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GAS STREAM PURIFIER

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ABSTRACT

A gas stream purifier has been developed that is capable of removing corrosive acid, base, solvent, organic, inorganic, and water vapors as well as particulates from an inert mixed gas stream using only solid scrubbing agents. This small, lightweight purifier has demonstrated the ability to remove contaminants from an inert gas stream with a >99% removal efficiency. The Gas Stream Purifier has outstanding market and sales potential in manufacturing, laboratory and science industries, medical, automotive, or any commercial industry where pollution, contamination, or gas stream purification is a concern. The purifier was developed under NASA contract NAS 9-18200 Schedule A for use in the international Space Station. A patent application for the Gas Stream Purifier is currently on file with the United States Patent and Trademark Office.

INTRODUCTION

Due to the high cost of using the Space Shuttle as a refueling vehicle for the international Space Station, a supplemental reboost system (SRS) was designed to augment the primary hydrazine propulsion system. The SRS collects waste gases generated from the Space Station laboratories, compresses and stores them at high pressures (1000 psi), and vents them through heated resistojets to provide extra reboost capability for the Space Station. Implementation of the SRS provides a savings of 3500 pounds of propellant per year and reduces the number of refueling shuttle launches by 1/3. The mixed waste gas produced by the Space Station laboratory modules is composed primarily of nitrogen, air, inert gases, oxygen and carbon dioxide. The mixed waste gas will also contain a wide variety of trace contaminant vapors and particulates generated from experiments performed in the laboratory modules (Table 1). The high pressure storage of mixed waste gases containing an uncertain mixture of chemical contaminants has caused grave concerns in regard to material reliability, corrosion, and stress corrosion cracking of hardware in the high pressure areas of the system. One method of alleviating these concerns was to remove the chemical contaminants from the mixed waste gas stream prior to entering the system. A gas stream purification unit was developed to remove corrosive acid, base, solvent, organic, inorganic, and water vapors as well as particulates from the mixed gas stream in one step using only the gas flow across the purifier. Because of Space Station weight, space, pressure drop, and dew point requirements and the zero gravity environment, commercial aqueous scrubbers could not be used. The Gas Stream Purifier (GSP) was designed to be small, lightweight, utilize solid scrubbing agents, and maintain a less than 2 psi pressure drop across the unit at flow rates up to 24L/min.

Table 1
Possible Waste Gas Contaminants

Acetic Acid	Carbon	Formaldehyde	Indium	Methanol	Silver Nitrate
Acetone	Tetrachloride	Freon	Iodine	Methyl Ethyl	Sodium Acetate
Acetylene	Chlorine	Gallium	Isopropyl	Ketone	Sodium Chloride
Aluminum	Chromic Acid	Arsenide	Alcohol	Nitric Acid	Sodium
Aluminum	Cobalt	Germanium	Lactic Acid	Oxalic Acid	Hydroxide
Oxide	Copper	Glycerol	Lead	Perchloric Acid	Sodium Nitrate
Ammonia	Copper Nitrate	Hydrochloric	Lithium	Phenol	Sulfuric Acid
Ammonium	Dimethyl	Acid	Magnesium	Potassium	Toluene
Hydroxide	Sulfide	Hydrogen	Chloride	Dichromate	Trichloroethylene
Ammonium	Ethanol	Iodide	Mercuric	Potassium	Trichloroethane
Chloride	Ferric Chloride	Hydrogen	Chloride	Permanganate	Xylene
Benzene	Fluorine	Peroxide	Methane	Silicon	Zinc Chloride

CONCEPT DESCRIPTION

The Gas Stream Purifier (GSP) prototype unit measures 15 inches in length by 2 inches in diameter (Figure 1). The Gas Stream Purifier from its gas stream input end serially through its output end consists of a stepwise arrangement of medium-coarse grade solid scrubbing agents designed to remove a wide variety of chemical contaminants. Particulates in the gas stream are removed by a particulate trap at the entrance of the purifier and a particulate filter at the exit end of the unit. Gas purification is performed by a series of purification stages inside the unit. Stage 1 of the purifier removes water vapor and large organic molecules. Stage 2 of the purifier removes water vapor and other small chemical contaminant molecules. Trapped water vapor also facilitates the removal of additional chemical contaminant vapors. Stage 3 of the purifier removes organic solvents and many other chemical compounds. Stage 4 removes inorganic and organic acid and base vapors by reaction, generating CO_2 and water, and transforming the stage 4 compound into salts. Stage 5 removes inorganic and organic acid and base vapors, ammonia, sulfur dioxide, and other chemical contaminant vapors by reaction, generating CO_2 and water, and transforming the stage 5 compound into salts. As an option, a 6th stage can be added to the purifier to remove a specified contaminant from a known process. Each purification stage is separated from the next by a layer of glass wool. Following stage 5 (or 6) the gas stream passes through another series of stage 3, stage 1, and stage 2 at the exit end of the purifier (Figure 1). The final three stages ensure complete removal of solvent contaminant vapors, and any water vapor generated by the central stages of the purifier. The pure dry gas exits the purifier through a particulate filter. The purification stages of the Gas Stream Purifier can be modified in quantity or substance to to meet different contaminant removal applications. The Gas Stream Purifier will remove chemical contaminant vapors and particulates from any inert gas stream, or any mixed gas stream consisting of air, nitrogen, inert gases, carbon dioxide, hydrogen, or oxygen. The Gas Stream Purifier will remove corrosive acid, base, solvent, organic, inorganic, and water vapors as well as particulates from an inert or mixed gas stream in one step using only the gas flow across the purifier. The purifier is not consumed by carbon dioxide or oxygen. The 15" by 2" diameter prototype purifier weighs 4.2 pounds, and has a less than 2 psi pressure drop across the unit at flow rates up to 24 L/min. The purifier is effective in removing chemical contaminants at levels from <1 to 10,000 ppm

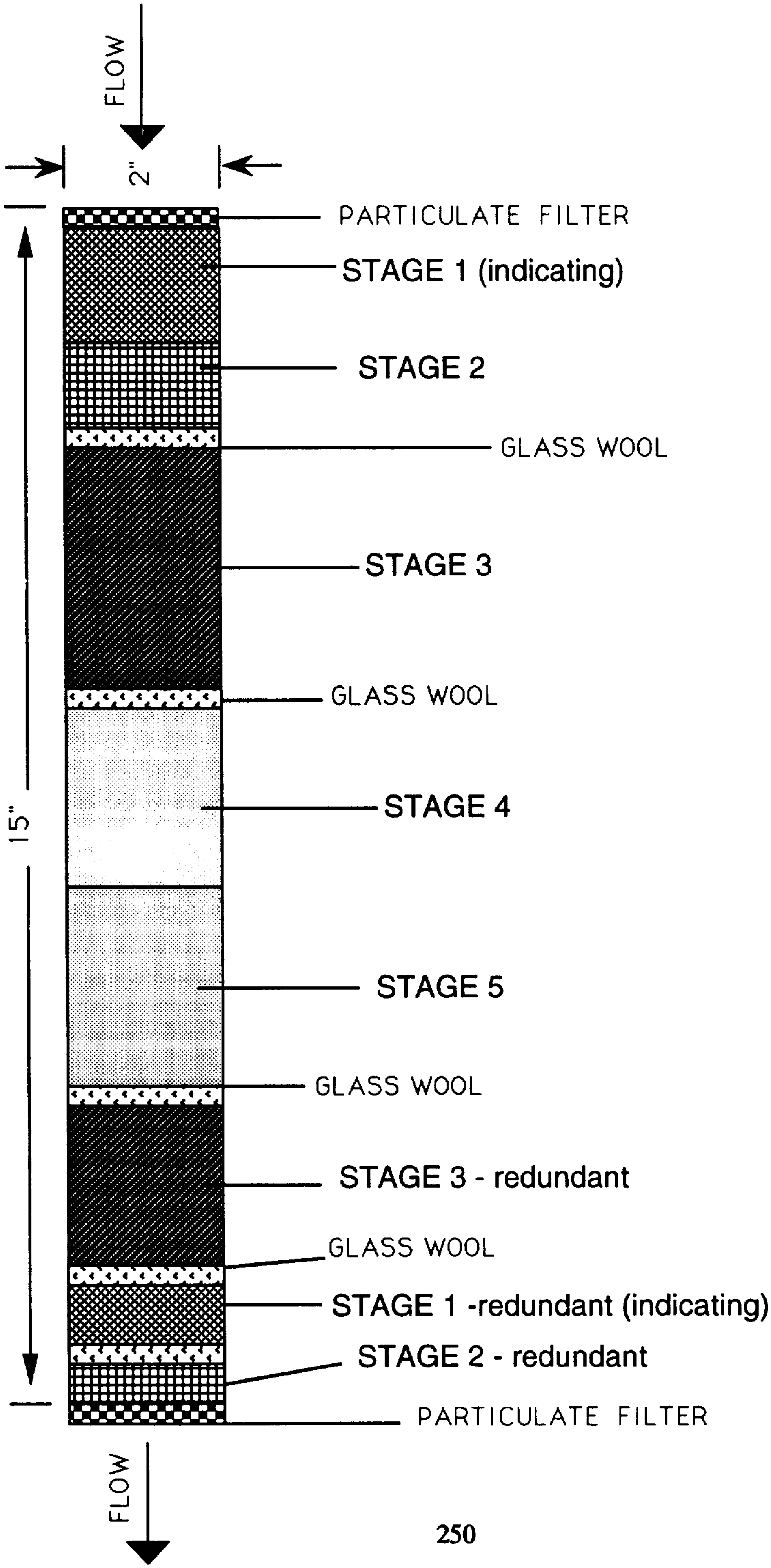


FIGURE 1 - GAS STREAM PURIFIER

with a >99% removal efficiency, and is designed to last for periods of 2-4 months or longer depending on the levels of contamination seen. After the purifier has been exhausted, the contents can be disposed of or regenerated. The cannister can be repacked with new purification stages and used again. The Gas Stream Purifier can be configured in different sizes and scaled up to meet higher contaminant removal and flow rate requirements.

TESTING

Pressure Drop Testing

Pressure drop testing was performed on the Gas Stream Purifier using the apparatus shown in Figure 2. The flow rate of a nitrogen gas stream circumventing the purifier was set and the corresponding back pressure was recorded with a calibrated Seeger Precision Pressure Transfer Standard pressure gauge. A valve leading to the gauge was closed and a valve at the exit end of the purifier was opened. The flow rate through the purifier was reset and the corresponding pressure drop across the purifier was recorded. Pressure drop measurements were taken for a tightly packed and loosely packed purifier at flow rates of 7 and 24 L/min. As the flow rate across the purifier increased the pressure drop also increased. The Gas Stream Purifier pressure drop tests yielded a pressure drop of 0.3 psi at a flow rate of 7 L/min for a loosely packed purifier constructed with medium-coarse grade materials. A pressure drop of 1.8 psi was observed for this same purifier at a higher flow rate of 24 L/min. A tightly packed purifier of the same configuration had a pressure drop 0.7 psi at a flow rate of 7 L/min and a pressure drop of 4.0 psi at a flow rate of 24 L/min. A tighly packed purifier containing fine mesh materials will have a much greater pressure drop than a loosely packed purifier with coarse mesh materials. The trade off is that finer mesh materials provide more surface area and thus more reactivity and will contribute to a longer lasting unit. Although coarse materials have less surface area than fine materials, they do not restrict flow as much and are less prone to channeling effects. By using medium-coarse grade materials of the same mesh size for each of the purification stages, where possible, and packing the purifier using only gravitational forces, the pressure drop vs surface area trade off can be optimized. Increasing the inlet and outlet line sizes and diameter of the purifier will also decrease the pressure drop and allow for a higher flow rate across the unit.

Efficiency Testing

Efficiency testing was performed on the Gas Stream Purifier using the apparatus shown in Figure 3. A solution containing the contaminant to be measured was placed in an impinger. Nitrogen gas was bubbled through the solution and the vapor generated was run through a line circumventing the purifier at a flow rate of 24 L/min. This gas/vapor mixture was tapped off into another line where a Drager Tube specific to the contaminant being measured was placed in line with a wet test meter. The wet test meter measured the quantity of gas being passed through the Drager Tube. A reading corresponding to the part per million (ppm) level of contaminant being generated was taken and recorded. The valve leading into the the purifier was opened, and the valve on the line circumventing the purifier was closed, forcing the contaminated gas stream through the purifier. The flow rate was reset to 24 L/min and after a few minutes of flow another reading was taken with a new Drager Tube. This reading corresponded to the amount of contaminant not being consumed by the purifier, or the contaminant ppm level after purification. A percent purification efficiency for the Gas Stream Purifier for each contaminant tested was calculated by taking the ppm level after purification, and dividing by the ppm contaminant level prior to purification, subtracting this number from 1, and multiplying by 100. The Gas Stream Purifier was tested for purification efficiency with hydrochloric acid, ammonium hydroxide, methyl ethyl ketone (MEK), xylene, isopropyl alcohol (IPA), ethanol, acetone, and trichloroethylene. The same purifier was used for all of the efficiency tests without replacing any of the purification stages.

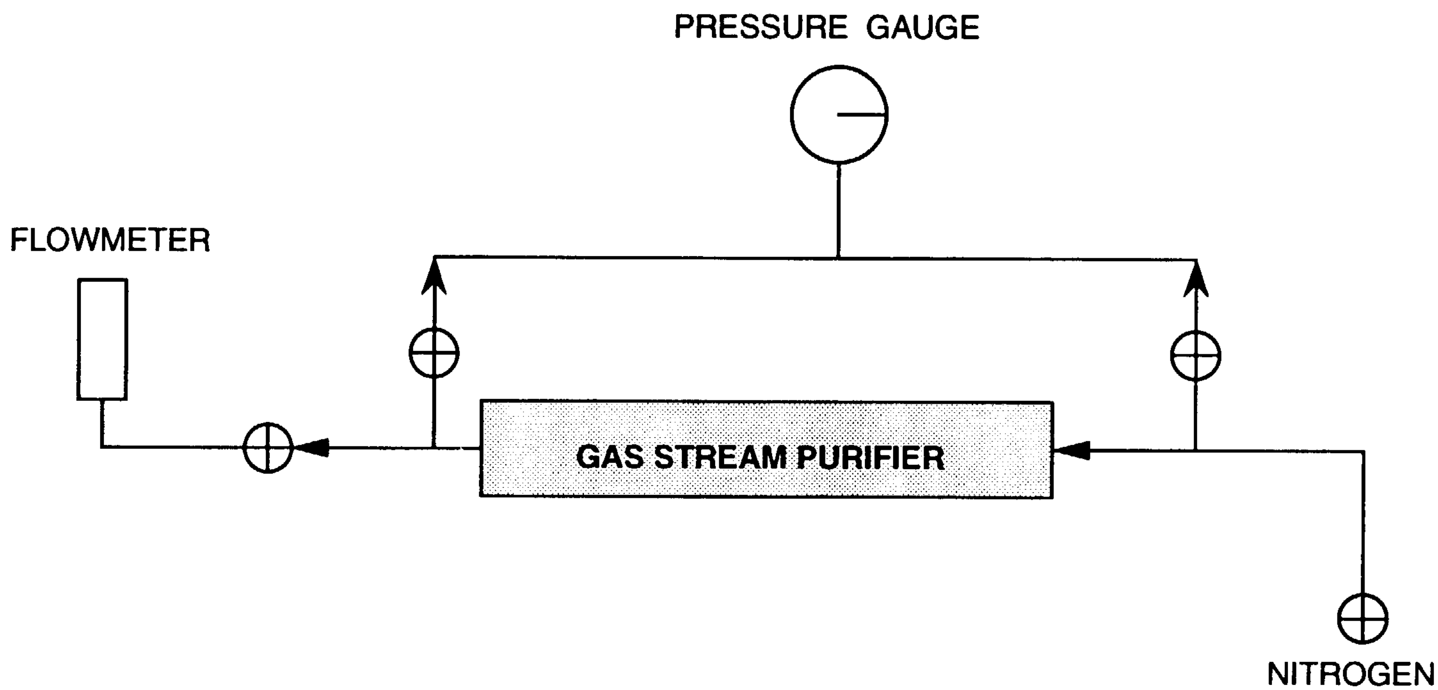
The results of the Gas Stream Purifier efficiency tests are listed in Table 2. The purifier demonstrated a removal efficiency of 99% or more for each of the chemical contaminants tested. Although contaminant levels in the Space Station mixed waste gas are anticipated to be in the 10-50 ppm range, the ability of the purifier to remove large slugs of contaminants in the case of accidental spillage was also demonstrated during the efficiency tests. Most of the testing was performed at a flow rate of 24 L/min, a worst case flow for the Space Station SRS. After this testing was performed a purifier was constructed that can handle flow rates up to 3 CFM (85 L/min). At lower flow rates removal efficiency will be sightly improved over experimental values due to increased contact time of the gas stream with the purification stages. During the efficiency testing no chemical reactivity of the purification stages with the reagents tested was observed, with the exception of the stage 4 and 5 reactions with the acid and base vapors which were part of the design. These reactions transform the stage 4 and 5 compounds into salts, and generate CO_2 and water along with a small amount of heat. Contaminant breakthrough of the purifier was tested by flowing nitrogen through the purifier for two hours after the efficiency tests were completed, and checking for breakthrough with new Drager Tubes. No breakthrough of contaminants was observed following the efficiency tests.

Duration Testing

Duration testing was performed using the apparatus shown in Figure 3. Hydrochloric acid was chosen as the contaminant due to its highly corrosive nature. A HCl solution was prepared and placed in the impinger. The solution generated 350 ppm of HCl vapor by volume when measured with a Drager Tube and a wet test meter at a flow rate of 24 L/min. A new Drager Tube was placed in the apparatus and the 350 ppm HCl vapor nitrogen stream was run through the Gas Stream Purifier for 16 hours at a flow rate of 24 L/min until a reading was finally observed on the Drager Tube. Purifier duration times were calculated based upon 5 and 20 ppm levels which are more representative of the contaminant levels that the purifier will see in actual usage. Theoretical values were calculated for the consumption of HCl by the stage 4 and stage 5 compounds based on stoiciometric calculations. At a 350 ppm HCl contaminant level, the purifier lasted 16 hours, which was 12.12% of the calculated theoretical value. There are two reasons why the actual consumption was only a fraction of the theoretical consumption. The first reason is the high flow rate at which the duration test was run. A lower flow rate will increase the amount of contact time of the contaminant with the purification stages, thus consuming more of the contaminant, which will increase the amount of time before breakthrough occurs. The second reason is surface area. Theoretical calculations were based on a total weight of purification stages 4 and 5, when in reality, the HCl vapor was only reacting with the outside surfaces of the particles in these stages. Thus, particle size and surface area are the limiting factors in determining solid purifier duration. Duration values for HCl were calculated for anticipated ppm contaminant levels based on a flow rate of 24 L/min. At 20 ppm the purifier should last for 281 hours of constant usage or 35 days based upon 8 hours of laboratory work with HCl per day. At 5 ppm the purifier should last for 1124 hours or 140 days. If the contaminant to be removed from the gas stream is known, the appropriate purification stage of the Gas Stream Purifier can be increased in quantity to promote a longer lasting purifier.

COMMERCIAL APPLICATIONS

The Gas Stream Purifier has outstanding market and sales potential in manufacturing, laboratory and science industries, medical, automotive, or any commercial industry where pollution, contamination, or gas stream purification is a concern. The Gas Stream Purifier can be implemented in a variety of commercial applications by simply resizing or reconfiguring the basic prototype unit to fit a particular application. The Gas Stream Purifier can be used to purify compressed gases, or it can be used to remove contaminants generated in an industrial manufacturing process. The Gas Stream Purifier is effective as a process tool in waste stream reduction and can also be configured as an air purification or smog removal system for homes, offices, and buildings. The advantages of the Gas Stream Purifier over presently known devices are numerous. Most gas scrubbers are large, heavy industrial units which use water as the scrubbing agent. Other known devices are capable of removing only one type of contaminant. Small lithium based gas purifiers used for instrumentation also react with oxygen and CO_2 and thus cannot be exposed to air. In applications that require a dry gas or low dew point, small size, and/or low weight, commercial aqueous scrubbing units are not feasible. The Gas Stream Purifier is able to remove many types of chemical contaminants (acid, base, solvent, inorganic, organic) without using aqueous scrubbing agents. Contaminants are effectively removed by using the gas flow through the purifier. The Gas Stream Purifier is small in size, lightweight, moveable, and can be plumbed into any existing system. The purifier maintains a low pressure drop, is not consumed by CO_2, oxygen, or air, and will effectively remove contaminants for a period of 3-4 months. By manifolding 2 or 3 purifiers together, change out can be accomplished by simply turning a valve. The purifier removes chemical contaminants at high and low contaminant levels with a >99% removal efficiency, and is an excellent safeguard against large contaminant mishaps in systems. The purification stages of the Gas Stream Purifier are composed of low cost solid materials, so that the purifier can be produced at a low cost and sold at a competitive price. The Gas Stream Purifier can be configured in different shapes and sizes to suit different applications, and the purification stages can also be scaled up or down to meet the individual customers' specific needs.



	COARSE MATERIALS LOOSELY PACKED		COARSE MATERIALS TIGHTLY PACKED	
	1.44 lb/hr 8.39 L/min	4.1 lb/hr 23.9 L/min	1.44 lb/hr 8.39 L/min	4.1 lb/hr 23.9 L/min
ΔP = PSI	0.3	1.8	0.7	4.0

FIGURE 2 - GAS STREAM PURIFIER - PRESSURE DROP TESTING

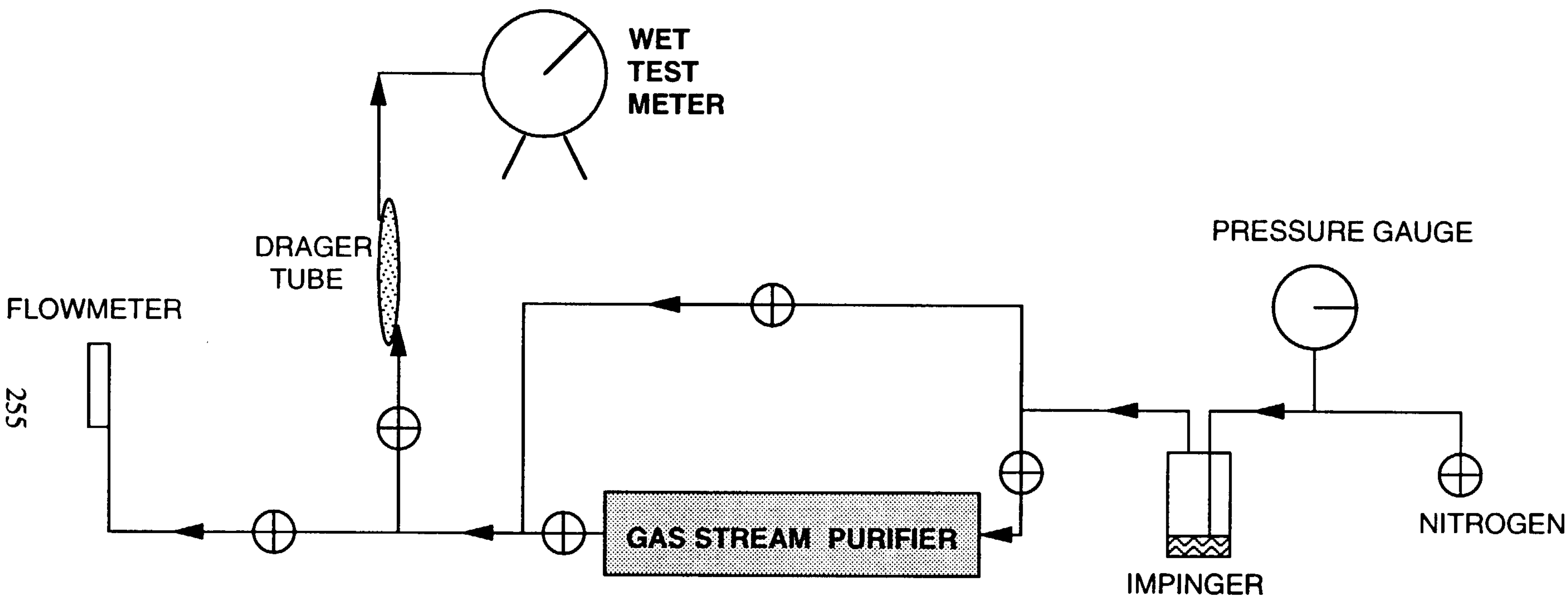


FIGURE 3 - GAS STREAM PURIFIER EFFICIENCY TESTING

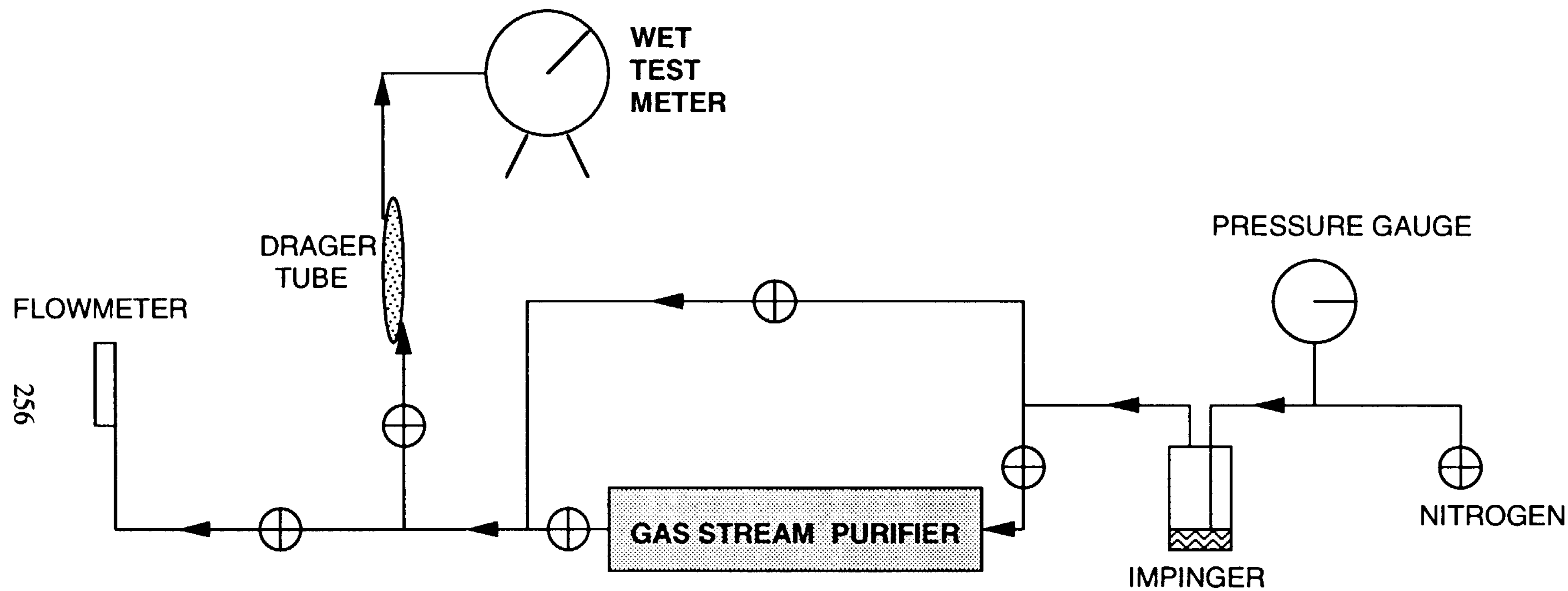


FIGURE 3 - GAS STREAM PURIFIER EFFICIENCY TESTING

TABLE 2

GAS STREAM PURIFIER CONTAMINANT REMOVAL EFFICIENCY

CONTAMINANT	Flow Rate LBm/Hr	PPM Level Contaminant	PPM Level After Purification	% Efficiency
HCl	1.4	1.9	0.0	100%
HCl	4.1	3.0	0.0	100%
HCl	1.4	20	0.0	100%
HCl	4.1	20	0.0	100%
HCl	4.1	350	0.5	99.76%
NH_4OH	4.1	500	1.0	99.80%
NH_4OH	4.1	2000	10	99.50%
MEK	4.1	15,000	50	99.67%
XYLENE	4.1	11,155	50	99.55%
IPA	4.1	10,000	100	99.00%
ETHANOL	4.1	15,000	100	99.33%
ACETONE	4.1	40,000	100	99.75%
TCE	4.1	10,000	50	99.50%