

Waste Anesthetic Gas Disposal (WAGD) Systems

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Notes

Notes on Using this Pamphlet:

This pamphlet is presented as a service to systems designers and operators selecting, designing and working with piped WAGD systems in medical facilities. The pamphlet seeks to improve understanding of what these systems are intended to achieve, how they interface with medical devices, what safety risks they pose, and what options are available under the NFPA 99 "Health Care Facilities" standard.

The 2002 version of the NFPA 99 is used for all references except where indicated. Users are cautioned that this pamphlet is intended to be used in conjunction with the standard, which should be obtained from:

National Fire Protection Association
1 Batterymarch Park
Quincy, MA 02269-9101
Phone 1-800-344-3555
Internet www.NFPA.org

Preliminary Edition 12 May 2004

Comments on this booklet or on any aspect of medical gases are welcome and encouraged.
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Some terms used in this booklet

AGSS : “Anaesthetic Gas Scavenging System”. The International Standards equivalent to WAGD (Waste Anesthetic Gas Disposal) as used in the U.S.

Dedicated Implementation : A system with a producer exclusively for the WAGD system. The opposite of a Dual Use implementation.

Dual Use : A combined system of medical vacuum and WAGD.

EN System : A system which complies in it’s essentials with the European AGSS standard EN 737-2:1998

High vacuum : As used herein, a vacuum above 5 inHgV (127 mm HgV). Typical high vacuum systems are run at medical vacuum levels 15-29 inHgV (380 - 760 mmHg)

Intrinsically Safe : A system which is designed so that no failure or combination of failures can cause the system to endanger the treatment or the patient.

Low vacuum : As used herein, a vacuum below 5 inHgV (127 mmHgV)

Introduction

Introduction

Why a booklet on such an obscure topic? Unique among medical gas and vacuum systems, failure of a Waste Anesthetic Gas Disposal (WAGD) system does not usually pose a life safety hazard to patients. WAGD is reasonably forgiving, and even a marginal implementation often can be induced to operate adequately. WAGD deals with an occupational hazard - not a problem usually considered part of medical gas work. Indeed the whole topic and the systems themselves might long ago have vanished but for NIOSH/OSHA mandates for testing trace gases in occupational workplaces, including operating rooms. Only because WAGD is the easiest way to control these trace gases does WAGD remain part of the O.R. landscape.

The whole subject remains controversial. There are many who would contend that waste gas presents no proven health hazard and that no adequate study exists to justify the continuing testing, much less the installation of WAGD in every O.R. However, given even casual consideration, commonsense must prevail:

"It only makes sense that if a potent anesthetic gas causes individuals to slump into a semi comatose sleep before they can count from ten to one backwards, incremental amounts of the same anesthesia ... would cause similarly acute effects in nearby surgical personnel."

"Reducing Exposure to Nitrous Oxide

Thom Wellington,
article, FacilityCare Magazine,
August 1998

Achieving this very commonsense goal creates hazards of it's own. Two in particular have exercised us in the past: The first was much discussed when WAGD systems (usually termed "Evacuation" or "Evac" in those days) first came into widespread use. There was much discussion about the consequences of drawing oxygen and nitrous oxide into oil lubricated pumps. Although the concern was theoretically valid, such implementations became less and less unusual and the fires or explosions predicted did not materialize. It is now true that some major engineering firms take no notice of this hazard at all and routinely specify Dual use implementations through lubricated machines.

The second hazard is the risk of applying full line vacuum to the anesthesia breathing circuit. Here too, the theoretical risk appears to not have proven to be the real problem originally feared. The interface valves on the anesthesia machine have proven reliable enough, or the intervention of the anesthesiologist has been swift

enough, that few if any serious problems of this type have been reported.

The average engineer designing medical gases is largely untutored in the function, usage, internal complexities and underlying hazards of a WAGD implementation. The result has been that North American medical gas designers have largely come to share this common set of assumptions:

1. Dumping the WAGD into the medical vacuum source is cheap. This is assumed to be true in equipment terms and also in the designer's own time - no line sizing or pump sizing needs to be done other than what must be done for the vacuum anyway.

2. In a Dual use implementation, any oxygen or other gases will arrive at the pump sufficiently diluted to render them harmless.

3. Any other problem will be handled by someone else.

These assumptions have lead to the most common implementation of WAGD in North America today - a WAGD terminal at each anesthetizing location piped into the medical vacuum line and thence into the medical vacuum pump.

In no area of medical gases are international practice and North American practice more widely divergent. Unlike the loose approach taken in North America, Europeans have put much effort toward perfecting these systems. The result of this work is found in the standard (EN 737-2) used in Europe, which includes some very interesting advances:

1. EN systems are designed to be intrinsically safe. That means that the system protects the patient, no matter what the anesthesiologist does or doesn't do. EN systems cannot expose the breathing circuit to the intense vacuum of the medical vacuum system.

2. EN AGSS is always implemented with a dedicated producer and a dedicated piping network. They do not use any components which are incompatible with the waste gases or with oxygen.

3. Piped systems are designed around low cost, low horsepower regenerative or vortex blowers instead of relatively expensive pumps. This makes the systems relatively inexpensive (no small consideration in today's environment.)

It appears that these EN assumptions about WAGD are no longer merely of curious interest. The major anesthesia machine manufacturers operate globally and these



*Fig. 1
A pump used in Dual Use
service which appears to
have suffered an oxygen fire.*

manufacturers have begun to bring anesthesia systems originally designed using these European assumptions into North America. Two unexpected consequences are being reported:

1. *Fires in vacuum pumps.* We had no verifiable reports of

fires in WAGD pumps for many years. But beginning in the last half of 2002 and continuing through today, there have been increasingly frequent reports of pump fires. Such reports are hard to corroborate, and many reports we have not been able to document, but we have been able to verify some others. (see Fig. 1).

The reports range from flashes at the exhaust through to complete explosive destruction of pumps. In all the cases corroborated so far, the pumps were in dual use WAGD and medical vacuum service, and all were oil lubricated.

2. *Vacuum pumps running excessively.* In numerous cases both with vacuum pumps in Dual use service and in dedicated WAGD service, pumps have been seen to be running much harder than expected or than that same pump had run historically. In extreme cases, this has resulted in pump failure.

We have been able to determine a possible set of causes for these reports. These bear directly on the assumptions under which WAGD is designed and installed:

1. There are now on the US market some anesthesia systems with interface valves which require larger inflows than previous machines.

The 'traditional' interface valve would draw in the 6-9 liters per minute range when in operation. Under EN standards, the inlets are required to draw 50 lpm (1.8 scfm). However, the standard sizing assumptions used in North America for WAGD (for instance in the NFPA 99 vacuum sizing methodology) assume only 1 scfm (28.3 lpm) per anesthetizing location.

2. Some anesthesia systems are now venting their ventilator drive gas (the gas used to power the ventilator itself and not breathed by the patient) into the waste gas stream.

In older machine designs, this drive gas is vented into the room. This gas may in many cases be pure oxygen, and of course may be flowing the entire length of the case, greatly increasing the total volume of oxygen entering the WAGD system. The potential for exposure of the pump to elevated oxygen levels is therefore greatly increased.

The claim is made that Dual use systems are safe because they enjoy 'dilution' - that is, the waste gas is diluted by the air entering the standard vacuum inlets. NFPA even lends credence to this argument in 5.1.3.7.1.2. The argument has been impossible to prove or disprove, because heretofore no evidence has existed either way, except an inconclusive absence of reports of fires in such systems.

There has recently been undertaken a study wherein the oxygen levels at the exhaust of a pump in Dual use service were actually measured. The study conclusively demonstrated that oxygen levels did in fact rise to dangerous levels (35%) when these new anesthesia machines were in service. While the effect of these new anesthesia systems in any given WAGD system will vary, it is clear that they can and do elevate the level of oxygen passing through these pumps. (Scott, *et al*, 2004) We therefore now can conclude that while dilution may be present in any given system, it is not a reliable substitute for a proper WAGD implementation.

How dare they!

It is very important to caution the reader that there is no proof of a direct cause-effect between these new anesthesia machines and these adverse effects, and that all evidence is at this writing circumstantial. The reader should use these reports and the information contained in this paper as a guide to making improvements in their WAGD systems in order to increase the absolute safety and reliability of their systems. It would be entirely inappropriate and irresponsible to use this information to influence decisions regarding medical practice or the selection of any given anesthesia system, which is an entirely medical decision.

While at first blush it may seem irresponsible for the anesthesia machine manufacturers to make these changes without notice, it's important to understand that what they have done is entirely consistent with the rules for WAGD as NFPA has them today.

NFPA has required WAGD systems be compatible with oxygen for many years. Although it has been watered down somewhat over the years, NFPA 99 still carries a warning about the mixing of WAGD and medical vacuum (ref: NFPA 99, 2002 5.1.3.7.1.2(2), A-5.1.3.7

The Anesthesia Machine

and also see NFPA Health Care Facilities Handbook, 2002 edition, commentary on 5.1.3.7). NFPA does not stipulate an inflow, but does require that the pump used in such a dual use system “be adequate to handle the volume” (ref: NFPA 99, 2002 5.1.3.7.1.2(3)). The new machines clearly will work very well and entirely safely on any system which complies with these rules.

Venting the anesthesia machine ventilator drive gas into the waste gas stream is done for a significant safety reason. It does sometimes occur that there is leakage from the breathing circuit past the ventilator bellows. In that case, the ventilator drive gas discharge can contribute to anesthetic gas levels in the O.R. By discharging the drive gas into the waste gas stream, this possible source of contaminant is eliminated.

Regrettably, operators of WAGD systems are not asking (indeed don't know *to* ask) questions about the anesthesia systems that are being purchased. As these newer machines come on line, the first anyone may know of the change is when the facility begins experiencing pump problems. The problems will worsen as these new machines replace older anesthesia systems still in use.

A natural question might be “If I just don't use this new machine, can I avoid any WAGD complications?” Obviously, the answer may be yes, for a while. But the simple home truth is that mechanical systems in a hospital are meant to facilitate the best medical practice, not to dictate it.

It is thus essential that we change our languid and comfortable assumptions about WAGD, both in new designs and even in existing installations.

It is the purpose of this pamphlet to offer some guidance on this very pressing issue. Before we begin, a short primer on anesthesia systems, WAGD and how the systems fit together may be helpful.

The Anesthesia Machine (ref. Figure 2)

We will not even attempt to address all the complexities of a modern anesthesia system here, but rather will look at a system reduced to those basic elements which bear on how waste gases come to be and what they look like to the WAGD system.

First a quick note on units of vacuum. In the patient care environment, pressures and vacuums are expressed in millimeters of mercury (mmHgV) or inches of water column (inH₂O_V). In medical vacuum design, we are used to expressing vacuum in inches of mercury (inHg). Perfect vacuum for those in the medical gas world is 30

inHgV, but for the medical professional, it would be 760 mmHgV. That same perfect vacuum could lift a column of water 405 inches. An inch of mercury is therefore roughly 25 mm of mercury or 13.5 inches of water.

Figure 1 is a simplified diagram of an anesthesia system. The breathing circuit is a closed loop with the patient connected at the end. Gas from the piped medical gas systems enter the machine through the flowmeters and is blended with an anesthetic agent in the Anesthetic Agent Vaporizer. It is the proportioning of these gases and the anesthetic drug under the control of the anesthesiologist which induces and maintains the desired level of anesthesia.

The gas mixture passes into the breathing circuit through the fresh gas inlet. When the patient breathes in, the gas is drawn through the inhalation valve, through the circuit tubing and inhaled.

As the patient breathes out, the gases pass through the other arm of the circuit, through the exhalation valve and into the rebreathing bag.

When the patient inhales again, the gases are drawn from the rebreathing bag, through the CO₂ absorber to scrub out excess CO₂ and the gas then passes back up through the inhalation valve, mixing with fresh gas on it's way back to the patient.

Since the circuit is closed, it is obvious that gas cannot be added indefinitely but must eventually be vented somehow. This is the function of the Adjustable Pressure Limiting Valve (APL valve), which is set by the anesthetist to maintain a certain pressure in the breathing circuit and to relieve any pressure in excess of that setting. The gas which is vented through that valve is the waste gas which our WAGD system will be expected to remove. It contains whatever mixture is present in the breathing circuit, including halogenated anesthetic drugs, nitrous oxide, air, oxygen, water vapor, and carbon dioxide.

It is important to note that there is a very slight (inches of water at most) positive pressure at the APL valve. The pressure at the APL valve is crucial to the proper functioning of the whole anesthesia system. If a vacuum were present at the APL valve, it could suck the anesthetic gases out of the breathing circuit. (In extreme cases, the breathing circuit could be placed under a vacuum, which in turn would put the patient's lungs under a vacuum and could be fatal). If the APL valve were to see excessive backpressure, the breathing circuit and the patient's lungs could also experience higher pressures. The function of the interface valve to the WAGD system is to prevent these two hazards.

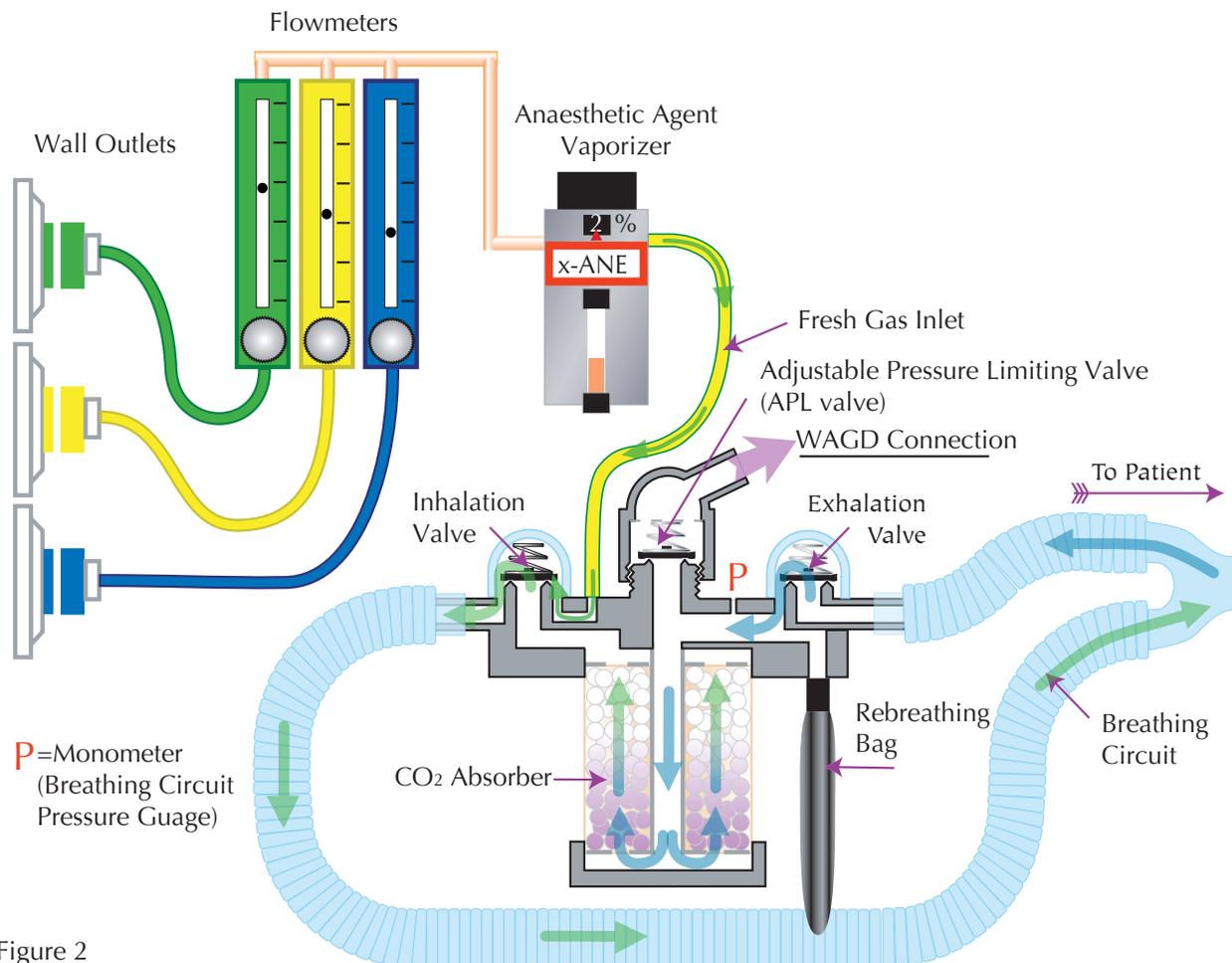


Figure 2
The Anesthesia Machine

As we set about designing the WAGD systems to connect to these interfaces, the above criteria is worth restating, particularly because to engineers it may at first appear counterintuitive. A properly functioning WAGD system (including the interface) must remove any waste gas from the APL valve, while never permitting either a vacuum or a pressure to appear at the APL valve itself.

The pressure and rate of flow from the APL valve is quite variable. Pressures in the breathing circuit fluctuate depending on the patient's breathing. Naturally, the pressure in the circuit will drop during inhalation and rise during exhalation. This will be reflected in changes in the flow at the APL valve. Patients might sigh, hiccough, stop breathing, cough, and otherwise cause the pressures and flows at the APL valve to fluctuate wildly during a procedure. Adults will produce more flow than infants. The diagram does not account for the anesthesia ventilator, which of course will also vary the pressure in the breathing circuit. The WAGD system must be able to handle all of these variations without dumping waste gas into the room. Most of this balancing act is performed by the WAGD interface.

The WAGD Interface (Ref Figures 3 and 4)

The interface between the anesthesia machine and the WAGD inlet has two major functions:

1. *It must guard the breathing circuit from exposure to vacuum or pressure.* If the vacuum at the WAGD inlet is 28 inches of mercury (as might be seen in a dual use WAGD/Medical implementation) the interface valve must reduce that to a vacuum which will not disturb the pressure relationship at the APL valve. In essence, the vacuum must be turned down by a factor of as much as 400. Naturally, a turndown this extreme is tricky to achieve and maintain, especially when one considers the variations in flow and pressure at the APL valve.
2. *It must ensure that the inevitable surges in waste gas volume are contained and passed into the WAGD system rather than overflowing into the room.*

The most common North American interfaces are diagrammed in Figures 3 and 4 (These diagrams are simplifications of the actual interfaces for ease of

WAGD Interfaces

understanding).

Figure 3 represents what are termed “closed” interfaces.

A tube from the APL valve connects at the interface inlet. The interface outlet is connected to the WAGD inlet on the wall or ceiling. Control is achieved with a valve, which is intended to balance the inflow from the APL valve line with the outflow to the WAGD system. This balance can be roughly observed by the behavior of the containment bag - if it inflates, the outflow is too small. If it deflates, the outflow is too great.

If more flow comes to the interface than it can handle, (i.e. a surge from the breathing circuit or the needle valve is not sufficiently open) the bag will inflate and ultimately there is an overpressure relief which will dump the excess gas into the room. If the flow from the breathing circuit is too small or the valve is open too far, there is an underpressure relief which will admit room air to prevent a vacuum in the interface valve.

However, the control valve is sometimes left wide open and the underpressure relief valve(s) simply remains open. Although this is incorrect usage, the interface is so designed as to be able to handle this as long as the interface is properly maintained.

A criticism of this style of interface is that they rely too much on the underpressure relief valves. If the underpressure valve becomes clogged with the lint or debris they can suction up when open, they may not function to protect the patient. Current designs for these valves specifically minimize this risk, for instance by providing redundant underpressure relief valves.

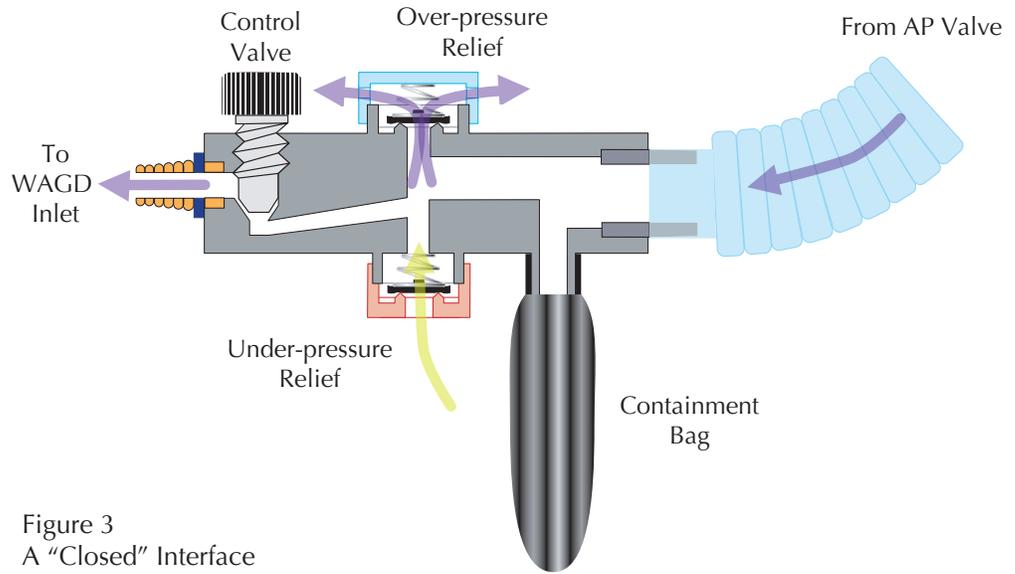


Figure 3
A “Closed” Interface

Flows through these interfaces and into the WAGD system are typically 6-9 lpm when properly adjusted. However, versions of these interfaces are now calibrated to draw 40 lpm when 12 inHgV is drawn at the interface outlet (i.e. using a fixed orifice instead of a valve).

European interfaces are based on another design sometimes called an open interface, a Bohringer tube or tube in a tube. These interfaces are simpler and operate on the most basic of physical principles, but are nevertheless quite effective when properly used.

Again, simplified for easy understanding, the interface works roughly as described in Figure 4.

The tube from the APL valve connects at the interface inlet. The interface outlet is connected to the WAGD inlet on the wall or ceiling. Unlike the closed interface, these interfaces often do not have manual adjustments. In those cases, a fixed orifice is simply placed in the outlet calibrated for the source vacuum and the required flow. Air is continuously drawn through the outer tube which completely encloses the inner tube. This constant flow and slight residual vacuum induces a flow in the inner tube. The waste gas, pushed by the slight positive pressure at the APL valve and pulled by the vacuum passes through the inner tube where it is simply pulled

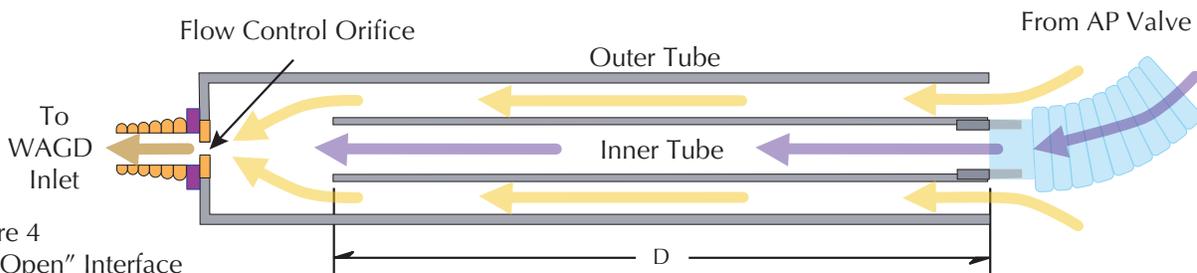


Figure 4
An “Open” Interface

out through the orifice along with the continuous flow along the outer tube.

Surges in waste gas flow are accommodated by the excess gas simply flowing down the outer tube. The dimension “D” and the relative diameters of the tubes are critical. Carefully selecting these dimensions limits the vacuum as well as providing capacity for handling the expected surges without the waste gas escaping into the room.

An underlying assumption for open interfaces is that the flows will be large. High flow is necessary to prevent spillage from the tube. Naturally, the higher the flow the smaller the interface itself. Flows of 80 to 130 liters per minute (2.8 to 4.6 scfm) are required under the British Standard 6834:1987, and 25 lpm minimum, 50 lpm maximum is required under the newer European Standard EN 737-2 1998.

The tubes are relatively large, which means the air velocity is low at the end. This in turn reduces the risk of sucking up debris which might block the tube. Some interfaces are provided with filters, and some with indicators or flowmeters to let the operator know they are within specification.

It is important to note that while either interface type could work with any WAGD system, the interface and the system must be matched in terms of pressure and flowrate. This may mean adjusting orifices or other modifications to adapt the interface.

WAGD According to NFPA 99

NFPA 99 has several sections on WAGD which are useful as a starting point for the design of the systems. The standard however is not comprehensive and the designer must also have other sources to rely on.

NFPA permits five different WAGD implementations. They are:

1. Dual use WAGD/Medical vacuum (high vacuum).
2. WAGD into a dedicated pump (high to moderate vacuum).
3. WAGD into a blower or fan (low vacuum)
4. WAGD into an inlet driven by venturi. The venturi must be driven by some system other than medical air (instrument air is ideal).
5. WAGD handled passively e.g. by ventilation and air changes (see Chapter 6, Environmental Systems, 6.4.1.6)

Of these five, the last often must be immediately disregarded. Handling WAGD through a passive system has long been discredited as ineffective and in most HVAC arrangements cannot effectively comply with 6.4.1.6. The arrangement of a typical O.R. makes the air very difficult to change and waste gases may linger in the many dead spots created by the equipment, drapes, etc. The air changes have to be set impracticably high and no recirculation is permissible, which makes such an approach undesirably expensive.

Venturi driven systems are unknown in North America, although they are not unusual elsewhere in the world. They offer the designer only limited advantages over other systems and are a relatively expensive and complex option. We will discuss them under distributed producer systems.

High vacuum systems (dual use and dedicated) are the most common implementation in North America. They use a vacuum pump as their source, typically running at the same vacuum levels as the medical vacuum (15 inHgV - 29 inHgV).

The standard permits almost any implementation for a dual use high vacuum WAGD/Medical system (see Fig. 5 for examples).

Dedicated WAGD permits two different implementations: high vacuum (pump driven) and low vacuum (blower or fan driven). These are not very different in the requirements from the NFPA 99 standard, but require very different engineering.

When we consider the basic requirements of designing a system we will revisit the specifics of these requirements as they apply to alarms, valves, etc.

The Ideal WAGD System

What constitutes an “ideal” WAGD system? These characteristics apply to either WAGD interface and might be used as something of a laundry list for anyone designing WAGD.

- *The ideal system is active.* That means there is some form of a “motivator” (NFPA uses the term “producer”) which actively moves the waste gas down the line. Passive systems (which rely primarily on the slight positive pressure from the APL valve) are not effective with the newer interfaces, and arguably never worked adequately.
- *The ideal “producer” is oxygen inert.* There is nothing in the producer likely to be a fuel for a fire.

The Ideal System

- *The ideal system operates at as low a vacuum level as possible.* There is nothing more essential to patient safety than preventing the breathing circuit from seeing a vacuum. The lower the maximum system vacuum, the lower the risk, without having to rely on the interface.
- *The ideal system has a high flow.* At a minimum, each inlet must be able to draw a continuous 50 lpm (1.8 scfm) through the interface.

In light of these criteria, there are two questions to be answered:

1. *What do I do if I have an existing WAGD system and am going to attach new anesthesia systems to it?*
2. *How do I design any new WAGD systems?*

Dealing with an Existing System

What do I do if I have an existing WAGD system and am going to attach a new anesthesia system to it?

Each of the many combinations of system layouts, producer technologies and other variables implies its own risk profile and will result in a different priority order for the available options.

As discussed, there are three primary concerns to consider. The most immediate is the oxygen sensitivity of the existing system. It is clear that any possibility of fire is the greatest hazard. A less critical issue, but one equally demanding a solution, is the problem of higher inflows. The third is the patient safety concern involved with any high vacuum implementation (see page 7).

Figure 5 illustrates a decision process for considering each of these concerns in order. Reference to the figure will lead the reader through the necessary decisions, explained under the main headings below:

WAGD Inlets:

It is a basic requirement that any facility must have dedicated WAGD inlets distinct from the vacuum inlets, marked "WAGD" or "Evacuation", colored purple and not interchangeable with the vacuum inlets. These have been required under NFPA 99 since at least the 1996 edition (ref NFPA 99 1999 edition, 4-3.3.2.3 (b).) If the facility does not have such dedicated WAGD inlets, installation of a new WAGD system will be required.

Dual use vs. Dedicated WAGD Producers:

The hazards involved with Dual Use and dedicated implementations are nearly identical if they are both driven with pumps, but removing any oxygen sensitivity will involve very different levels of complexity and cost.

What makes a pump "sensitive to oxygen" or "suitable for use with WAGD"?

Vacuum pumps vary greatly in their suitability for use with WAGD, based primarily on their compatibility with oxygen (although there are other considerations, they pale compared to this one).

The most important consideration is simply the availability within the pump of fuel, which practically means oil or grease. Any pump in which oil or grease are in contact with the gases is therefore unsuitable. However, to be acceptable for WAGD does not mean to be suitable for oxygen. As an example, a vacuum pump for WAGD does not need to be "oxygen clean" in the way an oxygen pipeline needs to be clean, or the way the same pump would need to be cleaned if it were actually pumping oxygen. Very small amounts of oil or grease, such as might be found on a machined part are unlikely to cause problems in this service. The greatest concern arises not simply from the mere presence of oil, but the presence of oil in quantity.

Similarly, graphite vane pumps are not ideal for WAGD service, because the vane dust can form a fuel and is present in some quantity. Nevertheless it needs to be said that we have no reports of fires with graphite pumps in WAGD service.

In rough order of concern, common pump technologies fall out roughly as follows:

Oil lubricated: These are typically rotary vane, oil seal liquid ring, screw or reciprocating pumps which contain large volumes of oil. These are at great risk with elevated oxygen. All reported fires have been in this category of pump.

Dry or graphite vane pumps: These are rotary vane pumps which use no oil in the machine but may have lubricated bearings and use sacrificial graphite vanes. These are probably moderate to low risk.

Regenerative blower (dynamic) and dry rotary lobe pumps: These machines have air ends in which there is no source of fuel (i.e. no oil). Although there may be lubricants in their bearings and in their gear cases, the oil containing chamber(s) and the compression chamber are separated. Generally, these machines are low risk as long as they are well maintained.

Water Seal Liquid Ring: These pumps contain no oil nor do they allow any practical way for the oxygen to reach their bearings. They also run very cool. They present the smallest risk.

Dedicated systems will of course also have dedicated piping, which greatly facilitates any solution.

High Vacuum and Patient Safety:
The concerns over the patient safety issues with any high vacuum implementation are explained on page 7.

Oxygen sensitivity in producers:
See the sidebar (page 11).

Pump capacity:
A pump may be compatible with oxygen but still be

problematic. The most commonly manifestation is simply inadequate capacity. In any case where a pump is stressed (i.e. running too much or calling in the lag pump), and the WAGD is demonstrably the cause, two basic options must be considered: dividing the systems (page 13) or replacing and upsizing the pump (below).

On the use of Medical Air to run the anesthesia ventilator:
If the O.R. has piped medical air, it may be possible to have the anesthesia machine modified to run the ventilator on medical air rather than oxygen. While this does not eliminate the concern with flowrate, it

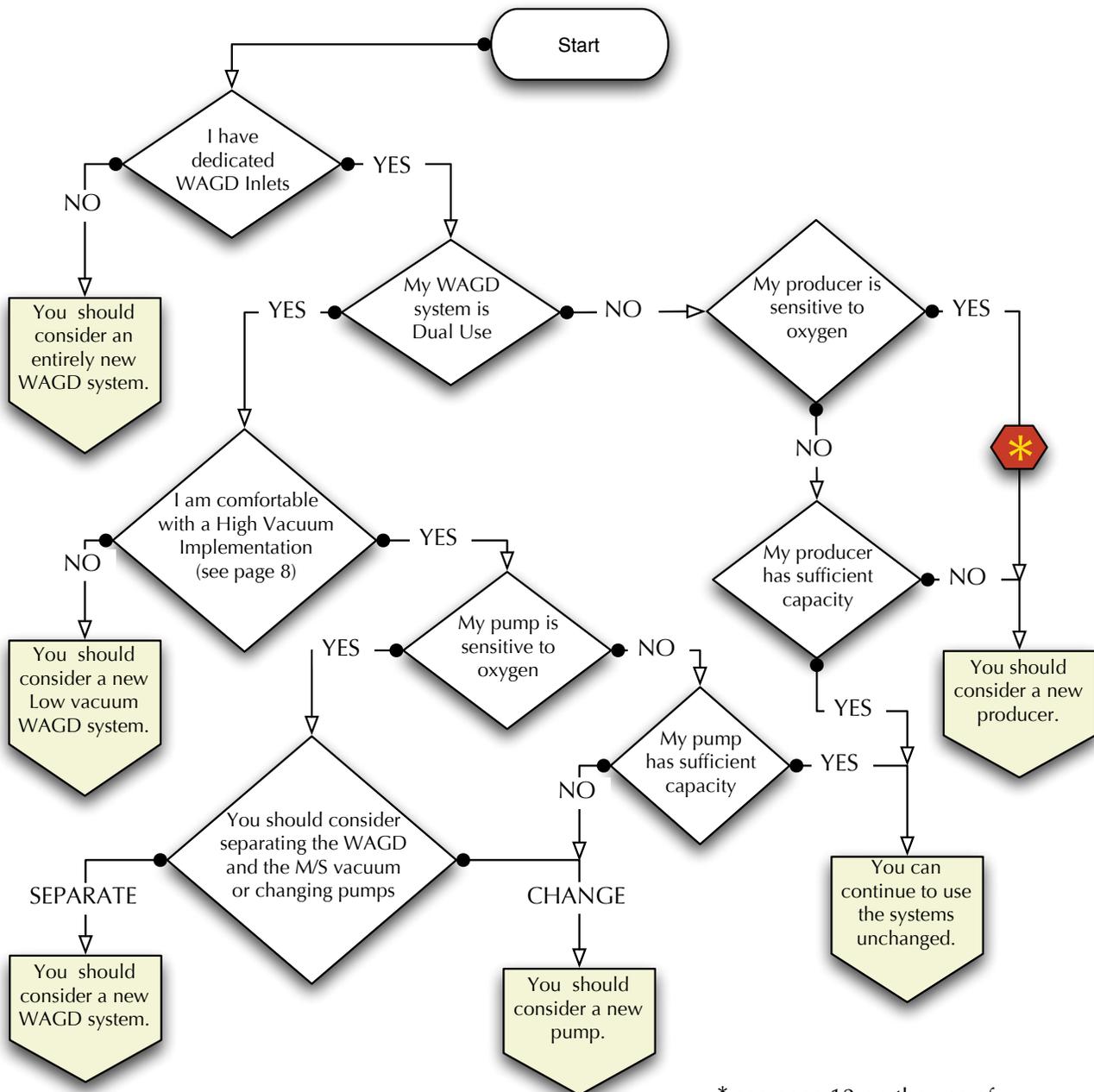


Figure 5
A Decision Tree for Existing Systems

* see page 12 on the use of Medical Air for anesthesia ventilators

Replacing Producers

does greatly reduce any hazard of fire in the pump. This can only be considered if the O.R. has piped air, since the volumes required will rapidly deplete cylinders. Medical air is not required in the O.R. under the 2001 *AIA Guidelines for Design and Construction of Hospital and Health Care Facilities*. To investigate air as an option, you must have the answer to three questions:

1. *Is medical air piped into every location anesthesia machines will be used?* include in your survey outpatient, inpatient, delivery, trauma and any other specialty O.R.
2. *Is there sufficient medical air capacity?* For calculation, you should assume 2 scfm per O.R. with a 100% simultaneous use.
3. *Is the medical air in good condition?* It is still true in some facilities that medical air is wet or dirty. In intensive care, it is often found that the medical staff has abandoned the piped air for these reasons, using instead portable compressors for their ventilators. This is not an option in the O.R., so the piped medical air must be as required by NFPA 99 before it can be used.

Replacing a Pump or Producer

Replacing a pump or producer is often the quickest, surest and cheapest solution. Obviously, if capacity is the primary problem, then replacement offers an immediate solution. If oxygen sensitivity is the problem, replacement alone can resolve this issue without further changes to the systems as piped.

When considering pump replacement, there are a number of considerations.

First: In some cases it is possible to change not the pump but the lubricant/sealant within the pump. There are halogenated lubricants which can withstand contact with oxygen and can be used in some existing pumps to make them "oxygen compatible". Note that these lubricants are NOT simply "synthetic oils" (which are essentially the same as natural oils as far as oxygen sensitivity is concerned).

Pursuing this option must first be discussed with the supplier of the pump to ensure it is even possible. The conversion typically requires that the pump be largely or totally disassembled, completely cleaned, reassembled, and filled with the special oxygen inert lubricant. In most cases the pump must be returned to the factory. Costs will include preparation and the first fill of lubricant. The whole process can be grotesquely expensive and the replacement lubricant is amazingly costly.

These specialty lubricants often outlast standard oils, but they still need to be changed periodically. Whenever the lubricant is changed, it must be done with this special lubricant both to preserve the oxygen compatible character of the pump and because the standard and special lubricants cannot be mixed.

This kind of a conversion should only be undertaken with full knowledge of the total costs and with a complete understanding of the manufacturer's limitations on the use of the converted pump.

The comments above are primarily directed at oil lubricated technologies such as liquid ring oilseal, screw and lubricated rotary vane. It is possible and even desirable to consider this kind of adaptation for technologies which are oil free as a way to reduce any remaining risk. For instance, in rotary lobe machines and in dynamic machines it may be possible to use these oxygen compatible lubricants with only a small increase in operating cost because of the longevity of the lubricant. Again, the manufacturer must be consulted before taking any action of this type.

Second: The pump may be replaced with a pump of appropriate capacity but which is inherently oxygen compatible. When this is done, consideration must be given to the additional WAGD demand. In many cases, it may be necessary to use a larger pump. The comment in the paragraph above on the use of oxygen compatible lubricants is applicable to this approach as well.

It is wise to recheck pipe and exhaust sizing, electrical capacity and ventilation, especially where a pump is upsized.

Dividing an Existing Dual Use System

When a decision to divide the systems is taken, there are many, many variations in how this might be accomplished. In order to evaluate a decision, you will need the answers for the following:

1. How is your present system organized? Figure 6 illustrates the common layouts. Systems resembling arrangement "A" are very easily and inexpensively divided, and lend themselves best to a dedicated pump. Systems resembling "B" are difficult to divide, but allow a number of options in doing so. In systems resembling "C", the options are many but they all have complications. There will have to be significant repiping, possibly inside ceilings or walls and even inside the ceiling columns, pendants, etc., depending where the WAGD unites with the vacuum piping.
2. Is the objective a complete update of the WAGD system

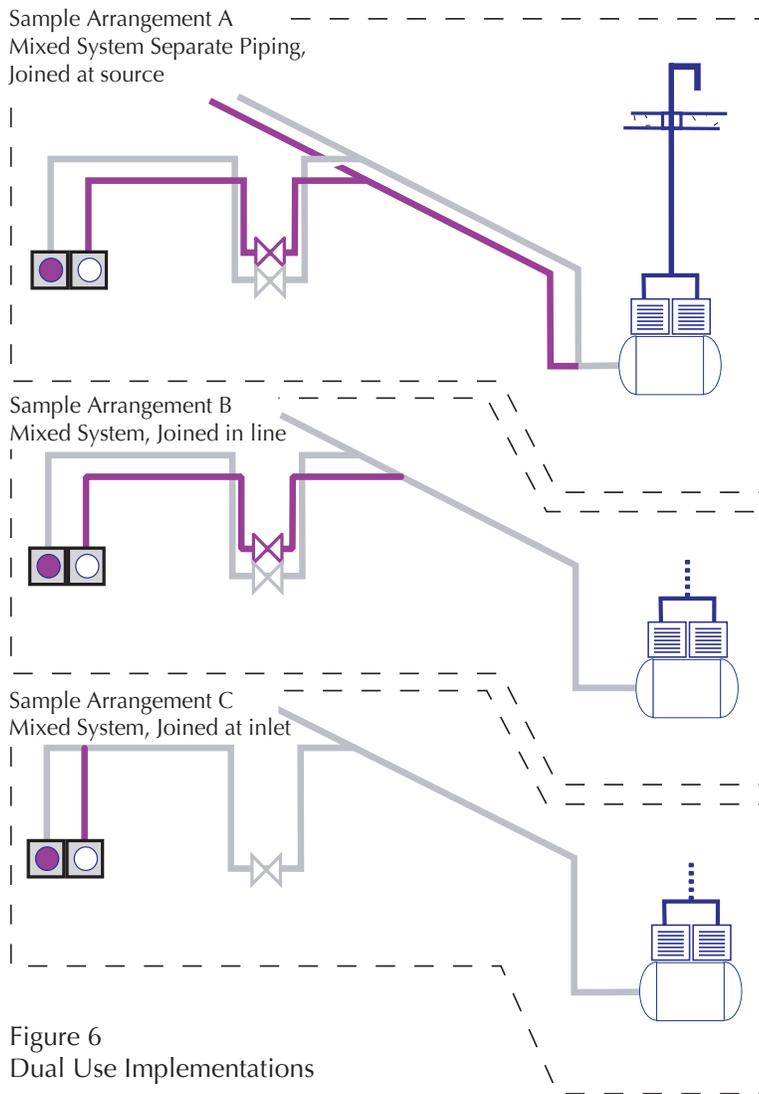


Figure 6
Dual Use Implementations

An Introduction to WAGD System Implementations

We will now examine in detail four of the five acceptable WAGD implementations under NFPA 99, along with some alternative ways they may be implemented. As mentioned previously, we will not deal with Passive implementations.

Dual use Medical Vacuum/WAGD implementations:

Dual use implementations are primarily medical vacuum systems into which the WAGD is introduced, more or less as a “free rider” on the medical vacuum network and pump.

Dual use implementations are high vacuum. The Medical vacuum application will always take precedence when setting pump cut in and cut out. This means the lowest vacuum a WAGD inlet can see is 12 inHgV (305 mmHgV) (per NFPA requirements for medical vacuum) and typical vacuums are 15-29 inHgV (380-760 mmHgV)

Due to the high vacuum, the networks for these systems must be relatively strong. Copper pipe is commonly used.

WAGD terminals look very similar to vacuum inlets except for color, and are nearly identical to vacuum inlets internally. Most significantly, this means that the internal porting is limited, and many WAGD inlets (particularly older ones) may have some difficulty with higher flows.

Piping is typically sized using the same loss tables as are used for vacuum, and valving and alarming generally follows the vacuum rules.

A rare variant on this implementation, which can be employed most simply where the system layout is like Figure 6, Arrangement “A”, is a regulated WAGD line. In these implementations, a regulator is installed in the WAGD line which reduces the top vacuum level to a medium or low vacuum and thus brings the WAGD pipeline closer to the ideal of an intrinsically safe system. Such an implementation requires separate sizing of the WAGD line at the lower vacuum. Copper pipe would still be the preferred material of construction.

to minimize all risks or merely enough to attenuate an immediate fire risk? A complete update will imply changing to a low vacuum methodology (see below “An Introduction to WAGD System Implementations”). An overhaul to reduce immediate fire risk may be much less sweeping. It is of course also possible to do some of both in many circumstances.

3. Are there obstacles outside of the engineering and construction related challenges? Is the anesthesia department aware of the issues and supportive of the improvements? Can they adapt their older anesthesia equipment to operate acceptably with the proposed new WAGD system?

Whether for an existing system upfit or a brand new system, it is important to understand the system options and their respective engineering challenges.

WAGD Implementations

Dedicated WAGD, using a Pump:

Pump-based implementations have in the past generally been run at vacuum levels similar to medical vacuum. Pumps usually selected are designed to run at vacuums of 15 inHgV {380 mmHgV} or higher. However, a variant of this system is a medium to low vacuum system wherein the systems operate more nearly in line with the ideal of an intrinsically safe system. This is achieved by sizing and setting the pumps to lower vacuum settings (e.g. 5-10 inHgV {127-250 mmHgV}) and sometimes also installing a vacuum regulator in line to reduce the vacuum at the inlet. This variant is appropriate only with technologies which are suited to low vacuum operation (liquid ring, dry vane, rotary lobe).

The networks must be designed to handle the full vacuum of which the pump is capable (even though the pump may in fact operate at a lower vacuum normally). Therefore, the networks for these systems must be relatively strong. Copper pipe is most commonly used.

At vacuums 12 inHgV {305 mmHgV} and above, piping would be sized using the same loss tables as are used for medical vacuum, but alternative sizing methods will be required at lower vacuums.

WAGD terminals used at the upper end of the vacuum scale (5 inHgV and higher) look very similar to vacuum inlets except for color, and are nearly identical to vacuum inlets internally. Most significantly, this means that the internal porting is limited, and many WAGD inlets (particularly older ones) may have some difficulty with higher flows. Therefore, at the lower end of the vacuum scale the terminals may need to be of a different type to ensure adequate flow.

Dedicated WAGD, using a Blower:

These implementations achieve all the objectives desired in a WAGD implementation, but typically are the most complex to design and install.

Unlike the two types discussed previously, these systems typically use a regenerative blower as their producer. Whereas a pump is designed to expand the air first (i.e. produce a deep vacuum) and move volume second, a blower is designed to move volume first and produce only a shallow vacuum. In this they more closely resemble a fan than a pump. It is this emphasis on moving lots of air at low vacuums that makes them ideal for WAGD.

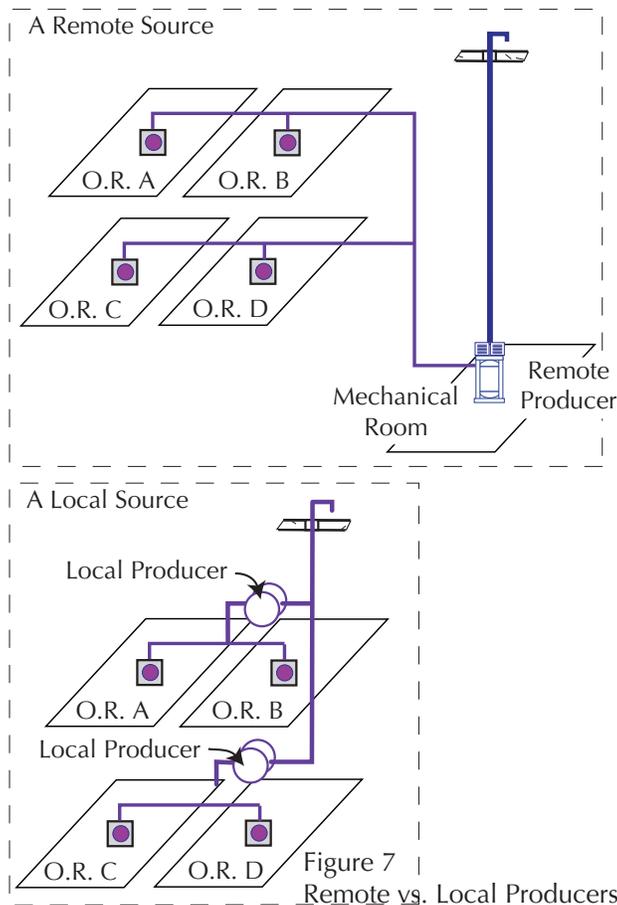
As an example, a liquid ring pump with a one Hp. motor will move 396 lpm (14 scfm) at 5 inHgV (if it could be operated there - most will run up to 28 inHgV). A regenerative blower driven with the same 1 Hp. motor will move 1,245 lpm (44 cfm) at 40 inH₂O V (2.9 inHgV).

This low vacuum creates its own issues. The sizing of the network is immediately different from that used for higher vacuum, and the terminals must be of a different type to pull enough flow at these low vacuums.

However, an important advantage of these low vacuum implementations is that the producer may be located close to the terminals, unlike pumps which typically must be located remotely. A blower (especially a small one) is sufficiently compact and quiet that it can sometimes be placed near the WAGD terminals (e.g. in a ceiling space, a mop closet, etc.)

The network can therefore be minimized. A pump, being typically larger and more noisy must typically be placed at some remove in a mechanical space. The resulting network is longer and potentially more complex. (see Figure 7)

At first glance, it may appear to be more expensive to implement and operate a local system possibly composed of multiple blowers vs. a single large pump. In fact, because blowers are less expensive, smaller, and internally less complex than pumps of similar capacities, the economics often slant in favor of the local implementation.



Low vacuum systems can be piped in a variety of materials. NFPA requires they be metallic and non-corroding, which rules out plastic or iron pipe. However, copper, stainless, and galvanized pipe might be used, as might ductwork and thin wall galvanized because of the low vacuum (an ideal material would seem to be electrical conduit with liquid tight fittings, but so simple an answer may be too exotic to be acceptable in many local jurisdictions). Copper pipe is the most common material.

These systems may require a means to balance the system and are tested in a somewhat different manner to high vacuum systems.

WAGD using Distributed Producers:

These implementations are in many ways the simplest, but have not been seen in the North American market and are thus unfamiliar. They tend to be relatively expensive to install because two separate piping networks are required.

Conceptually, they involve no central producer but instead use a venturi actually in each inlet. The venturi is intrinsically capable only of low vacuum.

The venturi must be served by an air line, and medical air is not permitted to be used for this service. Instrument air is ideal, but at this writing relatively few facilities have instrument air systems. Once the venturi is served by an appropriate air source, the exhaust must also be routed to the outside and sized.

The exhaust side may be made of pipe suitable to the pressure. Copper would be typical. There are no alarms which can practically be installed. Each inlet is individually controlled, and must have an operating indicator of it's own.

All WAGD implementations except the distributed producer styles share the same basic requirements as to the location of terminals, alarms, etc. All WAGD implementations share the same basic requirements as to the discharge from the building. Specific details of how these items operate will vary by implementation. We will consider the universal requirements here and then deal with the necessary variations under each specific implementation.

WAGD Selection

What factors should be weighed when selecting a WAGD implementation? There are several, and the weighting to be given to each will vary from facility to facility. They include:

1. *Effectiveness.* Will the system do the job of keeping the workspace free of waste gas? Efficacy usually has less to do with the type of system selected than the design and installation of the system, as all the implementations described herein are perfectly capable of being effective if well designed.

2. *Patient safety.* Will the system protect the patient and ensure the anesthesiologist's control of the procedure? Here, the low vacuum implementations are to be preferred over the high vacuum implementations due to the intrinsic safety implied in a lower vacuum.

3. *Cost.* Which system is least expensive to implement and operate? Evaluating this is complex and the result varies dramatically between facilities. In general, low vacuum systems are less expensive than are high vacuum systems. Low vacuum systems are also typically lower maintenance than are high vacuum systems.

However, an assertion often made in favor of dual use implementations is that WAGD dumped into a medical vacuum system is "free", since the medical vacuum "has to be there anyway". When the average WAGD inlet only flowed 6-9 liters, there were many cases where this was at least in part true. With WAGD flowing at 50 liters (1.8 scfm), it is true far less often. The additional capacity required and the additional operating hours mean that the cost of WAGD produced by a medical vacuum pump is considerably higher than has been assumed.

A simple rule of thumb test can be applied: Size the medical vacuum system without WAGD and select a pump of appropriate capacity. Add in the WAGD requirement (use at least 1.8 scfm per location). If the pump selected has sufficient capacity to handle the additional volume, an argument can be made that the WAGD produced is "free" or at least low cost. If the pump selected does not have the necessary excess capacity, and thus to accommodate the WAGD a larger pump must be selected, a properly selected dedicated system will almost certainly be less expensive. This is especially true when a low vacuum system is used for comparison. Remember that a horsepower of pump will move approximately 15 scfm, whereas a horsepower of blower will move approximately 44 scfm, a ratio of roughly 3:1.

4. *Technology.* Is the technology otherwise preferred for the medical vacuum source acceptable for WAGD? If not, can another option be equally acceptable? In some cases a technology otherwise preferred for use with medical vacuum may be oxygen sensitive, and there is not an equally acceptable oxygen compatible alternative. Naturally this will restrict the potential

General Requirements

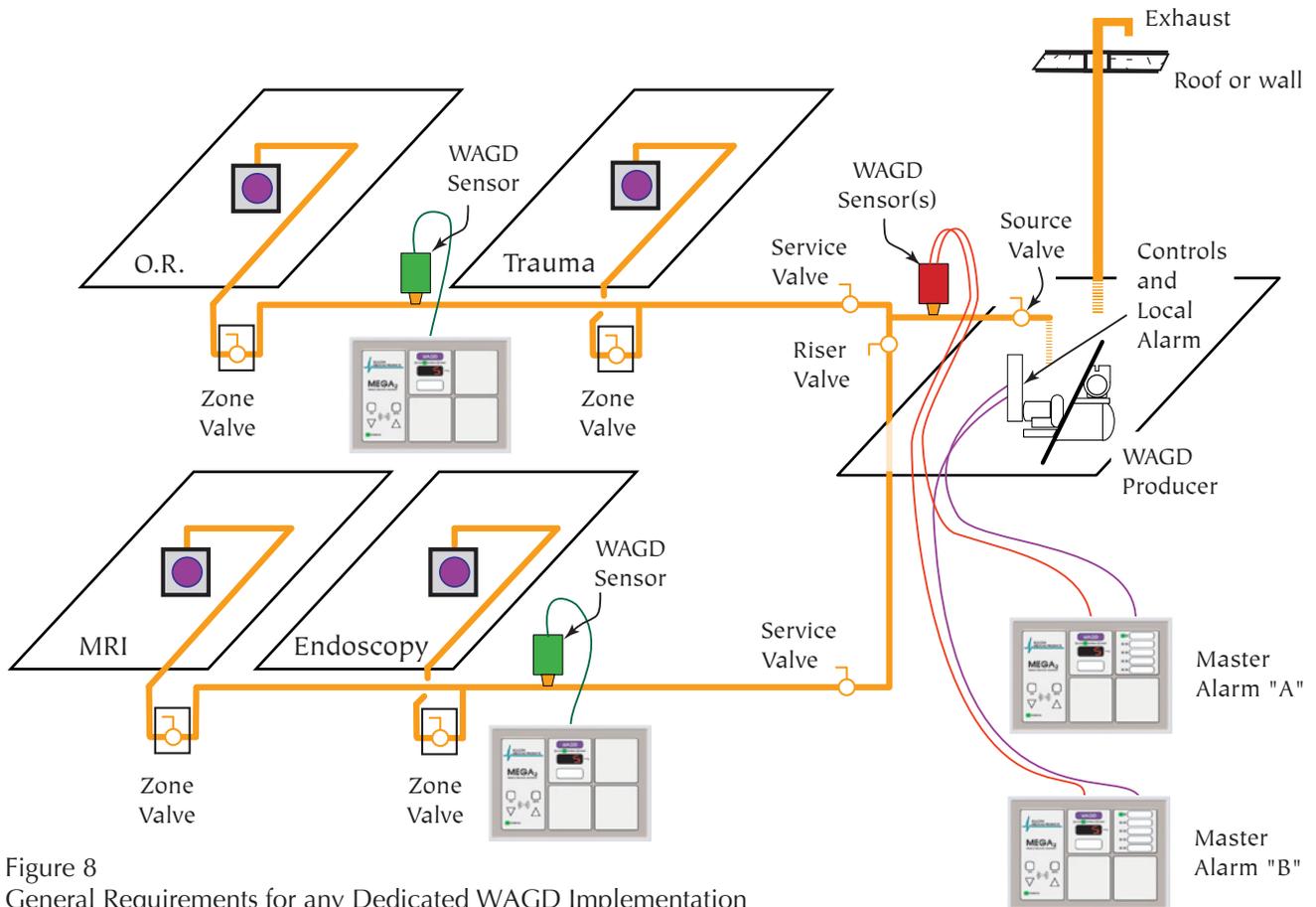


Figure 8
General Requirements for any Dedicated WAGD Implementation
(diagram is for general illustration only - requirements for specific occupancies vary)

for dual use. The same limitation may also render unacceptable pumps otherwise preferred in a dedicated pumped system. In such a case, the limited technology options may be a powerful argument in favor of a low vacuum alternative.

5. *Design complexity.* How difficult is the system to design and what are the chances of problems resulting from bad design? Whatever can be said against a dual use system, they are undoubtedly among the simplest to design. Correspondingly, low vacuum dedicated systems offer the greatest range of advantages for the user, but are probably the most complex to design and are also outside the experience of most North American designers. Low vacuum dedicated systems are also the most complex to commission.

WAGD Design : General Requirements

(Reference Figure 8)

NFPA 99 states that a unique, dedicated WAGD terminal should be placed wherever nitrous oxide or halogenated anesthetic is intended to be administered (13.3.5.2, 14.3.5.2). This will obviously include any

location piped with nitrous oxide. Consideration should also be given to areas which are not traditionally piped with nitrous, but where nitrous oxide mounted on the anesthetizing machine can reasonably be expected to be used. Common examples of these locations are CAT/MRI/PET scan rooms, lithotripsy, exam/treatment rooms, trauma rooms and other locations where patients are routinely sedated or anesthetized. Other areas which should receive consideration might include laboratories where veterinary anesthesia will occur, dental clinics and OB/Labor where nitrous oxide/oxygen self administration is practiced. WAGD terminals may also need to be placed in areas such as recovery, where exhaled anesthesia from recovering patients must be considered and the staff protected.

All dedicated WAGD producers are required to be duplex wherein one unit must be sufficient to serve the system, and a second of equal size is ready to operate in the event of any inadequacy in the first. A local alarm indicating Lag WAGD producer in service must be included and relayed to the master alarm. The WAGD producer is required to include a source valve.

Exhausts from the producer must exit the building, discharging at least 10 feet from any opening in the building, at a vertical level different from any air intake (preferably at a lower level) and in the a location which is open and permits free dispersion of the waste gas.

Electrical power must be from the essential electrical system, equipment branch.

Centrally piped WAGD is required to be valved like any other medical gas or vacuum system. Valves may be either ball or butterfly type. Required valves include: Source valve, main valve (in a limited number of circumstances), riser valves, service valves and zone valves.

WAGD inlets must be separate from and non-interchangeable with the vacuum inlets (even if they ultimately are piped to the same source). WAGD has it's own color code (White letters on violet). Many older WAGD or Evacuation inlets were "one way" interchangeable (you could plug vacuum into Evacuation, but not Evacuation into vacuum). This is no longer permitted and such inlets should be retrofitted to bring them up to standard.

The master alarms for a piped WAGD system will include at least an indicator for "Low WAGD" and an indicator for "WAGD Lag Producer Running"

Any area fitted with piped WAGD requires a WAGD area alarm at the nurses station just like any other medical gas. It will typically be piped into the line upstream of the anesthetizing location zone valve.

Distributed WAGD may be considered exempt from some of these requirements, but others may need to be fulfilled in unusual ways. As an example, while it is impractical to alarm a venturi, it is appropriate to alarm the drive air so that the facility knows if the WAGD is inoperable. It is necessary to observe intent in these cases and to ensure the essential functions are present even if it is necessary to use different methods to achieve the result.

Common Questions

Q. *How do I know if my current WAGD system is O.K.?*

A. You should always be concerned if your WAGD goes through a pump containing oil (if it does, see below). With any other type of pump the most important test is the periodic test for trace gases in the O.R. If you are passing this test without any problem, then the chances are very good your system is doing it's job. If you are failing the

trace gas tests or struggling to pass, then action must be taken to make the system work better and you can follow the guidance in this pamphlet to evaluate your options. Notwithstanding how you make out on the trace gas tests, check for excessive run time at the vacuum pump. If your vacuum pump is running hard or can't keep up with demand, this may be because the WAGD requirements have begun to run away.

Q. *Should I be concerned if my present WAGD pump contains oil?*

A. You should always be concerned if your WAGD goes through a pump containing oil. It is very strongly advised that you take some action to mitigate the possibility of oil and oxygen mixing in such pumps.

Q. *We're about to get some new anesthesia machines. Can I pretest my WAGD?*

A. Yes. If your WAGD goes through a pump containing oil you should immediately look to make changes. With other pumps, you can check the pump's spare capacity by simply timing it's operating cycle. In addition, you must test each WAGD inlet for inflow capacity of at least 50 lpm (1.8 scfm). The test in Annex A is the test required in the EN 737-2 standard, and will be useful in determining if your current inlets operate in the required flow range.

Q. *We run our ICU ventilators on air, can't we do that with the anesthesia ventilators?*

A. Yes, if medical air is piped to all your O.R.s and has sufficient capacity, the anesthesia machines can be modified to run off medical air. (see page 12)

Q. *Does pipe and fittings used for WAGD service need to be cleaned for oxygen service?*

A. No. They must be treated according to the same rules as apply for vacuum. However, use of cleaned pipe and fittings is always to be recommended.

Q. *Does all my WAGD have to be on a single system?*

A. No. In fact, with multiple areas of the facility being involved, it is often easier and less expensive to implement a separate, purely local WAGD system for each area. This same principle applies with distributed WAGD.

Q. *I have an older WAGD system implemented through ductwork and run with a fan. Do I have to replace it?*

A. Not if it is working (i.e. as demonstrated by passing periodic trace gas tests). These "semi passive" systems are sometimes quite adequate and there is certainly no

Sources & Annex A - Testing

reason to replace a working system. If your trace gas tests are coming up clean, then the system can be continued in use without concern. If you find the tests are getting hard to pass, then you will have to consider an active WAGD. Be aware that some of the newer anesthesia systems do need “pull” (i.e. a slight vacuum) at the WAGD inlet, and that these semi-passive systems may not have enough “pull” to be effective with EN compliant interfaces.

Q. *Can I use plastic pipe for WAGD?*

A. There is no problem with plastic in terms of the gases or sizing, but plastic pipe is not allowed by NFPA 99 or most local jurisdictions in commercial occupancies.

Q. *With a change to my WAGD system do I have to re-verify?*

A. Yes. A change to a WAGD system needs to be handled like a change to any medical gas system.

References

American Institute of Architects Academy of Architecture for Health Facilities Guidelines Institute
1919 McKinney Ave.
Dallas, TX 75201
www.aia.org

BeaconMedaēs
www.beaconmedaes.com

British Standards Organization
389 Chiswick high Road
London W4 4AL United Kingdom
www.bsi.org.uk

European Committee for Standardization (CEN)
Rue de Stassart 36
B-1050 Brussels, Belgium
www.cenorm.be

Medical Gas Professional Healthcare Organization
(*The Scott study cited in this paper (p. 6) will be found on this website in the “Forum” section.*)
www.mgpho.org

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269
www.NFPA.org

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Annex A

Testing a WAGD Inlet

The EN 737-2 standard gives a very simple and effective method for the testing of an inlet and also for the testing of the WAGD system. The device required is illustrated in Figure 9.

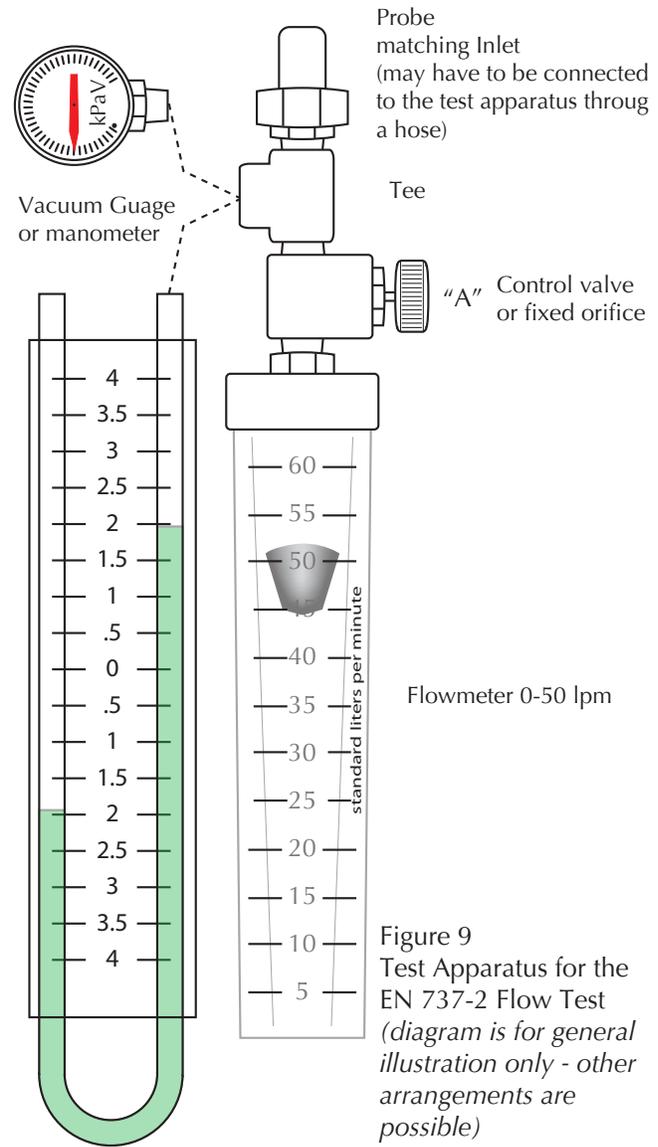
The procedure is very simple and might be applied to any WAGD terminal. You may expect some odd results when applying this test to standard WAGD inlets, as the EN Standard assumes a low vacuum implementation is in use. Nevertheless, it is possible for a high vacuum implementation to function within the parameters of the test.

The test is conducted at very low levels of vacuum (1kPa and 2 kPa {4 inH₂Ov - 7.9 in H₂Ov or 0.3 inHgV - 0.6 inHgV}). If you intend to test a high vacuum inlet, be aware that the gauge used in this test is extremely precise and probably delicate. It may therefore be ruined if exposed to high vacuums. Check the specification for the gauge you intend to use prior to using it and ensure it can handle the maximum possible vacuum in the system as well as be accurate in the range required by the test.

The test apparatus consists of:

1. A flowmeter which can measure at least between 25 and 50 lpm. An appropriate device might be a 0-60 lpm rotometer open at one end and having a threaded outlet at the other.
2. A metering valve with as wide an opening (a high C_v) as is available. It is not particularly important that the valve be capable of highly precise control but it is essential that the valve not make the test impossible to perform by too great an internal resistance. It is also possible to do the test very accurately with fixed orifices rather than a valve if the vacuum in the system is known and does not fluctuate widely.
3. A vacuum gauge accurate at 1kPa and 2 kPa {4 inH₂Ov and 7.9 in H₂Ov or 0.3 inHgV and 0.6 inHgV}. This may be an actual water column in a low vacuum test.
4. A probe or adapter matching the inlets.
5. Hardware as needed to assemble the components as shown. It is important to minimize the internal resistances in the test device, so selection of the components should be made with care. Larger fittings are always better.

To test a WAGD inlet, follow the decision tree in Figure 10.

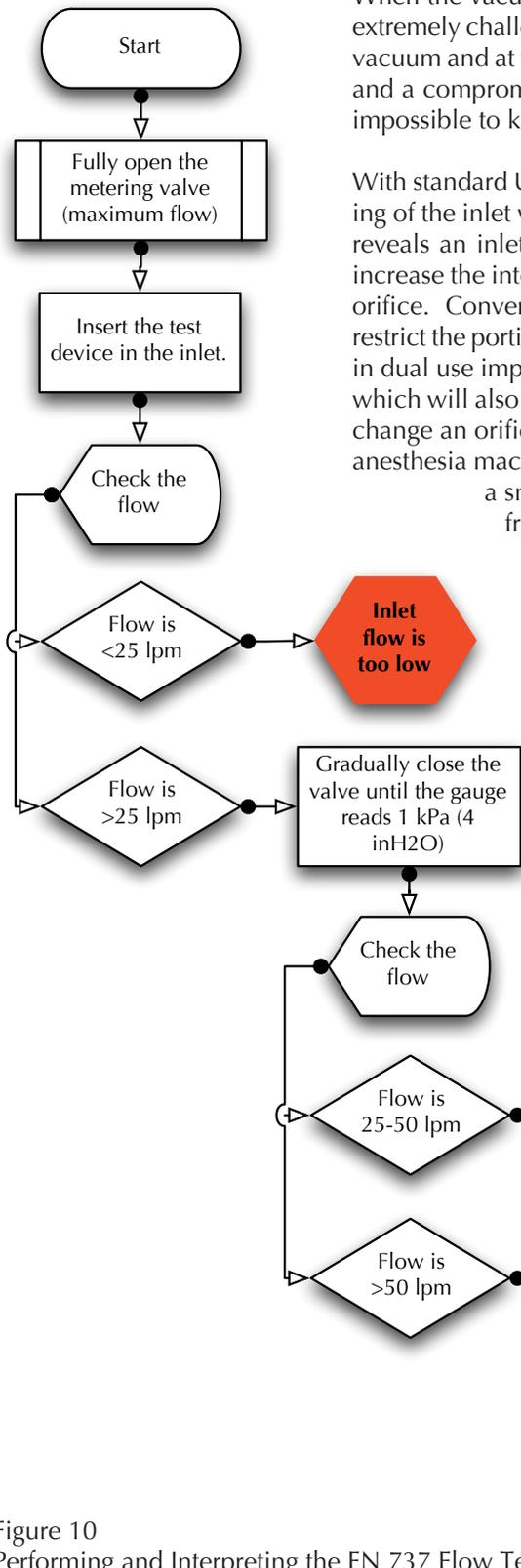


When a test reaches one of the stop signs in Figure 10, it helps to understand that the EN views the inlet as in essence an orifice. The vacuum on the pipeline side is (or should be) known and relatively stable (this is an important point, as the very large swing in vacuum level common in many dual use and pumped dedicated systems may alone be the reason they may not pass the test.) The inlet itself can then act as a controlling orifice, and inlets designed to the EN standard often actually physically contain an orifice.

As an example, in a low vacuum system, the vacuum level in the piping is controlled to 5 inHg. This inlet contains an orifice calculated to admit 50 lpm at 5 inHgV. When the flow test instrument is in place, a "drag" is placed on the inlet of 1 kPa or 4 inches of water column, and the inlet must flow 50 lpm or less. Increasing the "drag" to 7.9 inches of water column, the inlet must flow greater than 25 lpm.

Annex A - Testing

In a system like the example above, when an inlet has too little flow, it is relatively simple to enlarge the orifice in the inlet and increase the flow. If the flow is too great, a smaller orifice can be substituted. Since the system is consistent in vacuum level, the adjustments are very straightforward.



When the vacuum level in the system is not consistent, these adjustments become extremely challenging, involving the balancing of the inlet performance at the lowest vacuum and at the highest vacuum. Thus every inlet must be tested at two vacuums and a compromise orifice fitted. If the variation in vacuum is too great, it may be impossible to keep the inlet within the flow requirements of the EN standard at all.

With standard U.S. style inlets (designed for high vacuum service), the internal porting of the inlet will also act as an orifice (albeit a rather inconsistent one). If testing reveals an inlet which cannot provide sufficient flow, then it may be possible to increase the internal porting in the inlet and thus effectively open up the controlling orifice. Conversely, if an inlet exceeds the permissible flow, it may be possible to restrict the porting in the inlet, thus reducing the flow. It may also be possible (except in dual use implementations) to reduce or increase the vacuum level in the system, which will also influence inlet flow. In extreme cases, it may be necessary to add or change an orifice in the probe or interface, which will require the assistance of the anesthesia machine manufacturer. At least one manufacturer of interfaces includes a small flowmeter with an adjustable valve which acts to gate the flow from the interface when using a high vacuum inlet. This is another means of dealing with the control of the flow from the interface which could be implemented with any high vacuum system.

There is an additional test which is not required by the EN Standard but is highly recommended. This is the system test. In a system test, all inlets are opened to a calibrated flow and then each inlet is tested as described previously. The result assures that each inlet conforms to the flow specification when the entire WAGD system in operation. This test will identify design flaws and piping problems that would ordinarily never be seen when testing only inlets.

The system test simply requires a calibrated probe be inserted in each inlet while the inlet flow test is conducted. Each probe is calibrated to flow 25-50 lpm, placing the entire design load on the system.

Figure 10
Performing and Interpreting the EN 737 Flow Test



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