Flow monitoring proves key as oxygen demand peaks

During the early days of the COVID-19 pandemic last Spring, many NHS hospitals found themselves struggling for oxygen capacity, as the number of patients with the virus – and in particular those needing to be connected to ventilators or high-flow oxygen equipment – surged. To help healthcare estates and clinicians manage the situation, and ensure a sufficient ongoing oxygen supply, SHJ Medical Gas Specialists ('SHJ') developed a new monitoring and alerting system, FLO_2, which works in tandem with ultrasonic or integral flowmeters to continuously monitor oxygen flow rate and line pressure. This key data is then accessible in 'real time' via SHJ's customer portal, with alerts sent by email and SMS, enabling rapid decisions to be taken when oxygen flow is approaching maximum capacity. *HEJ* editor, Jonathan Baillie, reports.

To find out more about SHJ's recently launched FLO_2 oxygen flow rate and line pressure monitoring system, I spoke to the MD at the specialist in the supply, installation, and maintenance of complete medical gas pipeline systems, Stafford Scopes. He explained the background to the system's development, how the hardware is installed on a hospital oxygen pipeline system, and the fundamentals of its operation. He began: "During the first and second 'waves' of the pandemic last year particularly, there was exceptional – in fact unprecedented – demand for oxygen as coronavirus case numbers rose, and many of the Vacuum Insulated Evaporators (VIEs) delivering oxygen at large hospitals across the UK were approaching their maximum flow capacity. Once they reach this point, oxygen supply could be compromised – an unthinkable scenario for the NHS. Many Trusts were thus keen to know accurately – and this desire continues today – how much oxygen they were using, and to be made aware if they were approaching the pinch point which could affect the supply of oxygen to their patients."

NHSE/NHSI oxygen alert issued

Indeed, in the light of the unprecedented oxygen demand, NHSE/I issued an Estates and Facilities Alert, NHSE/I – 2020/0002, on 6 April last year, entitled 'Oxygen Usage'. Sent to Trust CEOs, Medical directors, Critical Care directors, Respiratory and acute medicine directors, Estates and Facilities directors, directors of Nursing, EPRR leads, and chief pharmacists, this warned that with hospitals now treating a large proportion of their inpatients for COVID-19 infection, the draw on oxygen was 'exceptionally high'. As a result, some hospitals were drawing more oxygen from their VIE systems than the maximum flow for which they were designed. This, in the words of the NHSE/I Alert, 'carries the risk of icing, that could cause flow to drop unexpectedly, compromising supply to patients, and/or permanent damage to the system'. The Alert said: 'It is thus critical that only approved guidance is followed to achieve maximum sustainable flow from existing installations.' It also emphasised that it was critical that clinicians and managers 'engage with their engineers in order to safely look after their patients and plan their surge capacity', adding: 'Regional leads should manage the location of care for patients that require oxygen demand through close collaboration with individual hospitals, and ensuring that this is considered when planning mutual aid (i.e. transfers between hospitals to increase capacity for patient care). This will help to ensure that critical oxygen systems are not damaged, compromising patient safety and the whole hospital.' The Alert went on: 'Please action oxygen alarms if they are triggered, ensure that there are cylinders available to replace piped oxygen supply in emergency, and ensure that you plan ahead – including as regards the potential for moving patients out of your hospital, if your system is nearing capacity.'

SHJ FLO_2 oxygen flow monitoring equipment installed at London's Royal Brompton Hospital.

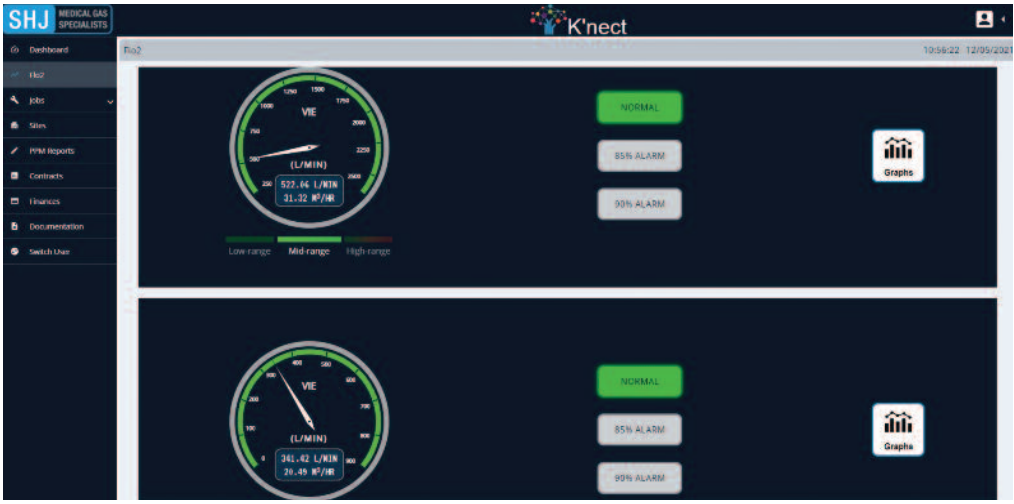
An exceptional case

Returning to my discussion with Stafford Scopes, and touching again on the exceptional circumstances those responsible for maintaining hospital oxygen supply faced at the pandemic's 'peaks', the SHJ MD said: "Hospitals with large piped medical gas have always monitored their oxygen pressure, but rarely the oxygen flow, simply because few have ever had to worry about reaching their maximum flow rates. As an analogy, a VIE could be compared to a thermos flask, full of liquid oxygen, and it is the capacity of the flask that hospitals will measure. As the liquid oxygen level depletes, a hospital Estates team will know the oxygen needs refilling. Measurement of flow, however," he added, "relates to how fast the gas is flowing out of the VIE, and, prior to the pandemic, this flow rate hasn't really been measured. We at SHJ have, in fact, measured flow in a couple of London hospitals – the Royal Brompton and Royal Marsden Hospitals – for some years. These hospitals share a BOC VIE, which we installed in 2000, and we put in two flowmeters even before 2000, which enables us to see the oxygen flow rates at each hospital day to day."

Oxygen flow rates

Stafford Scopes explained that SHJ had also installed similar flowmeters at the National Hospital for Neurology, and at Great Ormond Street Hospital, both in

London, which, again, share a VIE. I asked what determines the oxygen flow rate in a hospital medical gas pipeline system. He said: "Go back to the analogy of very cold liquid oxygen in a thermos flask. As the liquid exits into the ambient air, the warmer temperature warms it up – akin to changing water to steam – and it changes into a gas. Within the VIE plant," he continued, "there is a control panel, usually from an oxygen supplier such as BOC or Air Products. This panel incorporates two regulators, which control the maximum flow rates that go through them. While flow rates vary from hospital to hospital, the equipment is typically set up to deliver between 1200 and 1800 L/min. Before the pandemic, most control panels allowed a maximum flow rate of 3000 L/min." As well as the regulators, each VIE incorporates a vaporiser – as the liquid oxygen passes through this it is exposed to the ambient temperature, and 'gases off'. It then goes through the control panel, which allows the gas to enter the medical gas pipeline at the pre-selected flow rate. Stafford Scopes explained: "During the pandemic, some hospital vaporisers proved to be small to accommodate the sizeable liquid oxygen flows passing through them, with the danger they would not be able to warm the liquid sufficiently to turn it into gas. The liquid could then get into the control panel and freeze it up." Such a scenario tends, he emphasised, to occur only when oxygen flow is 'well above the design flow rate of the equipment'.



An FLO_2 dashboard screenshot.

Gas pressure reduced

A typical oxygen flow rate for a large teaching hospital under 'normal circumstances' might, Stafford Scopes explained, be 300-400 L/min, and thus a vaporiser able to deliver anything up to 3000 L/min 'would appear to be grossly oversized'. He said: "The VIE's vaporiser and control panel jointly determine the oxygen flow, while the control panel also reduces the gas pressure from perhaps 10.5 bar to a typical line pressure of 4 bar, for distribution throughout the hospital. The key issue for healthcare estates teams during the pandemic's 'peaks' was that the required higher flow rates were not being reached, or sustained – which was part of the reason that, for example, London's Charing Cross Hospital installed an oxygen concentrator (*HEJ* – October 2020), which we supplied, because the Estates team there realised that the hospital's existing VIE simply couldn't cope with the calculated flow rates they needed with all the extra COVID patients."

Having set the context, Stafford Scopes went on to explain how the FLO_2 system was developed. He said: "With many hospitals keen to be able to monitor their oxygen flow and pressure rates in real time, a number installed flowmeters for the first time at strategic points on their medical gas pipeline infrastructure in the Spring and Summer of last year. However, this generally still meant engineers having to go round and manually take readings from the meters at regular intervals. Some hospitals subsequently linked the flowmeters to their BMS systems, for instance using BACnet protocol technology to transmit the data from meter to system.

"Designated users could then access, view, and analyse, flow rate and other key data via the BMS 'front-end'. However, this tends only to be accessible from certain terminals on site. For this reason," Stafford Scopes continued, "and also in response to a call for help from a long-standing customer, Shane King, head of Estates Operations at London's Imperial College Healthcare NHS Trust, we developed FLO_2." Stafford Scopes explained that FLO_2's main hardware component is a compact 'box', which simply bolts onto the flowmeter, and sends flow rate and other data (depending on the transducers fitted) every five seconds to the company's servers, where the data is hosted, and is then viewable via SHJ's web-based customer portal, K'nect. The data is accessible 'at any time, and on any device', via K'nect to authorised personnel at any contracted SHJ customer. FLO_2 issues text or email alerts to users if oxygen supplies are reaching maximum capacity.

A screenshot from an FLO_2 gauge, and a graph of VIE output over a 24-hour period.

A 'box' of electronics

The FLO_2 'box of electronics' typically connects to the flowmeter via a two-core cable, and, once connected, measures the 4-20 ma output. This is then converted into the data sent to SHJ's servers. Stafford Scopes explained: "The user can then log on via K'nect from a desktop, laptop, or tablet device, and see live and historical data. The system also harnesses Artificial Intelligence to, for instance, predict an impending increase in flow rate based on what has been happening previously."

A major benefit of FLO_2 to, say, an Estates manager or engineer, he explained, is that the device is very quick to bolt onto a flowmeter, after which data on flow rates and pressures is read and transmitted to the SHJ server, and available to view, 'within minutes'. Stafford Scopes added: "We can also give access to the data to many different users working in different disciplines – from a senior nursing practitioner 'at the sharp end' on a ward, to the Estates engineer or manager in an Estates office, via K'nect. The data is sampled every five seconds, and logged and recorded. Users can thus keep a close eye on flow rates, and see, for instance, when they are gently coming down, or, conversely, if a significant influx of patients is seeing them surge."

SHJ Medical Gas Specialists' MD, Stafford Scopes.

Remedial action

I asked Stafford Scopes what steps an Estates and Facilities engineer might take if, via the data from FLO_2, they noticed an especially substantial increase in flow rate, to the point that the MGPS maximum flow capacity was in danger of being exceeded. He said: "The engineer can do one of two things very quickly – firstly they can 'load shed', by using portable cylinders, or, alternatively, they can introduced back-feed kits in critical areas. Imagine," he continued – moving from flow rates to line pressure considerations – "that the line pressure at the VIE is 4.4 bar, but that by the time the gas reaches the other end of the hospital, the pressure is significantly lower. To address this, we have installed some high flow rate oxygen manifolds in strategic locations in a number of hospitals to boost line pressure. For medical oxygen, the minimum pressure needs to be 4 bar, and with the high demands on hospitals' oxygen systems we have seen, that can fall to alarm levels – of 3.6 bar or below." FLO_2 was designed to be able to monitor both oxygen flow rate and line pressure. Stafford Scopes elaborated: "A hospital user can – for instance – put in a pressure sensor at the VIE, and see that it is delivering at 4.4 bar, and install another one at the end of the pipeline, where it may only be 3.9 bar. With our Artificial Intelligence, and using FLO_2, you can then work out that, as your flow rate increases, it's likely that the line pressure at the end of the system will fall even further. This data is all available with FLO_2 via K'nect."

Flowmeter options

SHJ stresses that for healthcare facilities wishing to have access to 'speedy, round-

the-clock' oxygen monitoring, but who don't have flowmeters installed, it can supply and fit one or more ultrasonic clamp-on or permanently plumbed-in integral models. The FLO_2 box is then connected to the flowmeter, or a number of meters if they are in sufficiently close proximity. The data read is transmitted back to the SHJ servers using the mobile phone cellular data network, and the flow rates of each meter, along with a 'totaliser' (and line pressure readings if required), are then displayed via SHJ's cloud-based customer data portal, K'nect. The FLO_2 system can also generate graphs and other 'charts' to show usage throughout the past four weeks. Users wishing to read line pressure as well as flow rates need simply to plug a pressure transducer into an existing NIST connector, without needing to shut down the system, and hard-wire it to the FLO_2 box. They can then see how the line pressure is responding to system demand. Trigger points are set at preset pressures and flow rates, which allows SHJ to send text or email alerts to the relevant healthcare estates or nursing personnel. K'nect is free to all the company's contracted customers, up to a maximum of five users, and SHJ says a typical supply and installation of clamp-on flowmeters can be completed 'within about four weeks'. It is also happy to send engineers to hospital sites to demonstrate FLO_2 on their medical gas pipeline system using portable clamp-on meters, thus enabling users to see for themselves 'the value of instant, easy access to such vital data'.

'Flowmeter 'agnostic'

Stafford Scopes said: "FLO_2 can be used in tandem with any type of flowmeter; we are 'manufacturer 'agnostic'. We recently, for instance, installed nine flowmeters at Doncaster Royal Infirmary, all of the integral, rather than the clamp-on variety; the former tend to be much more accurate." Plumbing in an integral flowmeter, he explained, 'might typically take a couple of hours'.

I asked him about the technology used within the FLO_2 boxes. He said: "All the technology and AI integrated into FLO_2 is the invention of my SHJ colleague, Professor Gaoyong Luo, who is also a Professor of Communications at Brunel University in the UK, and at Guangzhou University in China. An acknowledged expert on 21st century communications technology, such as 5G, Internet-of-Things-enabled devices, and AI, he previously, for example, played a key part in developing our original 'intelligent' plant monitoring system, Empower, and the medical gas alarm monitoring and alert system, Evolution. He has also helped us continuously develop and improve the K'nect customer portal.

At Doncaster Royal Infirmary, SHJ recently installed nine FLO_2 boxes linked to integral flowmeters, enabling staff there to monitor nine 'take-offs'.

"All the circuit boards in the FLO_2 hardware are our own, and to date it has proven an extremely reliable system."

The first systems

The first six FLO_2 systems, Stafford Scopes explained, were supplied to the Imperial College Healthcare NHS Trust, two each for the Trust's St Mary's, Charing Cross, and Hammersmith Hospitals, and were installed earlier this year. He elaborated: "The Trust, and specifically our main contact there, head of Estates Operations, Shane King, to whom we also supplied an oxygen concentrator last April to help boost oxygen capacity at Charing Cross Hospital, purchased some Flexim ultrasonic flowmeters as part of the recent NHS Oxygen Prioritised Resilience Programme and upgrade by BOC of its VIEs and associated plant early this year. However, Shane and his team had no easy means of then automatically collecting the data from the flowmeters, which is why he approached us. This led to my colleague, Professor Luo, developing FLO_2." He added: "We know there are ways to connect a hospital's MGPS flowmeters to a building energy management system, but that can be quite an expensive and slow process, whereas the FLO_2 box simply bolts on, and starts sending readings the same day."

In addition to the FLO_2 units supplied to Imperial College London Healthcare NHS Trust, SHJ has since supplied the 'boxes' to the Royal Brompton Hospital and Harefield Hospital, and to Doncaster Royal Infirmary. I wondered how many FLO_2 boxes a large acute hospital might need for optimal results. Stafford Scopes said: "That depends very much on their VIE, and the size and length of the medical gas pipeline infrastructure. Interestingly, during the pandemic, we found that if the fit of some of the patient CPAP masks wasn't great, or the masks were loose, a lot of oxygen can be wasted. At Charing Cross Hospital, we were able to pinpoint flow rates going high, and then go to certain areas within the hospital where they had COVID patients, and identify high use.

Individual line monitoring

"At Doncaster Royal Infirmary, where we recently installed nine FLO_2 boxes linked to integral flowmeters, the staff can monitor nine 'take-offs', so can see, for instance, that distribution pipe number one normally uses, say only 100 L/min, while distribution pipe number two may use 200-300 L/min, and so on. You can thus pinpoint any changes due to high demand, which can be a distinct advantage. The main risk, however," he continued, "is not necessarily a high flow rate, but rather the VIE's vaporiser and control panel not being able to cope with it."

I asked whether, typically, an FLO_2 box would be needed for each flowmeter. Stafford Scopes replied: "It depends on how near the flowmeters are to each other. If, for example, in a system with nine flowmeters we only had to run 100 metres of cable to each, you could have one box picking up the data from all the meters."

Accessible from anywhere via a web browser

Of the accessibility of the flow and pressure data to a hospital's users, Stafford Scopes added: "The data is accessible from anywhere with a web browser via our K'nect portal to all authorised personnel. Since the first installations of FLO_2 early this year, we have seen a good deal of interest, largely due to many more hospitals installing flowmeters to monitor oxygen flow rates. Users of the system range from those responsible for the safe and continuous supply of oxygen to clinical areas – normally the Estates engineers, to senior clinical managers on the ward. We believe the system – which is simple both to install and use – offers such personnel considerable benefits, both in time saved taking manual readings, and in giving them an accurate, up-to-the minute picture of the oxygen flow and pressure in their system. They can also very easily look at historical data for a previous period, compare current flow rates, and then, if necessary, take remedial action to avert a situation where there might be a risk to the oxygen supply." hej

FLO_2 units developed following customer's call for help

Shane King, head of Estates Operations at Imperial Healthcare NHS Trust, was concerned last Spring as to whether the VIEs at the Trust's three main hospitals – St Mary's in Paddington, Charing Cross Hospital in Fulham, and Hammersmith Hospital (pictured below) – would have sufficient flow capacity if COVID-19 patient numbers significantly increased.

Shane King, head of Estates Operations at Imperial Healthcare NHS Trust (the Trust has been an SHJ customer since the company's founding in 1967) explains that – concerned as to whether the VIEs at the Trust's three main hospitals – St Mary's in Paddington, Charing Cross Hospital in Fulham, and Hammersmith Hospital – would have sufficient flow capacity if COVID-19 patient numbers significantly increased, he and his team bid for funding under the NHS National Oxygen Programme in April 2020 to increase oxygen capacity and resilience. If its bid was successful, his team planned to use any funds awarded to upgrade the VIEs at all three hospitals, with the key elements being larger vaporisers and dedicated metering.

Flow capacity anomaly

Shane King had discovered that the maximum flow capacities at Hammersmith and Charing Cross Hospitals were significantly lower than previously advised by suppliers, at around at 1200 L/min. He said: "Looking back, we were certainly running the VIEs at or very near capacity at times during the first and second 'waves' last year."

Prior to acquiring eight ultrasonic FLUXUS G721CA oxygen flowmeters from Flexim early in 2021, the only means the Imperial College Healthcare NHS Trust Estates team had of monitoring the dynamic oxygen flow rates on the MGPS systems at the three hospitals was via the BOC telemetry facility that is part of the company's VIE systems. Shane King explained: "With the considerable additional demand for oxygen during last year, we had set alarms to alert us should flow rates across any of the systems approach 90, and then 95 per cent, of the reduced VIE capacity we had learnt we had from two or our VIEs late last year."

Flexim flowmeters

Shane King explained that, having learned that the Trust's bid for NHS National NHS Oxygen Programme funds had been successful, his team commissioned BOC to upgrade the VIEs at all three sites; a key element was increasing vaporiser output to 3000 L/min on all three. He said: "We had also been keen to be able to properly measure and monitor the oxygen flow exiting the VIE, and as part of its upgrade work for us, BOC supplied us with the Flexim ultrasonic flowmeters, which use transducers robustly attached to the outer wall of the copper piping to measure dynamic oxygen flow using the Delta T principle (see *HEJ* - January 2021). Initially, however, this still meant engineers having to visit each flowmeter several times per day to take a reading. We were keen to find a less labour-intensive and time-consuming means of obtaining regular flow rate and line pressure readings, and decided to talk to SHJ, with whom we have a long-standing relationship. Stafford Scopes noted our requirements, and SHJ developed the new compact FLO_2 units. In all, SHJ supplied us with four FLO_2 boxes for use across the three sites – a number of the 'boxes' gather readings from more than one Flexim flowmeter. The boxes," Shane King explained, "are wall-mounted close to the flowmeters, and connect to them via a collector box. Readings of oxygen flow rate and line pressure are taken every five seconds and transmitted wirelessly to the SHJ server. We can then closely monitor the flow rates and line pressures at all three sites via our K'nect portal, and spot any particular trends or anomalies – such as sudden increases in flow, or falls in line pressure. The FLO_2 units have really benefited us by eliminating the need for engineers to go out and take readings, we have instantaneous data, and the software enables us to compare current flow rates and line pressures with those from the previous day, week, or month, giving us confidence that we will spot any potential issues with supply before they become a significant problem.

"We do also," Shane King explained, "have a number of hard-wired connections from the flowmeters via modems to our BMS, but on occasion that system has failed due to connection errors, whereas the FLO_2 boxes have proven extremely reliable. Their linking to the SHJ servers, and our ability to then view the data in real time, is a big plus. Any of our authorised users can view the K'nect portal not only from their desk, but also remotely, anywhere with an Internet connection. The SHJ system will also send text or email alerts to designated Trust Estates and clinical management personnel should the embedded AI identify a potential issue on the oxygen infrastructure developing."