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The Use of Closed-Circuit Oxygen Sets in the Himalaya

Any man with a couple of coolies could easily get to Mt Everest, if he were allowed a free hand. To get to the summit is quite a different matter. Altitude will cause trouble.

A M Kellas, 1912

Following A L Mumm's first attempts to use oxygen cartridges on the slopes of Trisul in 1907, mountaineers experimented with a range of different oxygen generators and circuits in order to climb the highest peaks of the Himalaya. However, the success of the open oxygen circuit on the first ascent of Mount Everest in 1953 signalled the end to this colourful period of scientific research and led quickly to the adoption of the set by the wider mountaineering community. Despite this, an alternative 'closed' circuit had also seen action on Everest in 1953. This circuit had considerable advantages over the open device but owing to problems of safety and ethics it was eventually overlooked and consigned to the history books.

In the spring of 2007, a new system will be employed on Everest by the Xtreme Medical Expedition. This group of scientists from University College London intends to develop a system which utilizes the best of both 'open' and 'closed' circuit systems in order to carry out detailed experiments at high altitude. The Xtreme expedition aims to undertake the most comprehensive set of experiments at high altitude on Everest since the 1981 American Research Expedition (AMREE). It will involve collecting data from two groups – the first, a group of up to 200 trekkers heading for Everest Base Camp, whilst the second group of more than 20 scientists will be based in the Western Cwm and will be well placed to take advantage of the new device. By understanding the history of the discarded 'closed' circuit and the experience of those who used it, its role in extreme-altitude mountaineering can best be understood.

The open circuits worn by Tenzing Norgay and Edmund Hillary in 1953 allowed climbers to inspire a mixture of ambient air and oxygen from a pressurized cylinder before exhaling gases directly into the atmosphere. Although this system offers a reliable and effective means of delivering oxygen at high altitude, the open circuit has two limitations. Firstly, the majority of gas that the climber inspires is air from the atmosphere (only 21% oxygen), and thus only small improvements in climbing performance are achieved. Secondly, the open circuit is inefficient, with any oxygen present in expired gas escaping readily into the surrounding atmosphere

where it cannot be used again. The closed circuits taken to Everest in 1936, 1938 and 1953, and later to Kangchenjunga in 1955 were designed to solve both of these problems. In a closed circuit the climber is sealed off from the outside world by a tightly fitting mask and a complicated arrangement of tubes and connections. On exhaling, gases are directed through the mask and tubing before passing through a soda-lime filter. This filter absorbs carbon dioxide and directs unused oxygen into a reservoir bag for later use. Any oxygen that is taken up by the climber is then replaced from an oxygen cylinder attached to the circuit. Unlike the open circuit where air is also inspired, the tight fitting closed set only delivers pure oxygen. This high concentration of oxygen overcomes the effects of the low atmospheric pressure found at high altitudes and allows the climber to move more quickly and safely at high altitude.

The first closed circuits were manufactured by Siebe, Gorman and Company Ltd for the 1936 and 1938 Everest expeditions. Although the company had more than 60 years of experience designing sets for fire fighting and mine rescue work, little was known about the performance of closed circuits at altitude. The first tests conducted on the circuit were undertaken separately by Eric Shipton and paediatrician, Dr Charles Warren on Box Hill, Surrey, in 1935. According to Warren, on 'a surface of wet chalk set at a steep angle' Shipton was able to ascend at a respectable rate of 472m/hour. During a further trial, by Warren, a few days later, the apparatus failed to work smoothly and 'the unfortunate subject of the experiment became half asphyxiated and developed a splitting headache.' (Warren 1937) Eventually, after further improvements and tests in England and the Alps, two closed circuits were taken on the 1936 expedition. On the snow slopes below the North Col (7010m), Warren volunteered for the dubious task of testing the set. A witness later wrote:

He found that although the unit seemed to be in perfect mechanical order it tended not to stimulate but rather to suffocate him. He was actually moving more slowly than the other climbers, and was forced to stop every dozen steps to recover his breath.

Peter Lloyd shared a similar experience two years later. As Oxygen Officer to the 1938 Expedition, Lloyd had tested Warren's closed-circuit set at 3900m and found that it behaved 'satisfactorily'. However after a few minutes on the North Col:

It soon became evident that there was something very wrong. Mechanically everything was perfect, and the valves were opening and closing like clockwork, but inside the mask I was nearly suffocating and I had to stop frequently to take a dose of fresh air.

On both occasions the closed sets were quickly abandoned.



146. The closed-circuit oxygen set developed for use in 1953.
(Alpine Club Photo Library)

Following his return to England Lloyd conducted further tests on the malfunctioning circuit and soda-lime canister. On a climb in the Lake District, Lloyd found that the components of the circuit were functioning normally and the apparatus, 'worked perfectly well'. Why had the closed circuit failed dramatically above the North Col yet worked so well near sea level?

In a paper presented to the Royal Geographical Society in 1947, H L Roxburgh, a scientist at the Institute of Aviation Medicine, identified a number of potential problems which could explain the difficulties that Warren and Lloyd had experienced. Whilst not ruling out leaks in the system, Roxburgh suggested that the most likely reasons for the feelings of suffocation were due to a combination of back pressure inside the circuit, insufficient absorption of carbon dioxide and finally inadequate oxygen flows which didn't match the oxygen being consumed by the climber.

Despite the failure of the early sets, the potential advantages of the closed system still proved irresistible to some. During the 1952 British Himalayan Expedition to Cho Oyu, the physiologist Griffith Pugh conducted a range of tests with supplementary oxygen on the Menlung La at approximately 6000m (20,000ft). Using a 300-litre rubber bag fitted with a three-way tap, two climbers were able to inspire pure oxygen and therefore simulate a closed circuit. The positive results from a trial on the snow slopes above the camp led Pugh to conclude that there was a 'strong argument in favour of developing closed circuit apparatus for trial on Everest'. Later that year the Medical Research Council (MRC) Oxygen Advisory Committee would support Pugh's conclusions and recommend that both the open and closed circuits should be taken to Mount Everest the following spring. At first, the plan was to use the open circuit for the summit attempt whilst the closed circuit would be kept in reserve for 'research purposes'. However, the manufacture and shipment of eight closed circuits suggested greater ambitions. John Hunt, the expedition leader, would later write: 'If this system, still in an experimental stage in regard to work at high altitudes, should prove successful it might greatly simplify our task ...'

The closed circuit was designed by the expedition's oxygen officer, Tom Bourdillon, and his father, Robert Bourdillon, at the MRC Electro-medical Research Unit at Stoke Mandeville Hospital and manufactured by Messrs Normalair Ltd in Yeovil. Following laboratory tests at Stoke Mandeville, the circuit's components underwent further trials in cold chambers at Farnborough's Institute of Aviation Medicine and on the hillsides of North Wales.

In order for a closed circuit to be effective, the pioneering anaesthetist Ralph Waters had argued: 'The important point is to avoid leaks in the apparatus itself and in the contact of the mask with the face.'

Over the winter of 1952-53 the design team was able to demonstrate that two different RAF pilot's masks could provide between them a tight seal for each of the expedition members. This was important for two reasons.

The first and most obvious reason was that any air that entered the circuit would dilute the concentration of inspired oxygen and reduce the partial pressure of oxygen present. Secondly, if the circuit leaked when low flows of oxygen were used, nitrogen could accumulate and cause what Bourdillon would describe as, 'a most undesirable thing since under these conditions it would be possible to breathe gas containing less oxygen than air'. Unfortunately, this tight-fitting set would come at an uncomfortable price. On a sunny January day in Snowdonia, Hunt wrote with some alarm: 'I tried it myself during a short distance uphill near the hut. I nearly exploded with heat and discomfort...'

The heat was not the only problem. Norman Hardie, a member of the successful 1955 Kangchenjunga expedition, found, 'that after a long session I could hear bubbles blowing through water at each exhalation', making it, 'necessary to drain the outward tube [of] about one quarter of a cup of water' after only a few hours of use.

On the 19 February 1953 four closed circuits were ready for shipment to Nepal. In just four months the research team had designed, manufactured and tested an entirely new closed circuit oxygen apparatus. Although a great deal had been learnt from the earlier circuits, several problems still existed. Could these be overcome?

The closed circuit's finale

*Great will be the battle, but greater still the rewards,
of the man who first scales Mt Everest.*

G D Abraham, 1912

Following success with both the open and closed circuits on the approach slopes of Everest, Hunt took the decision to use both sets on the final approach to the summit. On the morning of 22 May, Tom Bourdillon and Charles Evans left Advanced Base at Camp IV (6460m) breathing 2 litres/min of oxygen through their closed circuits. Hillary would later write: 'The two men were an awe-inspiring sight! Clad in all their bulky clothes, with their great loads of oxygen on their backs and masks on their faces, they looked like figures from another world.' Over the next two days the pair climbed through the Western Cwm and up the Lhotse Face before arriving at Camp VIII (7930m) on the South Col. Following a day spent resting and preparing the oxygen circuits, they awoke early on the 26 May to the first rays of sunlight on their tent. Already dressed, they slowly laced their boots, drank a flask of lemonade and checked their kit. At 6am Evans exited the tent first and was passed his closed set, 'whose sharp edges caught on every possible piece of cloth'. At temperatures close to minus 20°C, those few frustrating minutes were just enough to freeze the valves shut and force a breathless Evans stumbling back inside the tent. Using a candle, Bourdillon

was able to slowly thaw the valves and restore the circuit to life. Now back outside the tent, Evans took a few steps before noticing 'a nasty sensation' and exclaimed to Bourdillon, 'in disapproving tones that it made me feel that I was going to die'. Back in the tent and now already an hour late, Bourdillon began to search desperately for the cause of the problem. Working with bare hands, his fingers began to blister and then bleed as he first checked the circuit's valves before switching his attention to the oxygen supply. Although the valves were moving freely, the reservoir bag was flat and the oxygen flow valve was jammed in its seating and could not be freed. Working quickly, Bourdillon replaced the valve with tubing fashioned from spare parts of an open circuit. Although this would provide his companion with a constant 2 litre/min flow of oxygen, Bourdillon knew 'this was extremely wasteful of oxygen when resting and would limit the maximum effort Evans could make'.

At 7.30am they were both finally ready.

Our early excitement was now tempered with some gloom, the loss of ninety minutes, the use of some of our oxygen and a reduction in our endurance had severely reduced our chances of reaching the summit.

With their circuits now working well they were soon able to overtake their support group. At 9am they arrived at the site of the 1952 Swiss Expedition's final camp and rested amongst the tent poles and strips of torn cloth. Bourdillon would revise his opinion, later writing:

The situation seemed promising. We had climbed from 25,800 feet to 27,300 feet in one and a half hours over ground not all easy and were still reasonably fresh.

Despite loads of more than 50lbs, the two climbers were able to ascend at a rate of 284m/hr. Griffith Pugh, the team physiologist, was surprised, as this rate was 'accepted as a reasonable speed for a party climbing under similar conditions in the Alps', and was significantly quicker than Hillary and Tenzing who followed later in prepared tracks at a rate 190m/hr. After a few minutes they began again, this time over a mixture of ankle-deep powder snow and patches of bare rock. At 11am, midway between the Swiss camp and the South Summit, they came across a flat, sheltered area and decided after some muffled debate to change their soda-lime canisters. This was a nervous time, with Bourdillon later realizing:

If we did succeed in changing them and the valves were to freeze on introduction of the cold canister it might be most unfortunate.

Now with lighter loads, the conditions soon became much easier. However after 10 minutes the situation markedly deteriorated with Evans later



147. Tom Bourdillon standing on the South Summit looking towards the true summit of Mount Everest.

(By courtesy of the Royal Geographical Society)

describing how 'I had an attack of breathlessness and all at once felt done in.' On steep, awkward ground Bourdillon tried frantically to identify the problem. The circuit seemed to be working. The reservoir bag was filling and Evans could be seen to be inhaling its contents, yet it was clear to Bourdillon that his partner was breathless and clearly distressed. Writing in his summit report three days later, Bourdillon would conclude:

It became clear that his second canister had been damaged and severe channelling was occurring. This was a bitter blow...

However, in an article written some weeks later for the *Alpine Journal*, Bourdillon would instead state:

We did not locate this fault which might have been due to a partially frozen valve, to a distorted valve or a small leak to atmosphere.

At low temperatures the valves and soda lime were both prone to freezing. The expedition members knew that if one or both valves froze shut during inspiration, breathing would cease abruptly and cause what Roxburgh had described years before as 'bottoming'. However if the valves froze in an open position, breathing could still continue but only at enormous expense. Breathing through partially open valves would increase resistance and dead space within the circuit, resulting in a straining climber inspiring large quantities of carbon dioxide. A sudden fall in temperature could also affect the contents of the soda-lime canister. In temperatures close to minus 25°C, Tom Bourdillon described that, 'everything took three times as long to do as it would normally' and gave ample time for the contents of the canister to freeze and affect the absorption of carbon dioxide. By exposing the canister and valves to low temperatures, large quantities of carbon dioxide would accumulate and cause the enormous rise in respiration seen in Evans who was, according to expedition doctor Michael Ward, 'taking up to six breaths per step'. Later, during their descent, Bourdillon converted his partner's set to an open circuit in order to ease this problem. Within seconds Evans found that he 'obtained less benefit than from the faulty closed circuit' and quickly asked for the circuit to be changed back to the original system. If Evans' circuit had been leaking, the change to an open circuit would have either improved the situation or made little difference. However, with such a rapid deterioration it is more likely that damage to the canister and valves was the cause of the problem.

At just after 1pm the pair emerged 'with surprising suddenness' on the South Summit of Everest (8760m). The last 280m had taken more than an hour longer than expected and, with time and oxygen quickly running out, a decision had to be made. Staring hard at Evans, Bourdillon knew that his partner had given 'a wonderful effort, but he and I both knew that there was no possibility of him going on...' And so with just 90 metres separating them from the summit they decided to turn back.

From bitter experience Charles Evans would later recall: 'The 1953 closed circuit set could be put out of action by the freezing of the water in the circuit.' It is therefore hardly surprising to learn that in 1955 two important improvements were made to the set that was taken on the Kangchenjunga Expedition. The first involved fitting it with 'all rubber valves which could be squeezed to free them from ice' whilst the second led to changes in the way the breathing bag was attached to the soda-lime canister such that the chances of water freezing inside the circuit were reduced. Although, according to Norman Hardie, the circuit 'worked well and gave no

mechanical trouble', the problems encountered by earlier teams soon resurfaced. The all too familiar combination of weight, heat, moisture and resistance meant that the closed circuit was abandoned and the open set was chosen by the successful summit teams.

Fifty years after the first ascent of Kangchenjunga, the open circuit is the only option available to those mountaineers who want to use supplementary oxygen at high altitude. Nevertheless, Tom Bourdillon and Charles Evans demonstrated that climbers could ascend above 8000m at a rate of more than 250m/hr with closed-circuit oxygen. If a comfortable and reliable closed circuit could be developed, the journey from the South Col to the summit of Everest could take less than four hours. By combining modern advances in breathing circuit technology and examining the history of closed-circuit oxygen at altitude, it may be possible to transform the way we climb at high altitude. Although for some this will undoubtedly prove controversial, it might realise a future first described by Raymond Greene nearly 80 years ago:

If one could design a perfect closed circuit apparatus there is no doubt whatever that climbers could walk up the last part of Everest as easily as they could at sea level...

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