain mix with values of 2133.04, 2030.00 and 1727.23 kcal/kg intake/day, respectively.

When all animals were considered as a group, a positive energy balance existed for all diets. Mean values were 27.66, 863.38 and 1396.11 kcal/kg intake/day for the hay, corn and commercial diets.

Crampton and Lloyd (1959) stated the resting heat production for horses in a fasting state was 11.3 kcal/kg weight. Mean energy weight in this experiment was 263.46 kg. Based on the above value of 11.3 kcal/kg weight, heat production for these animals should be 2977.09 kcal/day. The average heat production for all ponies across all diets was 5340.5 kcal/day. This value is greater than that predicted by Crampton and Lloyd (1959), since it represents non-fasting animals.

An interspecific species fasting heat production value of $70.2 \text{ kcal/W}_{\text{kg}}^{.75}/\text{day}$ was reported by Kleiber (1932). Knox et al. (1970) reported a similar heat production of $70.8 \text{ kcal/W}_{\text{kg}}^{.75}/\text{day}$ for fasting horses. Using the mean metabolic weight of 65.39 kg for animals in this experiment and Kleiber's (1932) value of $70.2 \text{ kcal/W}_{\text{kg}}^{.75}$, average fasting heat production for the ponies is 4590.37 kcal/day.

Knox et al. (1970) reported heat production values ranging from

TABLE 8. MEAN DIGESTIBLE AND METABOLIZABLE ENERGY AND HEAT PRODUCTION VALUES OF DIETS

	Diet 1	Diet 2	Diet 3
	Alfalfa-grass hay ^c	Cracked corn ^d + hay	Commercial ^e grain mix + hay
Digestible energy ^a	2181	2916 ± 69	3141
Urinary energy ^b	20	23 ± 2	18
Metabolizable energy	2161	2893 ± 70	3123
Heat production	2133 ± 250 ^f	2030 ± 138	1727 ± 89
Energy balance	28 ± 250	863 ± 200	1396 ± 89

^aNRC (1978).

^bHintz and Schryver (1972).

^cMeans based on 10 observations.

^dMeans based on 23 observations.

^eMeans based on 21 observations.

^fMean ± S.E.

7089 to 14027 kcal/day for animals consuming 0 to 496 kcal GE/ $W_{\text{kg}}^{.75}$ /day and weighing 81.4 to 108.4 kg $\cdot^{.75}$. Although these values represent horses of larger metabolic size they are similar to those reported in this experiment of 5802, 5522 and 4698 kcal/day for hay, corn and commercial grain diets, respectively.

Heat production values reported by Burke (1980) for conditioned pony geldings before exercise ranged from 5909 to 8650 kcal/day. The lower range of Burke's values are similar to those observed in this experiment.

SUMMARY

A respiratory apparatus was designed and constructed for equine based on the indirect, open circuit method of calorimetry. The face mask of light plexiglass was designed to fit over the muzzle of the animal and was secured via a modified halter. Six one-way rubber inhalation valves were located along the lower portion of the mask, permitting the animal to inspire atmospheric air. Four one-way rubber exhalation valves were situated in the false bottom of the mask. When the animal expired, the inhalation valves were forced shut and the exhalation valves were forced open, thus channeling the expired gas out of the mask. A series of flow meters, pumps, drying columns and storage containers were connected to the mask. Aliquots of expired gases were taken and analyzed for carbon dioxide and oxygen content to determine respiratory quotients (RQ) and to calculate heat production values.

Two ponies received 1% of their body weight in alfalfa-grass hay (Diet 1). A mean RQ of .995 and a mean heat production value of 2133 kcal/kg intake/day were recorded.

Heat production decreased to a mean of 2030 kcal/kg intake/day and a mean RQ of 1.08 was obtained when 3 animals consumed a cracked corn and alfalfa-grass hay (Diet 2).

The third feeding period all animals received a commercial

grain mix and alfalfa-grass hay (Diet 3). Mean RQ was .956 and mean heat production was 1727 kcal/kg intake/day.

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APPENDIX

APPENDIX TABLE 1. ENERGY DATA FOR ALFALFA-GRASS HAY (DIET 1) FOR PONY 29

	Day				
	1	2	3	4	5
Digestible energy ^a	2180.61	2180.61	2180.61	2180.61	2180.61
Urinary energy ^b	19.65	19.65	19.65	19.65	19.65
Metabolizable energy	2160.96	2160.96	2160.96	2160.96	2160.96
Heat production	3629.00	2706.00	1565.30	1596.97	2095.05
Energy balance	-1468.04	- 545.04	+ 595.59	+ 563.98	+ 65.90

^aNRC (1978).

^bHintz and Schryver, 1972.

APPENDIX TABLE 2. ENERGY DATA FOR ALFALFA-GRASS HAY (DIET 1) FOR PONY 30

	Day				
	1	2	3	4	5
Digestible energy ^a	2180.61	2180.61	2180.61	2180.61	2180.61
Urinary energy ^b	20.17	20.17	20.17	20.17	20.17
Metabolizable energy	2160.44	2160.44	2160.44	2160.44	2160.44
Heat production	2752.79	2562.74	2104.89	1131.29	1186.28
Energy balance	- 592.35	- 402.30	+ 55.55	+1029.15	+ 974.16

^aNRC (1978).

^bHintz and Schryver, 1972.

APPENDIX TABLE 3. ENERGY DATA FOR CRACKED CORN AND ALFALFA-GRASS HAY (DIET 2) FOR PONY 22

	Day								
	1	2	3	4	5	6	7	8	9
Digestible energy ^a	3240.87	2995.01	3027.13	3027.13	3027.13	3227.75	3182.95	3198.31	3052.44
Urinary energy ^b	15.42	21.36	20.56	20.56	20.56	15.72	16.81	16.89	19.96
Metabolizable energy	3225.45	2973.65	3006.57	3006.57	3006.57	3212.03	3166.15	3181.42	3032.45
Heat production	1396.12	1683.18	2115.48	1740.94	1510.03	1347.89	1443.90	1556.04	1712.72
Energy balance	+1829.33	+1290.47	891.09	1265.63	1496.54	1864.14	1722.24	1625.38	1319.73

^aNRC (1978).

^bHintz and Schryver, 1972.

APPENDIX TABLE 4. ENERGY DATA FOR CRACKED CORN AND ALFALFA-GRASS HAY (DIET 2) FOR PONY 29

	Day								
	1	2	3	4	5	6	7	8	9
Digestible energy ^a	3082.85	3050.20	2400.99	3028.04	3028.04	3149.31	3149.31	3149.31	3149.31
Urinary energy ^b	18.38	19.13	34.16	19.65	19.65	16.84	16.84	16.84	16.84
Metabolizable energy	3064.47	3031.06	2366.83	3008.39	3008.39	3132.47	3132.47	3132.47	3132.47
Heat production	1900.60	2528.50	4113.95	1788.74	1783.58	1399.57	1695.59	1770.09	1914.24
Energy balance	1163.87	502.55	-1747.12	1219.65	1224.80	1732.90	1436.87	1362.37	1218.22

^aNRC (1978).

^bHintz and Schryver, 1972.

APPENDIX TABLE 5. ENERGY DATA FOR CRACKED CORN AND ALFALFA-GRASS HAY (DIET 2) FOR PONY 30

	Day				
	1	2	3	4	5
Digestible energy ^a	2381.89	2405.69	2357.32	2370.20	2390.55
Urinary energy ^b	35.53	34.96	36.11	35.80	35.32
Metabolizable energy	2346.36	2370.72	2321.21	2334.39	2355.23
Heat production	2322.38	2511.59	3000.31	2899.76	2556.38
Energy balance	23.97	- 140.87	- 679.10	- 565.36	- 201.15

^aNRC (1978).

^bHintz and Schryver, 1972.

APPENDIX TABLE 6. ENERGY DATA FOR COMMERCIAL GRAIN MIX AND ALFALFA-GRASS HAY (DIET 3) FOR PONY 22

	Day						
	1	2	3	4	5	6	7
Digestible energy ^a	3140.97	3140.97	3140.97	3140.97	3140.97	3140.97	3140.97
Urinary energy ^b	17.63	17.63	17.63	17.63	17.63	17.63	17.63
Metabolizable energy	3123.34	3123.34	3123.34	3123.34	3123.34	3123.34	3123.34
Heat production	1558.86	1417.13	1666.67	2283.83	1801.43	2217.23	2044.01
Energy balance	1564.47	1706.20	1456.66	839.50	1321.90	906.10	1079.32

^aNRC (1978).

^bHintz and Schryver, 1972.

APPENDIX TABLE 7. ENERGY DATA FOR COMMERCIAL GRAIN MIX AND ALFALFA-GRASS HAY (DIET 3) FOR PONY
29

	Day						
	1	2	3	4	5	6	7
Digestible energy ^a	3140.97	3140.97	3140.97	3140.97	3140.97	3140.97	3140.97
Urinary energy ^b	17.63	17.63	17.63	17.63	17.63	17.63	17.63
Metabolizable energy	3123.34	3123.34	3123.34	3123.34	3123.34	3123.34	3123.34
Heat production	1702.10	1437.42	1417.13	1853.98	1804.31	2067.18	1612.46
Energy balance	1421.23	1685.91	1706.20	1269.35	1319.02	1056.16	1510.87

^aNRC (1978).

^bHintz and Schryver, 1972.

APPENDIX TABLE 8. ENERGY DATA FOR COMMERCIAL GRAIN MIX AND ALFALFA-GRASS HAY (DIET 3) FOR PONY
30

	Day						
	1	2	3	4	5	6	7
Digestible energy ^a	3140.97	3140.97	3140.97	3140.97	3140.97	3140.97	3140.97
Urinary energy ^b	17.63	17.63	17.63	17.63	17.63	17.63	17.63
Metabolizable energy	3123.34	3123.34	3123.34	3123.34	3123.34	3123.34	3123.34
Heat production	1720.73	1382.30	851.73	2790.66	1543.41	1806.28	1292.51
Energy balance	1402.60	1741.03	2271.60	332.67	1579.92	1317.05	1830.82

^aNRC (1978).

^bHintz and Schryver, 1972.

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CONSTRUCTION AND TESTING OF A RESPIRATORY
APPARATUS FOR EQUINE

by

Stephen A. Rich

(ABSTRACT)

Experiments were initiated to design and construct a respiratory apparatus for equine based on the indirect, open circuit method of calorimetry. The face mask, of light plexiglass, fit over the muzzle of the animal and was secured to the head, via a modified halter. Six one-way rubber inhalation valves were located along the lower portion of the mask permitting the animal to inspire atmospheric air. Four one-way rubber exhalation valves were situated in the false bottom of the mask. When the animal expired, the inhalation valves were forced shut and the exhalation valves were forced open, thus channeling the expired gas out of the mask. A series of flow meters, pumps, drying columns and storage containers were connected to the mask. Aliquots of expired gases were taken and analyzed for carbon dioxide and oxygen content to determine RQ and to calculate heat production values. All values were recorded at standard temperature, pressure and density.

Three different diets were fed to equine in an attempt to alter the RQ: two ponies were first fed alfalfa-grass hay (Diet 1), then cracked corn and hay (Diet 2) was fed to 3 ponies and finally a commercial 18% protein grain mix and hay (Diet 3) was fed to the 3 ponies. Consumption problems occurred on some diets. Mean RQ's were

.995 for Diet 1, 1.08 for Diet 2 and .956 for Diet 3. Mean heat production values were 2133.04, 2030.00 and 1727.23 kcal/kg feed/day for the alfalfa-grass hay, cracked corn and alfalfa grass-hay diet, and commercial grain mix and alfalfa-grass hay diet, respectively.