Oxygen concentrator helps meet surge in demand

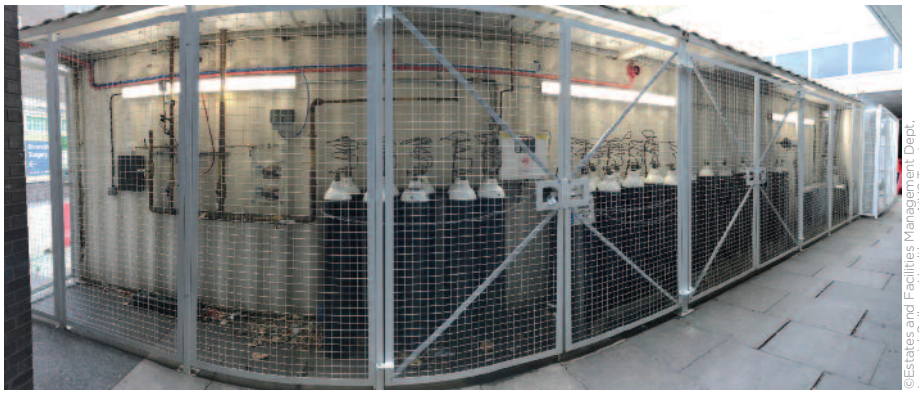
Like many large acute hospitals, London's Charing Cross Hospital in west London has seen increased oxygen demand over the past six months, and in March, with the coronavirus pandemic beginning to ramp up, its Estates team found the site's existing oxygen VIE (Vacuum Insulated Evaporator) was already beginning to struggle to meet demand, and would not be capable of meeting the predicted COVID-19 surge demand. As *HEJ* reports, when two already overstretched oxygen suppliers were unable to help upgrade the VIE, Imperial College Healthcare NHS Trust's long-standing medical gas pipeline supplier, SHJ Medical Gas Specialists, stepped in to help with an oxygen concentrator-based solution.

In March this year – when the effects of the COVID-19 pandemic were beginning to hit the UK – the Estates Department at Charing Cross Hospital (part of the Imperial College Healthcare NHS Trust) started to prepare for the first influx of patients. While the oxygen infrastructure pipework at the hospital was good, the site's Vacuum Insulated Evaporator (VIE) was struggling to supply the predicted surge requirements. Although technically capable of delivering 3,000 litres per minute, the vaporisers created a pinch point, bringing the supply down to just 1,833 L/min. The Trust contacted two major oxygen suppliers to request assistance with upgrading the VIE, or providing additional VIE plant, but, with their resources stretched nationwide, and directed primarily to new field hospitals, neither was able to help. Charing Cross Hospital was then facing the prospect of having to turn patients away.

Oxygen concentrator solution

The Trust's long-standing medical gas pipeline supplier, SHJ Medical Gas Specialists, suggested using an oxygen concentrator. Although common overseas, concentrators had rarely been used in a UK mainland hospital before, where the 'tradition' has generally been to rely on liquid oxygen stored in a Vacuum Insulated Evaporator. Rather than relying on stored liquid oxygen, a concentrator uses a compressor and a refrigerant dryer on the ambient air to generate a tank of air compressed to 7.5 bar. This air is then filtered and passed through a PSA (Pressure Swing Adsorber), which sieves and retains the oxygen, while discharging the waste nitrogen. The oxygen is stored in a buffer vessel and then used as normal. The concentrator supplied to Charing Cross had a theoretical maximum oxygen flow of 850 L/min.

The hospital decided to allocate the concentrator to one of its blocks, the Riverside Wing, which houses the hospital's Acute Medical Admissions Unit, Day Surgery Ward, theatres, and Recovery, and in which new COVID beds had hurriedly been placed. Pipework was laid to enable the concentrator to supply the block independently, while retaining the connection to the main VIE to allow maximum flexibility. It also allowed generated oxygen to be supplied to the entire hospital site via a ring main in the event of total failure of the VIE.



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The oxygen concentrator connection and distribution manifold, and emergency standby manifold, arrangement.

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Oxygen generator vessels.

The engineering challenges

Plant space

As at most hospitals, space is at a premium, and there are not many plant rooms lying empty waiting to accommodate an oxygen concentrator. Charing Cross Hospital is no different, and so to overcome the problem, SHJ suggested a technique it had used before – housing the concentrators in two 40 ft metal shipping containers installed in the hospital car park. In an ideal world, the containers would have been pre-fitted out and placed in position already up and running. In this instance, however, given the urgency, the empty containers were craned into position and fitted out on site. Figure 1 shows the layout of the concentrator plant within the container: In addition to the new plant, an external wraparound ring main was created to increase oxygen carrying capacity to key wards. Figure 2 shows the configuration of the new plant within the hospital.

Oxygen purity

While oxygen from a VIE will produce a nominal 99.6% purity, an oxygen concentrator produces at 93% +/–3% (i.e. the purity will range from 90% to 96%). With a lighter load a high purity is

easier to obtain, but as the load increases, the generator has to work harder, and lower purity is a consequence. This is acceptable for patient use, as the impurities are not significant. In fact the new plant's installation resulted in Charing Cross Hospital having two different oxygen products conforming to two separate European Pharmacopiea Monographs. Having taken advice from its Chief Pharmacist, The Trust was happy to accept these constraints, and understood that, while switching between the two products was acceptable, mixing the two was not an option.

As no 93% back-up cylinders were available, other options had to be considered. An automatic manifold was fitted with two banks of 10 cylinders of 99%. In addition, a new 54 mm main was installed to link the 99% supply in the event of an extreme emergency. This was double valved and double locked off.

Medical gas alarms

The oxygen concentrator plant and the emergency standby cylinder manifold systems were both connected to plant and local alarms. The plant alarms were repeated at the 24-hour manned security base, Marjory Warren Ward, and SHJ's K'nect portal. The units are monitored remotely by SHJ, where a predetermined response has been set up to automatically despatch a service engineer to site in the event of a problem.

Successful outcome

A team including engineers from the Trust, SHJ, project managers, ETA Projects, and supplier, Atlas Copco, began sourcing all the plant, pipelines, and electrical supplies required at the beginning of April. Working around the clock, seven days a week, engineers

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The container-sized plant room solution strategically located adjacent to the oxygen load.

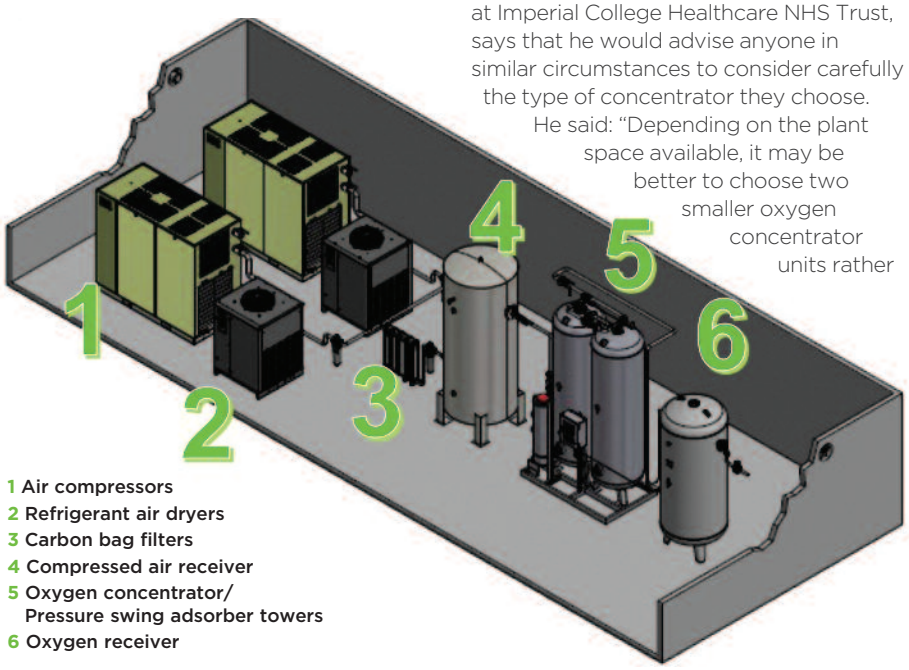
were able to begin Quality Control pharmaceutical testing less than four weeks later. The plant was operated under trial load conditions for three days prior to being connected to the hospital's medical gas pipeline system. On the last day of April, final QC testing verified that oxygen production met the requirements of the European Pharmacopeia Monograph 2455 and ISO 10083 for Oxygen 93 (oxygen purity of 93% +/- 3%). The new system went into service at 4 pm that day.

Recommendations

SHJ Medical Gas Specialists said: "The Charing Cross oxygen concentrator project was an astonishing engineering feat given the constraints and the timescales. As one team member put it, 'We completed two years of infrastructure work in two months'."

Shane King, head of Estates Operations at Imperial College Healthcare NHS Trust, says that he would advise anyone in similar circumstances to consider carefully the type of concentrator they choose.

He said: "Depending on the plant space available, it may be better to choose two smaller oxygen concentrator units rather than a larger one, which would also offer greater resilience. I would recommend going for the highest specification available, as the units are not always able to run at 100% capacity. Equally, since concentrators can have issues at extremes of ambient temperature, they are ideally better installed within the hospital building if possible. If not, then a containerised solution can work well, but the insulation and ventilation need to be carefully considered. It is also vital to ensure that the works are completed and certified in accordance with the requirements of HTM 02-01."



1 Air compressors
2 Refrigerant air dryers
3 Carbon bag filters
4 Compressed air receiver
5 Oxygen concentrator/ Pressure swing adsorber towers
6 Oxygen receiver

Figure 1: The layout of the concentrator plant within the container.

The future

SHJ added: "Oxygen concentrators are ideal for field use where delivery of liquid oxygen is not a practical option. Due to the amount of wasted nitrogen and the electricity required, however, they are expensive to run, although they don't attract the costs and emissions associated with bringing oxygen on site. They offer resilience during a situation of disaster or threat, although their reliance on electricity presents a single point of failure in locations with infrastructure challenges.

"Nevertheless, they certainly provide a viable emergency back-up solution to crises such as the one that faced Charing Cross Hospital in March. There has been considerable interest in this project from other UK hospitals as the NHS considers how best to prepare for a potential 'second wave' of COVID-19 later in 2020 and into 2021."

Firm's first ever customer

By way of background, Stafford Scopes, managing director of SHJ Medical Gas Specialists, whose father, Ronald, founded the business in 1967, explained that one of the Imperial College Healthcare NHS Trust's other hospitals, Hammersmith Hospital was, in fact, the company's first ever customer, and that SHJ had provided medical gas pipeline services to the Trust ever since. He said: "In those days Imperial was not a five hospital Trust; Hammersmith Hospital thus joined us as a customer as a single hospital, and thereafter St Mary's, Charing Cross, Queen Charlotte's, and the Western Eye Hospitals became clients, and then of course, the Trust was formed. We provide the majority of the Trust's medical gas pipeline services, including regular planned preventative maintenance visits, installation work, and servicing of its plant. The Trust also uses our Evolution medical gas alarm system, and our K'nect portal, for its medical gas records and data."

Moving to how the oxygen concentrator project came about, Stafford Scopes said he visited the Charing Cross Hospital site in early March to talk through how to address a major increase in oxygen demand. He said: "At the time, SHJ was so

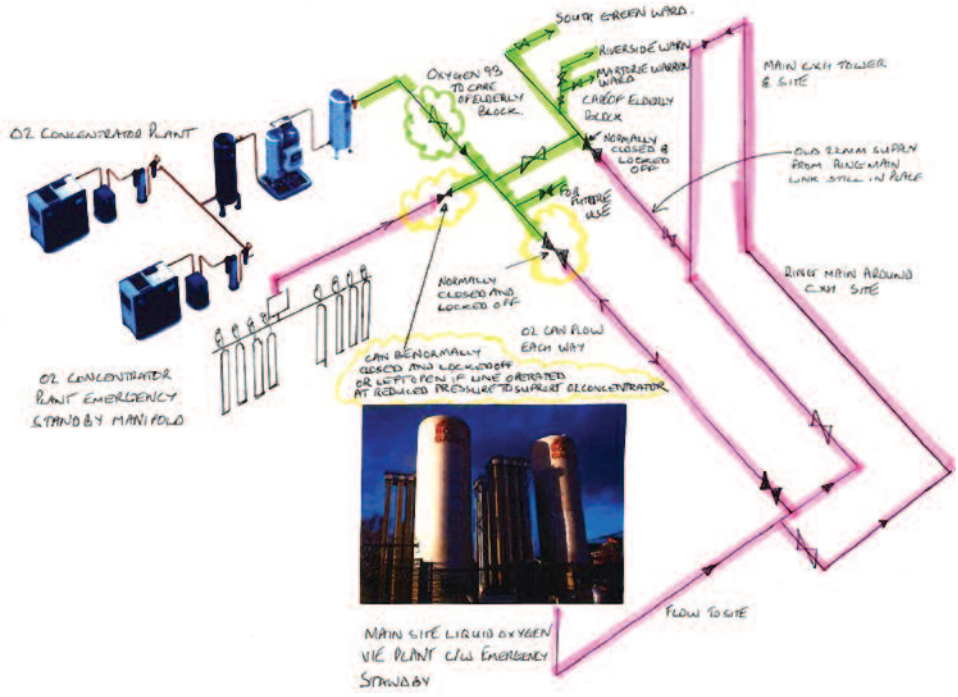


Figure 2: A sketch plan of the configuration of the new plant within the hospital.

busy that we decided we were only going to support our existing clients. Shane King, the Trust's head of Estates Operations – with whom we have a long-standing relationship – needed a lot of medical gas infrastructure reinforcement to ensure adequate oxygen flow rates and pressure at newly designated ICU beds, and SHJ just didn't have the resources to do it. Shane's response was that we should go out and get them, so we did – harnessing the services of sub-contractors, who, under our Competent Person guidance, supported SHJ with the installation of the plant and pipework."

An enthusiastic project lead

Stafford Scopes was keen to highlight how enthusiastically Shane King had led what proved a complex engineering project right from the start. He said: "It was Shane who asked: 'We don't have enough oxygen; how are we going to address the issue?' There is, of course, a limit to what a VIE and the vaporisers can supply, and, keen not to exceed the limit, Shane asked us what we could suggest. Our 'out-of-the-box' thinking was to supply an oxygen concentrator."

Normally, largely because the performance of large oxygen concentrators is impacted by ambient temperature, standard practice would be to install such plant in a hospital plant room. However, at Charing Cross Hospital, a lack of space made this impractical. "In fact," Stafford Scopes explained, "as there was no such space available here, we obtained two 40 foot shipping containers from a company that can adapt them, Adaptainer, who Shane suggested."

With the local roads quiet in late March, not long after the national lockdown, getting the plant, and indeed the specially fabricated containers that house them, onto site, using cranes, did not prove too much of a challenge. Stafford Scopes explained: "We undertook what proved a quite demanding project ourselves, using a team of about 10, who on some days worked an 18-hour shift in tandem with the Trust's Estates team to get the scheme completed promptly.

Two compressors for added resilience

"An oxygen concentrator uses a compressor to manufacture air, and the air is then sieved for the oxygen, "Stafford Scopes explained. "To produce this air, you need an air compressor, and a refrigerant dryer to cool the air. However, there was only enough power – a 100 A supply – on site to run one air compressor. We wanted two compressors available, so that in the event of one failing, the system would switch to the other. We thus adapted our existing Empower control panel to be able to change duty between two machines to ensure that one compressor is powered down before the other one starts up."

Stafford Scopes explained that the project team also had to deal with a significant unexpected obstacle when the shipping containers and concentrator arrived. He said: "On examining the concentrator, we soon realised that the measurements we had for it gave the height when it was lying horizontal, rather than vertical. To address this, we cut an aperture into the roof of the first container, craned the oxygen concentrator in through the roof, and then located the second container onto the top, to weatherproof it all."

Four weeks from start to finish

To ensure that the system would be resilient, SHJ ran a new medical gas main from the existing VIE to the generator – a distance of about 100 metres – and installed a cylinder manifold, so that if the supply from the concentrator failed, the hospital could run on cylinders. From agreement on the plan to the completion of all the works took only four weeks, Stafford Scopes explained, necessitating some very long days on site for some personnel. He said: "The team was absolutely excellent in terms of its

attitude and commitment." The oxygen concentrator system is all linked up to SHJ's K'nect portal, so that, from its offices in Chesham, its can see all the temperatures, via 10 different temperature sensors, as well as the ampage it is running at. Stafford Scopes added: "We know the cost of electricity per amp/hour, so we can tell the Trust exactly how many litres of air are being produced per minute, and the costs entailed. All the data is collected by our Empower system, which sends it to us here, and we then host it and present it on our K'nect portal, which the Trust's Estates Department can access any time."

He went on to explain that the concentrator at Charing Cross Hospital is currently supplying oxygen at a rate of up to 850 litres/min exclusively to COVID-19 wards at the site, supplying all the wards and theatres in the Riverside Wing, equating to about one-third of the site's overall oxygen capacity. He added: "The project, of which I am very proud, entailed completing an amazing amount of work in a short time. It's great to have a team of engineers who will respond with the commitment and enthusiasm that those from SHJ demonstrated on this project."

Asked to 'ramp up' ICU capacity

Shane King said: "In early March the Trust was asked to ramp up its ICU capacity, and, based on the numbers required across the area, we didn't have sufficient oxygen capacity from the VIE at Charing Cross. BOC was unable to upgrade the VIE, or to provide us with any additional temporary capacity. Had we – working with our hard FM provider, CBRE, and SHJ – not come up with a solution, we might not have been able to safely provide the Level III emergency care beds at Charing Cross. As soon as we became aware of the increase in patient numbers requiring oxygen therapy, we began looking at our oxygen distribution network, to try to balance where the clinicians wanted to put the additional beds with our oxygen and medical air infrastructure. Once numbers were firmed up, and the clinicians had identified which wards might be suitable for stepping up to critical care units, we reviewed all the infrastructure, and did a lot of work on upgrading the hospital's ring main to enable us to move oxygen around the site. When we were looking at the calculations for Charing Cross, we were significantly short. The VIE had an output capacity of 1,833 litres, but we were looking for a requirement somewhere close to 3,050 litres in total."

Close adjacencies sought

Shane King explained that he and the Estates Management team were looking to put the additional intensive care beds in close adjacency to the existing ICU beds up on the eleventh floor of the hospital's main tower block. However, once it became clear there was not enough VIE-piped oxygen, SHJ came in and began discussing how the additional oxygen capacity could be optimally provided – whether via additional standby manifolds, or temporary VIEs. He said: "That is when SHJ suggested that the only other practical option would be to install an oxygen concentrator. While such concentrators are always mentioned on medical gas training," he added, "I had never worked with one operationally before. We were fortunate that this particular concentrator had become available, and although several Trusts were interested in it, we were able to obtain the funds to purchase it. Between purchasing it, and installing and connecting it, however, we had some deliberations about how we could use this Oxygen 93, and whether it could be used with our pure oxygen, or used separately. It was agreed that it should be used separately, to supply the Riverside Wing."

Once this has been decided, the Wing's oxygen supply was disconnected from the main medical gas ring main, and the whole building and another adjacent area were then supplied from the oxygen concentrator. "At Charing Cross Hospital," Shane King explained, "even where COVID-positive patients didn't occupy a whole ward, they occupied part of it. The concentrator ended up serving three wards, and has the potential to serve all day theatres and 'Recovery' in the Riverside Wing and the adjacent area."

The compact plant layout in a standard high-roof shipping container.

Upgrading pipework

The shipping containers from Adaptainer were delivered in the first week of April, with the installation of all the plant completed, and the concentrator tested, completed, and operational, by the end of that month. Shane King added: "In addition, the work included upgrading the oxygen pipework within the wards to get the required flow rates to the beds, and installing both an emergency standby manifold, and an emergency link to the VIE. All of this work was undertaken by our Estates Management team, SHJ, and CBRE. The scheme involved a lot of detailed design and calculations."

He added: "Clearly there was a significant increase in oxygen demand flow rates across the site and the building. Some of the wards we were working on had COVID-19 patients on them, so we had to devise ways to upgrade the pipework in the wards concerned, while minimising risk to patients and staff. We did this by creating local ring mains in the wards, downstream of the AVSUs. We also undertook some significant reinforcement and upgrading of the medical gas ring main – the main distribution infrastructure – to enable it to carry the oxygen with acceptable pressure drops.

"SHJ was extremely helpful – especially in the very flexible way its team approached the work, including via extended hours working, and its staff being prepared to work within COVID-19 designated areas. We all did some very long days. Pleasingly, it all came together and proved well worthwhile, and we managed to stay ahead of the capacity requirements, which were changing daily."

Praise from the Trust's Chair

The Trust's Chair, Paula Vennells, also praised SHJ's work; in a letter of thanks to Stafford Scopes, she said: "When I thanked the Imperial Estates team for their work, they told me how grateful they were for the support from SHJ. They were especially appreciative for your supporting the Estates teams across all sites in the detailed assessment of existing piped medical gas system capacity to meet increased ICU ventilator requirements. They also thanked SHJ for its work on the redesign of systems and installation of new pipework infrastructure to provide adequate oxygen and medical air flow capacity to designated points of use, as well as for the turnkey solution in supplying and installing the innovative oxygen concentrator plant – increasing site oxygen capacity by 850 L/min when conventional liquid oxygen supplies were unable to meet estimated demand, often working in close adjacency to COVID-19 positive patients." hej