# A Simple Deployable Artificial Rumen for Production of Emergency Nutrition

## Contents



## Report Objectives

This report is a compilation of concepts from peer-reviewed literature, ecology, evolution, organismal biology used by the report writer to develop a plausible system that is easily and cheaply produced for the purpose of sending (deploying) to developing countries or areas with little technological infrastructure in order to provide a means to extract nutrition from local plant-life for human consumption. The system described is intended to replicate the natural processes and thereby limit the work and involvement required by the operators. The use of an artificial rumen as a deployable means to generate food in emergency situations is a novel purpose though artificial rumen have been used for many years to study digestion in ruminants. Though theoretically sound the idea would require significant testing to ensure:

- The food-stuffs generated are healthy to consume
- The food-stuffs generated are palatable
- The system is sustainable in an austere environment

It is the objective of this report to;

- Provide a theoretical framework for the design of an artificial rumen that can be deployed to food-deprived areas
- Provide a guide for setup, operation, and maintenance of the artificial rumen
- Provide a series of questions and concerns necessitating further study prior to employ
- Provide theoretical solutions or testing concepts for further development

## System Components

***The system will be composed of 3 main components***

- The Artificial Rumen
- A Rumen-fluid Extraction Kit
- A Rumen-fluid Collection Container

***Operation and maintenance of the system will require the following processes***

- Knowledge of the Rumen-fluid extraction Process
- Available Ruminants
- Water Source
- Available vegetation

***Tools of the Trade***

- 1 – 0.5 liter syringe
- 1-2 meters of Plastic Tubing for syringe
- Artificial Rumen
- Rumen-fluid Collection Container

## Concept of Operation

The system will function off the principle that; ruminants, such as cows, sheep, goats, buffalo, etc.. persist in some of the most austere environments on earth where food-availability is low. These animals have unique anatomy that allows them to use available vegetation for nutrition. The rumen is the initial compartment of a ruminant's digestive system and is the primary location of cellulosic digestion allowing the animal to extract nutrition from vegetation.

The unique combination of microbial flora and fauna in the rumen is specific to species and region, therefore the deployment of artificial rumen to apriora unknown locations would require a system that by its design and operation takes advantage of the existing local natural system. Using local ruminant

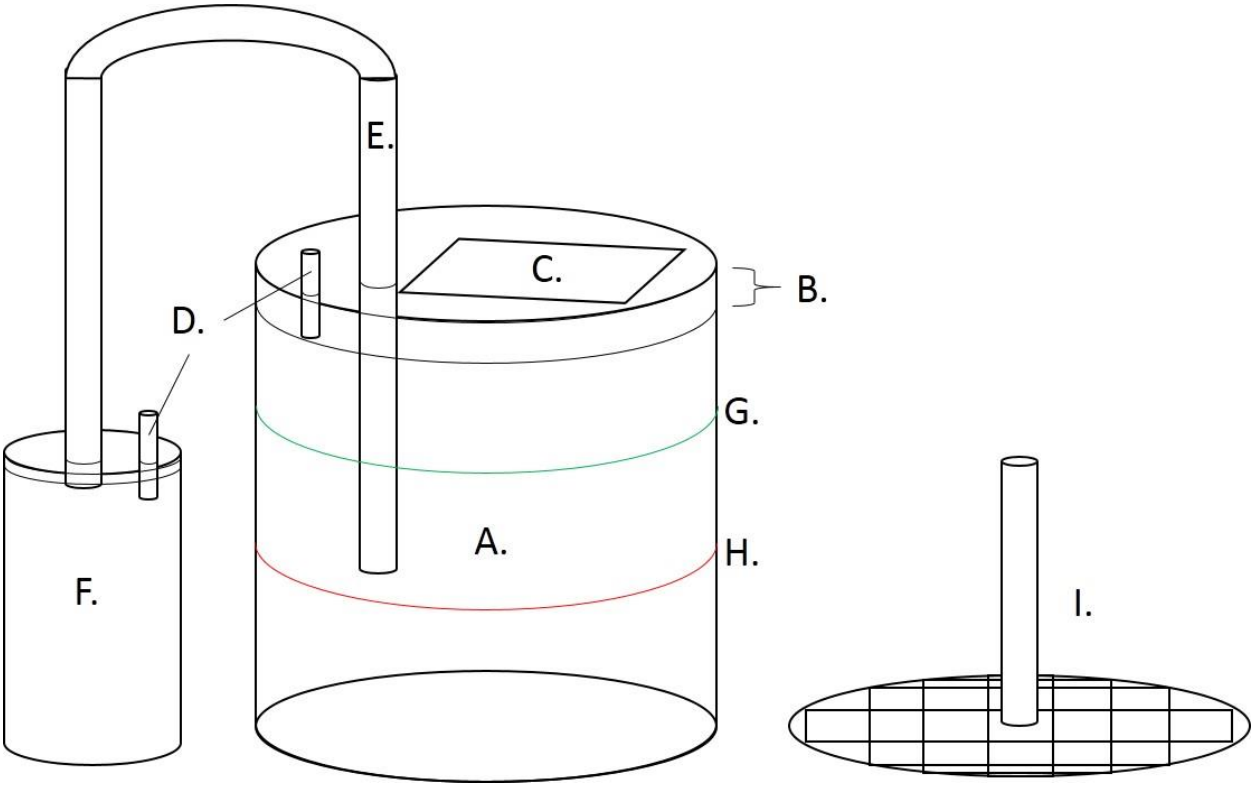
rumen-fluid to start the artificial rumen ensures the artificial rumen will be able to digest local vegetation.

The Artificial Rumen Kit would be deployed as the artificial rumen, a rumen-fluid extraction kit, and a rumen-fluid collection container. Operators would use the rumen-fluid extraction kit (a large syringe with a hose attached) to extract rumen fluid from the ruminant. The extracted fluid would then be placed in the artificial rumen and vegetation would be added. The top would be closed, sealing the rumen fluid inside. As gases are produced the pressure built inside the container forces digested fluid through a sub-merged inlet and into a collection container for consumption.

## System Design

The Simple Artificial Rumen (Figure 1) would be a plastic container (A) with a capacity between 1-2 liters. The sealable screw cap (B) would require a sealable opening to introduce vegetation (C) during production. Pressure release/introduction valves (D) allow the operator to vent gas or introduce pressure via a syringe if necessary to move digested material through the Digested Material Tube (E) into the Digested Material Collection Container (F). The Fill Line (G) represents how much the container should be filled with rumen-fluid for digestion. The Fill Line should represent 95% of the container's volume The Re-Fill Line (H) represents the minimum level at which point more rumen-fluid should be added. The Re-Fill Line should represent 25% of the total container volume. The Digested Material Tube (E) should terminate above this line. This tube can also be shortened or lengthened depending on pressure requirements that should be determined experimentally. Prior to starting the waste removal screen (I) should be placed inside the reaction vessel (A) for easy removal of un-digested debris.

**Figure 1. The Simple Artificial Rumen**

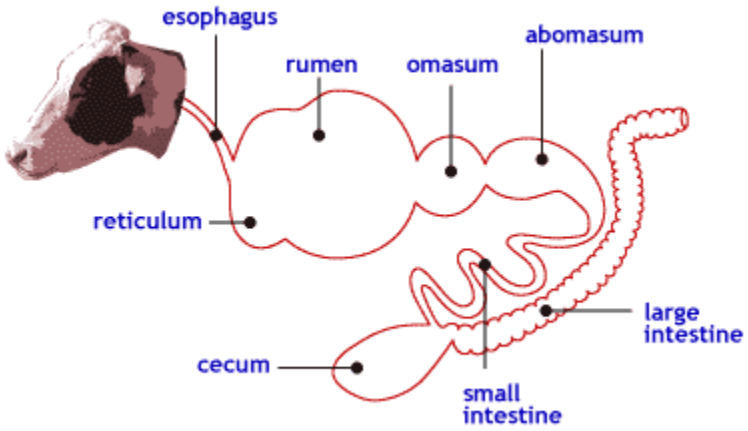



## Rumen Ecology and Function

The Rumen is an anaerobic environment meaning devoid of oxygen. Inside the rumen of a ruminant (Figure 2) are numerous types of anaerobic organisms. Bacteria, Protozoans, Fungi, and Archea live together in a dynamic balance that ebbs and flows as food is introduced and digested. This complex ecology has been studied for years and artificial rumen have been used to study the process of digestion in the rumen (Czerkawski, 1976). Plant matter contains sugars, proteins, and numerous compounds that are available to human digestion, however the greater proportion of nutrition comes from the digestion of the plant matter and it primary structural component, cellulose. Human's cannot digest cellulose and is often referred to as fiber or dietary fiber. The rumen, with its special conditions and ecology is able to digest this structural component which then spurs growth of rumen occupants to produce a number of useful and nutritional intermediates. In-short, the rumen ecology will turn plant material into peptides, amino acids, sugar, other saccharides, and volatile fatty acids (short-chain fatty acids). The organisms will use the digested plant material to grow and incorporate minerals and nutrients into usable vitamins. Fats and lipids will also be liberated in the process. After plant material is digested into its constituent pieces in the rumen and used for growth a significant amount of the digested material (digesta) is transferred to a next significantly more acidic stomach to complete digestion (abomasum). The rumen itself is not significantly acidic and creates an

organismal slurry of digesta which can then be processed in the more familiar highly acidic stomach. This digesta is the proposed food source, created by the artificial rumen.

## Figure 2. Example Ruminant Gastrointestinal Tract

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## Operation of the Simple Artificial Rumen

***Extraction of Rumen fluid from the Ruminant***

1. The Rumen fluid Extraction Kit would consist of a 500 mL (milliliter) syringe and a meter long plastic tubing.
2. Attach the tubing to the end of the syringe and depress plunge
3. Insert tubing down the esophagus of the ruminant to the rumen (Figure 2).
4. Pull the plunger of the syringe to extract rumen fluid in this manner.
    a. In experiments (Czerkawski,1976) 1 Liter of Rumen Fluid can be extracted from a goat.
5. The extracted rumen fluid would be placed into the main chamber of the Simple Artificial Rumen (Figure 1).

Note that the rumen will contain three layers of digesta, gas, liquid, and sedimentary layers. Organisms are known to segregate among these layers therefore attempt should be made to gather both from the liquid and sedimentary layer.

Vegetation ordinarily consumed by the ruminant should be gathered and used for digestion in the Simple Artificial Rumen. Between 12- and 24 grams of plant material should be digested each day per liter volume of rumen fluid.

Experiments have shown that dilution rates around 75% per day yield excellent growth and digestive potential with between 12 and 24 grams of material to a liter of rumen fluid (Czerkawski, 1976).

### *Starting the Artificial Rumen*

1. The Simple Artificial Rumen should be filled to the Fill Line (Figure 1. G) with Rumen fluid.
2. Place inside the main chamber with the rumen fluid 12-24 grams of vegetation.
3. Screw the lid of the chamber on.
4. Attach the digested material tube (E) between the lid of the Artificial Rumen Lid (B) and the Digested Material Collection Container (F).
5. Open the valve on the collection container (D) and close the valve on the Artificial Rumen (D).

In normal digestion, contractions in the wall of the Rumen every 1-3 minutes mix digesta and promote growth. Therefore it is recommended that the Artificial Rumen should also be agitated as often as possible, however experimentation will be required to determine how often such shaking would be necessary for good growth and digestion. If constant agitation is necessary, the Artificial Rumen is small enough that it could be carried around and as a result the periodic jostling of contents might mimic that which occurs inside the ruminant in the course of a day.

### *Maintenance of the Artificial Rumen*

1. After approximately 24 hours since introduction of vegetation, the digested collection container should be filled and the volume in the main chamber should be down to the Re-Fill Line (Figure 1.H)
    a. If not, attach the Extraction Kit Syringe and Tubing to the valve (D) on the Artificial Rumen (A).
    b. Open the valve and depress the plunger until enough fluid from the main reaction chamber (A) has passed through the Digested Material Tube (E) and into the Digested Material Collection Container (F) such that the main chamber rumen fluid level is at the Re-fill Line (H).

2. Clean using the Waste Removal Screen (I) as Necessary.
    a. Some material maybe un-digestible by the artificial rumen. Some material will digest slower than others.

   b. If large identifiable un-digested particle are observed over the course of several days the screening tool placed into the artificial rumen can be used to remove them.

3. Add water to the Fill Line (G)
   a. Note that over time the required rumen enzymes and basic nutritional material provided by the animal in-vivo may become too dilute to support effective growth. Therefore it may become necessary to extract additional rumen fluid from the ruminant to refresh the Artificial Rumen.
   b. This may also vary by ruminant, vegetation, and other environmental conditions. A best range should be determined through experimentation.

4. Add 12-24 Grams of additional vegetation (C).

It is unlikely the Simple Artificial Rumen will continue indefinitely as the ecology will likely change drastically over time. Therefore it may become necessary to remove all the material and re-start the Artificial Rumen.

## Nutritional Developments

### *Palatability*

Creation of a nutritious dietary supplement for emergency use in food deficient areas of the world is plausible using local ruminants and the artificial rumen but will depend upon the palatability of the product, the rumen fluid itself. If even starving people will not drink it to gain the nutrition it does not matter how nutritious it may be. Rumen fluid characteristics can vary by species and region but in general they have similar characteristics (Barbosa, 2007)

- The odor of rumen fluid is often used to diagnose conditions or digestive problems in ruminants (Chiba, 2009). A healthy rumen fluid is described as aromatic, grass-like, unobjectionable odor. Additionally, survival guides suggest that rumen fluid can be an emergency source of water and nutrition.
- A sour or acidic odor indicates the rumen fluid may be acidic and likely less palatable.
- A fecal, foul, or putrid odor indicates rot. This condition is likely to be un-palatable and indicates a significant degradation of healthy rumen fluid.

Additionally, experiments can be conducted to determine if simple methods of purification such as straining or sand filtration can enhance palatability while maintaining nutritional value.

### *Nutritious for Human Consumption*

The nutritional value of digesta and rumen fluid is well-known and sustains all the nutritional needs of the animal. However, except for survival situations, rumen fluid has not be determined to be a human consumable food for extended periods of time. The following should be considered:

*The Nutrition Requirements between Humans and Ruminants*

Human nutritional requirements and ruminant nutritional requirements will differ greatly if evaluated directly from evaluation of food stuffs (Preston, 1995). Humans and other non-ruminants do not have rumen and therefore cannot take advantage of the nutrition liberated from much of a ruminant's food. However, the process in a ruminant after the rumen is quite similar. Similar enough that nutritional value from that liberated by the rumen bacteria and the microorganisms themselves would be digestible by the human stomach as it is similar in nature to the ruminant acidic stomach the abomasum.

*Zoonotic Diseases maintained in the Rumen*

Ruminants are host to numerous types of parasites, some of which may be present in the rumen. Most parasite stages include voiding from the animal as an egg. Subsequent hatching, intermediate hosts, and then a return to the ruminant in the later stages of development. If the ruminant is domesticated, humans have likely been exposed to such parasites already. However, a cost-benefit of such additional and direct exposure should be considered.

Some bacteria and virus also have zoonotic capability. However, pathogenic bacteria may find it difficult to survive in the rumen as it is a thriving ecology and exogenous organisms can be quickly outcompeted by those specialize rumen-microbes. However, the human digestive tract may not be prepared to survive on such a rich bacterial soup. If our digestive system is unable to kill all the rumen bacteria they would then enter into our own intestines and mingle with the digestive fauna human harbor. The potential impact needs to be considered that the rumen bacteria may displace or disrupt the natural human digestive ecology causing diarrhea, constipation, or other mal-absorption conditions exacerbating the purpose of providing the rumen fluid.

In many of these cases simple sand filtration may be able to remove the impact by sequestering microbes while allowing fluid and nutrients and a lesser amount of organisms through so as to not overwhelm the human digestive tract. However, considering much of the nutrition of rumen fluid is provided by ingesting the bacteria the filtration process should not be too thorough. An ideal range should be identified and a simple filtration system could be added to the system to target the desired range.

## Experimental Developments

### *Metrics for Development*

In order to conduct further development of the Artificial Rumen for the purpose of deployment to food-deprived regions as a means of providing nourishment from local vegetation metrics for performance must be established to properly evaluate the following additional variables that should be controlled for through design or use. Numerous methods are identified in resources such as the *Animal Nutrition Handbook* (Chiba, 2009) and the *Tropical animal feeding: a manual for research workers.* (Preston, 1995). These references can provide additional details on how to evaluate the color, viscosity, odor, chemical compositions, sedimentation, and additional indicators of health of the rumen fluid. Such metrics would not be required at final deployment only in the experimental stage for determining the feasibility of the system to deploy anywhere and use local resources. Problems encountered may be able to fixed through a modification to design or change to an instruction for use e.g. (To maintain a closer to optimal temperature in cold climates the artificial rumen might be carried around close to the body to share body heat.)

*Microscopic Observation*

Most often microscopic evaluation of the rumen fluid will be an excellent indicator of its "health" Healthy rumen fluid under the microscope will have lots of activity of bacteria as well as the larger protists.

*pH – Acidity and Alkalinity*

The acidity of the rumen fluid should be between 6 - 8 for proper function though 7 is ideal. This is a simple test with pH strips. The pH of the rumen will tend toward acidity as organisms metabolize the sugars and saccharides from the plant material. If this fermentation persists too long Acidosis can occur (Quigley, 2005) leading to a soured rumen fluid due to high levels of lactic acid. However, the removal of 75% of the rumen fluid and replacement with water should help to keep the pH within range. Prolonged use of such dilution will directly impact the digestibility of the Artificial Rumen and therefore it should be refreshed with rumen fluid. The number of days it can be diluted in this way and when refreshment with raw rumen fluid will need to be determined experimentally.

*Agitation*

The ruminant rumen agitates the rumen fluid every 1-3 minutes even while asleep. The effect of sedimentation and the requirement for agitation will need to be established.

*Tube Lengths and Collection Container Placement*

The Digested Material Tube (Figure 1.E) will remain empty until sufficient pressure is applied in the primary container (A) to force material through the tube (E). Once material has sufficient pressure and the tube is filled to the Digested Material Collection Container (F) a siphon can be created, thus as gases are produced in the main container the pressure will allow more material to pass through the tube until the level of rumen fluid in the main container (A) reaches the bottom of the tube inlet. Whether the pressure will be significant enough to begin this process should be experimentally determined. However, an additional method for increasing pressure artificially is described in ***Maintenance of the Artificial Rumen.***

*The Effects of Temperature*

The inside of a cow is a pleasant 38.6°C, a goat 39°C. The ambient temperature will likely fall well outside these values and as such the effects of such changes in temperature may represent a significant impact to the health of the rumen fluid produced. Simple ways to attempt to maintain temperature in an austere environment is through sharing body heat. The effect of temperature and the inability to maintain an optimal temperature are unlikely to kill the process unless extreme (freezing/boiling/pasteurized). Will the reaction vessel need to be protected from sunlight? Using metrics such as microscopic motility and pH can help you to identify the effect temperature will have on the final product.

*Amount of Digestible Material*

Under experimental conditions (Czerkawski,1976 and 1979) the amount of vegetation added to an Artificial Rumen is used to evaluate changes in rumen fluid for the purpose of understanding the digestion process. These experimental levels are likely far lower than what a rumen of equal size would be capable of digesting. However, understanding the limitations of the artificiality without a living system to provide additional nutrients, constant agitation and essentially optimal conditions it is best to start with these small amounts and increase the quantity while observing the basic chemical (pH) and biological (microscopic observation of motility) to ensure that the artificial rumen can digest such quantity and produce a healthy product.

*Filtration*

The rumen fluid collected from the digestion process may be enhanced for palatability by filtration. Extremely efficient simple filtration systems exist however removal of too much of the rumen fluid components will reduce the nutritional value. Sand, pebbles, to charcoal could be used as simple available filtering components. Filtration could be incorporated into the Digested Material Tubing to provide a simpler mechanism for filtration. Rumen fluid should be evaluated for palatability and determine what level and type of filtration enhances palatability while maintaining nutritional value.

*Communication of Instructions*

All the efforts will be wasted if the use of the instrument cannot be communicated to the end-user. In general once optimized through experimentation the operation of the instrument should be distilled to its simplest steps. For example: Simple indications such as odor can be used to signal the user to restart the artificial rumen.

## Safety Considerations

The Archea are a type of prokaryote (like bacteria) and a group of Archea inhabit the rumen and are methanogens. They produce methane gas from carbon dioxide and the hydrogen produced by other bacteria in the rumen. The primary gas produced in the rumen is methane and is flammable. Therefore, once started the Artificial Rumen will contain flammable methane and hydrogen gas and therefore should not be used near flame or other source of ignition such as sparks. Additionally if the valve on the primary reaction container (Figure 1. A) is open, gas will vent into the surrounding environment, therefore, small tightly enclosed spaces would be at risk for accumulation of such gases.

Rumen fluid is a biological fluid and may contain material pathogenic to humans.

Animals are unlikely to cooperate with the rumen fluid extraction process. Precautions should be taken to humanely secure the animal and ensure the intubation is performed without significant injury to the animal and in accordance with local animal care laws.

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