A Review of Oxygen Systems

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"*. . . I know the answer to the problem of oxygen systems—climb without oxygen,*" Doug Scott.

IN January of 1976 a group of climbers became interested in obtaining a permit for Chomolungma (Mount Everest) in Nepal. Although the permit was not obtained until March 15, I consulted with Dr. Thomas Hornbein in January about existing oxygen systems on the market. We found a mass of information on individual systems, but no attempt had been made to evaluate or summarize the comparative performance and cost of these systems. This brief paper presents some of the basic concepts important to those who choose to use oxygen as a climbing tool, especially for the few summits in the world above 27,000 feet.

As early as the 1920's, supplemental oxygen was deemed important to an ascent of Chomolungma. Two methods were discussed. The first, "sipping" on a tank with a single regulator, was thought useful when one felt an additional burst of oxygen might be helpful. One tank would theoretically supply several people, and the weight of the system would be minimal. In 1975 (and possibly 1960), the Chinese-sponsored climb of the Northeast Ridge of Chomolungma was reportedly done in this manner. There is a heroic account of a comrade fainting and being revived by his partner's oxygen bottle. He then climbed on to the top. This method has an advantage of minimal weight, but performance is erratic with intermittent use of oxygen.

The second method involves one tank and regulator per person, both to be carried during those times when oxygen is used. This method however is heavy due to the weight of the oxygen tanks. It has been used by all expeditions attempting Chomolungma from the Nepalese side.

Several problems must be considered in an evaluation of this sort. An adequate amount of oxygen must be supplied with minimum waste. The tanks should hold as much as possible and yet the weight of the container should be as light as possible. Finally, the system should be fool-proof and reliable.

Early Designs. The first basic models used up until 1965 by the

British, Indian, Swiss, and French are basically similar in design and operation. Some are still in use today. The aluminum oxygen tanks contain from 2000 to 3000 psi (700 to 1000 liters) of oxygen. Attached to the tank is a simple pressure-reducing valve which provides a low constant flow of oxygen (1 to 4 liters per minute). A tube then connects the tank to the mask via a rubber "bladder" or "economiser" (which acts as a reservoir for the oxygen). The masks are of World War II, military vintage and carry several valves, inspiratory and expiratory valves to the atmosphere plus one to prevent exhaled air from reentering the bladder.

The major problem encountered has been ice formation in the mask itself from heavy, humid exhaled air and cold temperatures. The unfrozen valves create some resistance to breathing at sea level and become totally impassible when frozen. The tanks last from 3 to 6 hours. In general, these systems probably waste only small amounts of oxygen if used correctly and are fairly reliable. Several ascents of some of the world's highest peaks have been climbed with these systems.

Maytag. In preparation for the 1963 American Everest Expedition, Thomas Hornbein M.D. developed a mask that was significantly different from those previous designs. The mask itself communicates to the ambient air via an open tube without valves. Lying inside and parallel to the outer tube is a smaller inner tube that connects to an oxygen bladder. There is one small rubber valve capping the inner tube to prevent rebreathing into the bladder. This mask has the advantage of allowing most moisture to drain out of the mask and has no expiratory valve to freeze. Both inspiratory and expiratory resistance to breathing is less than with the previous models and the entire mask is of rubber and can be deformed with the mittened hand to free any ice that does form. The mask works with a constant flow of oxygen provided by a single-stage pressure-reduction valve similar to earlier models.

Also similar is its efficiency. It is adequate if the apparatus is used correctly. The resistance to breathing is slightly less than earlier models, and the icing problems are handled more easily. The failure rate is low and the tanks last the same length of time as the earlier models.

Robertshaw. In preparation for the 1971 International Everest Expedition, Duane Blume PhD., developed a climbing apparatus modified from existing military oxygen hardware. The basis of this design is a "second stage" regulating unit (similar to skin-diving two-stage regulators), that delivers oxygen only during inspiration, i.e. diluter-demand system.

A necessarily tight-fitting mask of military design, with an expiratory valve, connects to the second-stage diluter-demand unit. When inspiratory suction in the mask is sufficient, the unit opens a needle valve which mixes oxygen with ambient air. This produces a high inspiratory resistance. Four settings are designed to keep a constant partial pressure of oxygen (PO_2) between 75 and 90 over the range of 18,000 to 29,000 feet. Only the last two settings are useful, since the mask is rarely used below 24,000 feet. The diluter-demand unit attaches via a high-pressure hose to the reducing valve on the tank. This design has the advantage of essentially 100% efficiency in conserving oxygen, simplicity in operation (no constant readjustment of flow), and a fairly high level of oxygen (PO_2). However, two problems have been reported in its six years of use. There is a propensity for freezing much as with the earlier designs and the diluter-demand unit has been reported to be unworkable when high on various mountains. These sets were invariably working correctly when returned to the factory. For example, Bonnington claimed 13 out of 18 sets were inoperable at the conclusion of the 1975 Southwest Face Everest Expedition (they placed 5 people on the summit). Thus, the sets have not been dependable in the last six years.

Tanks. The tanks we used were made by Luxfer, USA, out of aluminum with a fiberglass wrapping enabling them to be filled to about 4000 psi under current United States Department of Transportation regulations. Filling to 3000 psi can be a problem in the United States but can be done in Europe. So far, NASA has been the only place to get the tanks filled to 4000 psi (1500 liters). The tanks weigh 16.5 pounds full.

Testing. During the spring of 1976 we evaluated the Robertshaw regulators and masks in two separate evaluations.

A cold chamber (−25° F) at the University of Washington Geophysics Department was used at normal atmospheric pressure to simulate the freezing problems of these sets. The earlier British and Swiss designs indeed did freeze as previously described. The expiratory valves could be thawed fairly simply with several normal breaths, but the inspiratory valves often couldn't be unfrozen so easily. The Maytag mask formed ice in the large tube but it could be freed easily by crushing the mask. The Robertshaw sets had accumulation in the main tube from the diluter-demand valve; however, the diluter-demand valve itself worked satisfactorily during this trial.

The second test was done to compare the resistances and oxygen level (PO_2) reached by both Maytag and Robertshaw sets. PO_2 refers to the partial pressure of oxygen in the inspired air. The PO_2 of the atmosphere depends on a number of variables including total atmospheric pressure and the percentage of oxygen present. Consult any text in thermodynamics for a full discussion, but for the purposes of this paper, the higher the PO_2, the easier it is to breathe. Figure #1 gives the approximate PO_2 of ambient conditions, and extrapolated PO_2's that may be reached while using one of these sets.

Maytag sets were compared to 15 Robertshaw sets, obtained from the 1975 K2 Expedition, at normal sea-level conditions. Expected PO_2's were then calculated up to 9000 meters from the data obtained. The Robertshaw sets (except one) were factory sealed, but had been carried up to K2 and back. The results indicate that the Robertshaw sets might produce a higher PO_2 than the Maytag mask, but a larger range of PO_2's were observed from essentially no enhancement to quite high PO_2's. Inspiratory resistances were markedly higher than the Maytag mask, but expiratory resistance was only slightly higher than other systems. We picked out the ten Robertshaw masks and regulators that functioned best to take on our climb.

Operation of the Systems. From these data a guide to usage of both Maytag and Robertshaw sets was established and used on our trip to Chomolungma. Oxygen was used in general by climbing members above 24,200 feet and by Sherpas above 26,200 feet. No oxygen was used during rest breaks, cooking, or establishing campsites. Low flow (0.5 liters/minute/person) was used in order to sleep at and above those altitudes. Higher flows were used while actually climbing; the amount varied according to the amount remaining in the tank and the difficulty of the climbing.

For sleeping, a "Y" connector was attached to a single, constant flow regulator and tank, and the flow put at one liter per minute. A simple hospital "ventimask" was connected to each side of the "Y" for each of two people.

The tanks were checked each morning before use to ensure no leakage had occurred, using the pressure gauge present on each regulator. Care was taken not to accidentally loosen the valve during transport. A cap was used on the tank or a regulator was constantly kept in place to prevent any ice or snow contamination. (The tanks were filled with oxygen that had a minus 70° F dew point.) The valve was opened slowly to reduce the spontaneous ignition potential. And finally, an effort was made to make each tank last as long as possible.

The Maytag hose and bladder were kept free from all obstructions. Constant adjustment of the regulator (made by Hudson) flow from one to four liters per minute was done to keep the bladder about one third full at all times. This prevented waste of oxygen by overfilling. The ambient air mix was plugged by the fingers if higher concentrations of oxygen were acutely needed for more difficult climbing. If icing occurred, the mask was crushed to free ice.

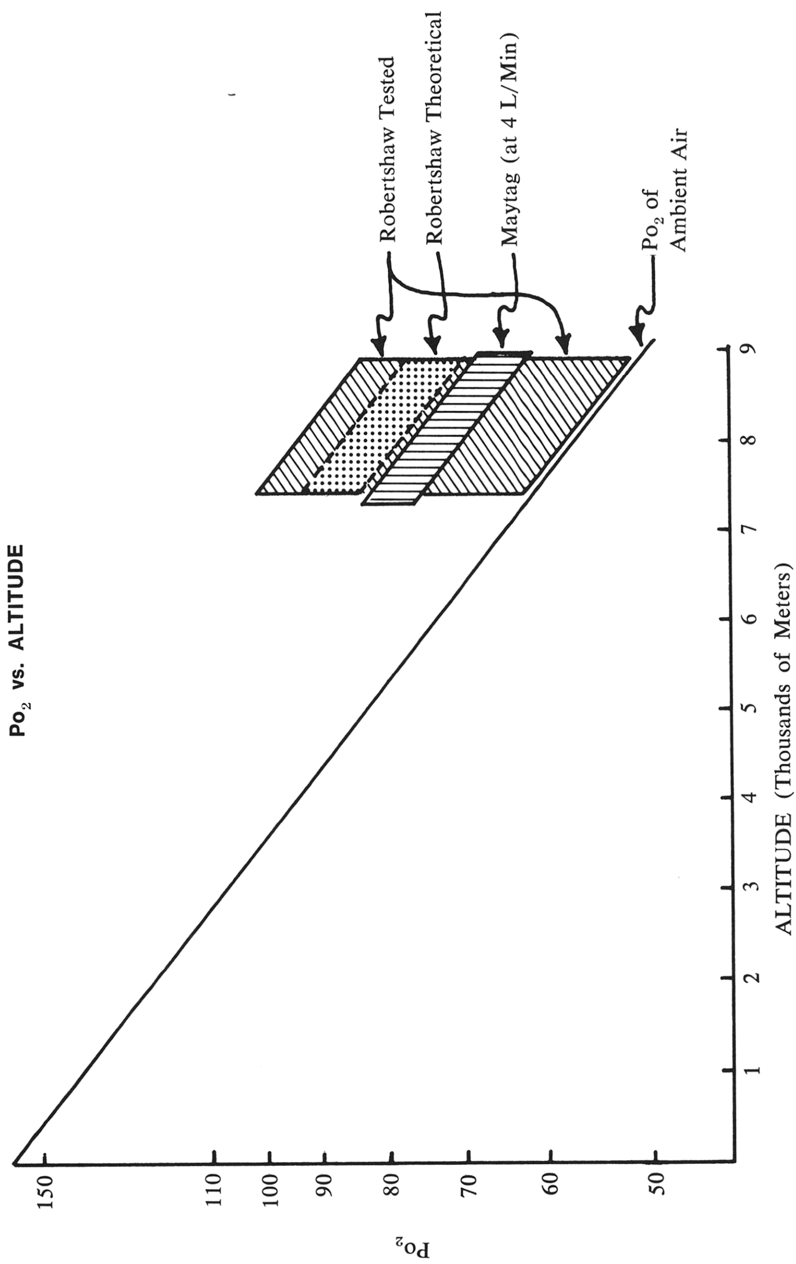
In order to keep it at body temperature, the Robertshaw diluter-demand valve was placed inside the clothing. A cotton stuff sac was placed over the valve to keep out spindrift. The mask was disconnected prior to entering a warm area, so no water would fall into the diluter-demand valve. If icing occurred in the mask, it was warmed to remove it. Frozen exhaust valves were breathed on to open them. The setting was put on "3" above 24,200 feet and "4" above 26,200 feet in most cases.

Performance. In October of 1976 we used both the Robertshaw and Maytag systems on Chomolungma. Nine Maytag sets were used by the climbers and camera-people on our trip. Robertshaw sets were used by the Sherpas. Each person chose the set he or she wished to use, but it seems the Sherpas had used Robertshaw sets previously and liked the simplicity of operation. The Hudson regulator used with the Maytag masks worked poorly due to its simple one-stage nature. It was not designed to be used at such low flows with such high tank pressures. An improved regulator for the Maytag masks could easily be designed and produced. However, by watching the bladder and adjusting the flow, we could get around six to eight hours of use from a single full tank. Severe icing occurred above 28,000 feet, but could be easily removed from the Maytag by crushing the mask. The system allowed sufficient oxygen enhancement to climb the mountain in winds exceeding 100 mph and temperatures well below 0°F. The cost of this system is less than $200 per set. It was dependable but required constant readjustment of flows.

The Robertshaw system was used by the eight Sherpas when they began the carry to 27,700 feet. Five of those sets worked well, with only minor icing in the mask and hose. Two other sets performed erratically, due to icing in the hose, mask, and possibly the diluter-demand unit. One Sherpa returned from that carry, probably because of the failure of the diluter-demand unit. Subjectively, there was no major difference in individual performance between those using Maytag and Robertshaw sets. On the summit day our sirdar, Ang Phurba, stopped after only 100 feet when the diluter-demand unit failed to work. No amount of warming or manipulation could restore its function, and he was unable to continue the climb. Unfortunately, we had no back-up system and he returned down the mountain. These sets cost around $600 per set, and the tanks lasted about eight hours.

Both climbers and all Sherpas returned from near 28,000 feet without supplemental oxygen. We used approximately six tanks of oxygen per person for the summit climbers. This included four full tanks for climbing and several partially used tanks for sleeping. During the course of the trip around 40 full tanks were emptied, 60 were left behind, and 100 brought back down from the mountain.

In summary, the Robertshaw unit offers a greater efficiency of oxygen use than the Maytag mask with less hassle adjusting flows, but even under ideal conditions it imposes a higher resistance to breathing. Ice accumulation is easily managed with the Maytag mask and is probably the cause of the very poor reliability of the Robertshaw system. Reliability is probably the single most important requirement for high altitude breathing apparatus.



Po2 vs. ALTITUDE
Robertshaw Tested
Robertshaw Theoretical
Maytag (at 4 L/Min)
Po2 of Ambient Air
150
110
100
90
80
70
60
50
Po2
1
2
3
4
5
6
7
8
9
ALTITUDE (Thousands of Meters)