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CARBON FILTER DETAIL (1)



CARBON FILTER DETAIL (2)

ACTIVATED CARBON

This presentation was originally written in 1992. It has been revised in 2005 to reflect the newer carbon filter products that are now available and being utilized throughout the HVAC industry.

Introduction

Improved Indoor Air Quality continues to be one of the MAJOR issues facing the HVAC industry.

The Air Movement Industry has been very effective in the areas of human comfort and the removal of particulates. However, to totally "clean" the air, the gases and vapors – the chemical pollution that affects health and productivity – must also be removed.

For HVAC applications, adsorption is the most effective and the most economical process. Activated carbon, known as the universal adsorbent, is the most effective adsorbent.

A variety of products utilizing activated carbon are readily available. Some have been in use for decades, others for I0 years or less. When applied properly, the vast majority have proven to be effective in eliminating the chemical pollution found in HVAC systems.

Why Is It Used?

Theoretically, we can remove almost all particulate matter from the air stream. We are now faced with "how should the gases and vapors – the chemical pollution – be removed?"

HEPA filtration is effective down to the .3 micron range and will remove some particulates smaller than .3 microns. Gases and vapors are .01 microns and smaller. Benzene and naphthalene, two compounds that are strongly adsorbed by carbon, are approximately .0006 and .0007 microns respectively. One micron equals 1/25,400 of an inch.

Very simply, particulate filters do not, and can not, remove material that is this small and is a gas. If particulate means cannot be used to remove gases, then how can they be removed?

For HVAC applications, where the concentrations are very low and the contaminant loading varies constantly, adsorption has proven to be the most effective and the most economical process.

Adsorption with activated carbon is also the process of choice for applications such as gas masks, space capsules, nuclear submarines and radioactive iodine removal (nuclear plants).

Are there other processes to remove gases from an air stream? Certainly, there are other processes. When higher concentrations are present, incineration, chemisorption and solvent recovery [an adsorptive process] all have their places.

Absorption vs. Adsorption

A question that is often asked – "What is the difference between **ABSORPTION** and **ADSORPTION**?"

ABSORPTION can be understood if we think of sugar being dissolved in water and mixing evenly throughout, or cream being mixed into coffee. Industrial absorption would be a gas being **ABSORBED** (taken into and mixing evenly) by a "scrubbing" liquid.



In contrast, **ADSORPTION** is the physical attraction and adherence of gas or liquid molecules to the surface of a solid. The attractive force is very small, van der Waal's forces, and exists between any two bodies, such as between the earth and the moon. Gas molecules are **ADSORBED** by activated carbon.

Why Is It Known As The Universal Adsorbent? Why Is Activated Carbon Used As The Adsorbent With HVAC Processes?

Activated carbon is truly a unique material. There are no other materials, natural or man-made, that will do all that it will do.

Activated carbon:

- 1. Has a capacity for virtually any vapor contaminant; it will adsorb "some of almost any vapor".
- Has a large capacity for organic molecules, especially solvents.
- 3. Will adsorb and retain a wide variety of chemicals at the same time.
- 4. Has an extremely large capacity to catalytically destroy ozone, a major component of smog.
- 5. Works well under a wide range of temperature and humidity conditions.
- 6. Adsorbs odors and chemicals preferentially to moisture. It is not a desiccant and will release moisture to adsorb chemicals.
- 7. Can be used as a carrier of one material to attract and hold or react with another material.
- 8. Is inert and safe to handle and use.
- 9. Is available and affordable.

What Is It?

It is a material that has been treated (activated) to increase the internal surface area of the structure to the range of 950 to 1150 square meters per gram for gas phase applications. The internal area is the area that holds the adsorbed chemicals, in effect, this is where the "work" is done.

How Much Internal Area Is Available For "Work"?

Using the number 1000 square meters per gram, which equals 1197 square yards, and multiplying 1197 by 454 (454 grams/lb.), results in 543,438 square yards of available surface area per pound of carbon. Comparing this to a football field, which is 50 by 100 yards, or 5000 square yards, this would be the surface area of more than 100 football fields.

When the 543,438 sq. yards is multiplied by 9 (9 sq. ft/sq. yd.), it equals almost 5 million square feet of available surface area per pound of carbon. Utilizing a maximum working capacity of 33%, up to 1,650,000 square feet would be available for adsorption.

How Much Gas, Or How Many Gas Molecules Can Be Adsorbed And "Held" On This Area?

Consider the gas molecule benzene, which has a molecular weight of 78 and is approximately 6 x 10 $^{-4}$ microns in diameter. Utilizing one pound (454 grams) of carbon and a maximum capacity of 33%, then 150 grams of a gas, (in this case, benzene) can be adsorbed.

Dividing 150 grams by 78 gram moles of benzene yields 1.9 gram moles of benzene that can be adsorbed by one pound of carbon. Multiplying the Avogadro number*, 6.023×10^{23} , by 1.9 yields 11.44×10^{23} molecules.

Therefore, 1 pound of carbon would have enough internal surface area to adsorb (hold) 11.44 x 10^{23} molecules the size of benzene.

How Many Molecules Is 11.44 x 10²³

The U.S. national debt is over seven trillion dollars, (\$7,000,000,000). Two trillion times the U.S. national debt would be an approximation of 11.44 x 10²³. Simply put, whether the working capacity for a specific application is 33%, 5%, or 2% - this is a huge number of gas molecules!

*The Avogadro number states that the number of molecules in a gram mole of a gas is 6.023×10^{23} .

Activated Carbon

There are many types and grades of carbon that can be used for adsorption. There are carbons used for liquid and gas phase applications; they are not interchangeable. For the purpose of this presentation, only gas phase carbons that are used for general HVAC applications will be addressed.

The commercial quality HVAC carbons that are being manufactured today are produced from either coal or coconut shells. These materials are interchangeable, as long as the activity level and the average particle size are the same.

Activated Carbon Specifications For HVAC Applications

The HVAC industry currently uses 60% activity** carbons in a variety of mesh sizes depending upon the manufacturing process and the application. In the newer products, where fibers and granular carbons are blended, 20/50 mesh carbons are applied. Where polyesters are impregnated by a slurry process, fine carbon powders are used. For the older filled

OdorGuard Pleated

Roll Media

Filters and CarbonWeb

CarbonWeb Media with

Activated carbon and

impregnated alumina.





trays, used in Vbanks, either 6/8 mesh (3mm) [pelletized] or 6/12 mesh [granular] are utilized. I believe there are definite advantages of pelletized over granular materials, but either of these materials will do a satisfactory job.

**This activity level will insure that the internal surface area is in the range of 1000 – 1100 square meters/gram.

Activated Carbon or Activated Charcoal?

The term CHARCOAL is used widely, and the question often asked "What is the difference between activated carbon and activated charcoal?"

There is only one material, and the terms are used interchangeably. Normally, those who are in the carbon business will use the term carbon. Those outside the industry, or just learning, will use the term charcoal. ASTM – The American Society of Testing Materials – utilizes the term carbon.

How Does It Work? What Does It Do?

Activated carbon ADSORBS a wide variety of gases and vapors – chemical pollutants.

Whether there is one gas molecule and one carbon particle, or many of each, the adsorption process is the same. The physical process begins with a gas molecule coming into contact with the surface of an activated carbon particle and coming to rest in a large surface pore. Then, due to unbalanced forces on and within the carbon particle, the gas molecule will begin to move "down" into the carbon particle – into the smaller pores, where it will finally stop and be held in place. At some point between the surface and the "stopping point", this gas molecule will condense and become a liquid particle.

For those who would like a more technical version: The adsorbate diffuses thru the surface film to the macropore structure. Then, due to van der Walls' forces, the gas molecule migrates into the micropore structure, condensing during this movement, and finally stopping when either the forces become balanced or it becomes physically blocked.

This molecule, which was an objectionable gas, will remain a liquid inside the carbon until it receives enough energy, in the form of heat, to excite it.

If this condition arises, the molecule will begin moving toward the surface. If enough energy (heat) is absorbed, it will be vaporized, returned to a gas and be released back into the air stream, i.e. the process will be reversed.

In HVAC applications, there is normally not enough heat to excite, or re-energize, adsorbed molecules. With regular carbon filter or bulk carbon "changeouts", sufficient capacity will always be available.

It is interesting to note, the adsorbed gases that condense and become liquid molecules will "line" the internal surface area – and this "lining" will be one (and only one) molecule thick.

How Is It Applied In HVAC Applications?

As a reminder, this presentation deals only with the removal of gaseous and vapor contaminants.

The application of carbon to HVAC installations is considerably different when compared to how carbon is applied to solvent recovery systems and other industrial removal applications. For the latter, air streams with hundred to thousands of parts per million (ppm) of gas molecules are recovered, or removed, with beds that can be several feet thick and contain thousands of pounds of carbon.

For HVAC applications, thin bed filters with comparatively small amounts of carbon are utilized. Therefore, it is not only important that these differences be recognized, but that the parameters be defined. First, air in a structure can be treated as it:

- 1. Enters.
- 2. Leaves.
- 3. Is re-circulated.
- 4. Or a combination of the above.

For the majority of HVAC applications, the air to be treated is a combination of air entering (make-up) and air that is re-circulating. The gaseous contaminant loading that should be removed:

- 1. Is always a combination of many odors and pollutants chemicals.
- 2. Is normally unknown either as to the chemical make-up, the amount of each pollutant, or the total loading.
- Varies constantly with changes in occupancy levels, activity within or without the structure, and shifts in the wind.
- 4. Is in the 1 ppm range.

Loading Variations

In four above, the "1 ppm range" has been used. When the loading drops below 1 ppm, down to the ppb [parts per billion] or to the .1 ppb range and below, there is no concern. When the loading increases, which it can do for short periods, there are concerns and questions.

Knowing that the industry has utilized, and continues to utilize, thin bed carbon filters, the following situations must be considered:

How high are these higher loadings (peaks), and how long do they last?

Answer: Unless the structure has been studied over a period of time, there is no definite answer. Ten to 20 ppm would be a heavy overload and may be within reason for this application. This condition may last for minutes to hours as opposed to days.

During the peaks, how effective is the filtration system?

Answer: The percentage of these peaks, which exceeds the design capability of the filter or the capacity of the carbon at that time, will pass thru and into the inside air. Since the air is being re-circulated, these peaks will be adsorbed on future passes.

As stated earlier, carbon must be changed on a regular basis. This regularity, which should be established during the first year of operation by utilizing test samples, will insure that these peaks, typical to that installation, will be quickly adsorbed.

How Much Carbon Should Be Used?

The old ASHRAE specification of 45 pounds per 1000 cfm per year has been used for many years as the design guideline. In all probability, the vast majority, if not all, of the older carbon V-banks that are being utilized in airports, sports stadiums, and commercial buildings were designed with these numbers. When this amount of carbon is changed regularly, these filters perform effectively.

Is this the optimum amount of carbon? From experience with many installations, the answer would certainly be

"This has proven to be enough carbon." A remaining question is "Would somewhat less carbon be as effective;

and if so, how much less?" The older V-banks were "designed" to be changed out in approximately one [1] year. This time would be adjusted, based on the specifics of the application. Obviously, utilizing less carbon per filter, but changing more frequently, would produce similar results.



Ring Panel Filters with self-sealing edges and an internal wire "ring" for added support.

For the newer "clean room" type applications, which may call for the removal contaminants in the ppb or less range, filters with significantly less carbon are being used successfully.

Commercial vs. Industrial Application

The carbon adsorption products that have been designed and utilized for HVAC applications are very effective. When they are misapplied in industrial applications, problems can and do arise.

Normally, it is not that the carbon does not adsorb, but rather the concentration exceeds the capability of thin bed products, and neither the pass efficiency nor the life (capacity) are satisfactory.

Industrial applications, although they will contain many of the same chemicals found in HVAC applications, can be defined as having:

- 1. Primarily one contaminant (chemical).
- 2. A chemical that is known, both as to it's formulation and quantity (ppm).
- 3. Either a constant quantity or a constant range.
- 4. A loading well above the 1 ppm range.

Very simply, this will be, by comparison, a heavy-duty application, and the information concerning the contamination will be known.

One example that will crystallize the differences between these applications:

A printing company with a large printing press may have a solvent recovery system to recover the solvents from the inks. This system will remove the high concentrations of solvent with large amounts of carbon. However, the solvent "leakage" that escapes into the general air and into the air handling system will be heavily diluted and be just one of the many other chemicals in the HVAC system. This air, that re-circulates thru the offices, lunchrooms, laboratories, etc., would now be treated as an HVAC application, with thin bed products.

Adsorption may not be the most effective process for industrial applications. Companies skilled in these fields should be consulted to make the determination regarding the most effective process and system.

Non-Vented Areas

Activated carbon will adsorb without the air being drawn thru it, i.e. without a fan or blower. This is of importance when there are rooms or closed areas that do not have ventilation ducts, electricity and/or where the use of a portable air cleaner would not be practical. Carbon pads can be placed in these areas and be a very effective solution.

How Does Carbon Work in Non-Vented Areas?

Gas molecules will disperse (mix) themselves evenly throughout a given area, in accord with the "Perfect Gas Laws". Activated carbon will attract and adsorb the odor or pollutant molecules to which it is closest, causing an unequal mixture to result. Whereupon the gases will redistribute themselves, the carbon will again adsorb the closest, and the process will continue until the air is "cleaned" or the carbon reaches its capacity.

A relatively small amount of carbon can, and will, keep these types of areas odor and pollutant free.

An example of utilizing a small amount of carbon is to maintain a refrigerator odor free. By adsorbing gases, it thereby eliminates the transfer of odors and tastes from one food to another, and to ice cubes.

Activated Carbon Adsorption Products

For HVAC applications, adsorption products can be divided into several categories:

Panel filters, extended surface filters and V-banks.

1. **Panel Filters:** Panels filters are available in a variety of designs and configurations. They are available in a variety of thickness', 1", 2" and 4", with 2" being the predominant commercial product.

Panel filters can in turn be divided into two groups:

A. **The newer products:** Carbon filter products that are designed to have a low pressure drop and are normally interchangeable with particulate filters.

Filters using either pads or pleats, contain either granular or powdered carbon. Carbon is either integrated with fibers during manufacturing or impregnated via a slurry process into an existing non-woven product.

For 2" filters, in either pad or pleat form, carbon loadings will vary from approx. 300 grams per square foot of filter face area, down to about 35 grams per square foot.

Products include, three stage filters, pads, pads in die cuts, pleats and ring panels.

B. **The older products:** Filled or honeycomb filters have relatively high pressure drops and therefore can not be interchanged with particulate filters. They are utilized in V-banks.

Filled filters have perforated metal faces, held in place with welded metal spacers, surrounded with a metal frame and filled with carbon. Honeycomb filters utilize a honeycomb shaped material as the internal structure, which is either partially or completely filled with carbon. The carbon is contained within the honeycomb structure by a thin netting and a metal frame which surrounds the structure.

As filters, they are available in ³/₄", 1" and 2" thickness'. When used in V- banks, the ³/₄" and 1" "trays" account for almost all HVAC applications. The 2" thickness is used only in special applications.

Both filters contain packed granular carbon. Loadings vary from approx. 2.1 lbs/sq. foot of filter face area for a 1" filled filter, to slightly under 1 lb/sq. foot for a ³/₄" honeycomb filter.

2. Extended surface

filters [Rigid Cells]: Deep Pleat, rigid cell extended surface filters, are the newer products. They are applied in many normal HVAC applications, previously reserved for the older V-banks. They are also used in clean room and microelectronic



applications where contaminants are in the ppb or ppt [parts per trillion] range.

These "Rigid Cells" utilize several different types of "thin bed" activated carbon media, that are formed into pleats that are 4", 6", or 12" deep, the later being by far the most popular. The "deep" pleats are then sealed into a metal frame [rigid cell]. They can be used individually, but are normally used in a filter bank.

Activated carbon loadings for a 24" x 24" x 12" cell, vary from as high as approx. 7 lbs, to as low as slightly over 1 lb, depending upon the carbon filter media that is utilized.

3. **V-Banks**, the older products, are still in use. They are used in airports, stadiums and commercial buildings and in many clean room applications.

These products will offer from approx. 30 to 45 pounds of carbon per 1000 cfm of air, and are available for flow rates of 500, 1000 or 2000 cfm.

Virtually all units will have a face area of either 24" x 24" or 12" x 24"; utilize removable trays, V sections, or have a serpentine bed configuration; can be applied individually, or be built into filter banks.

Product Application

The application of these products can be divided into two areas – either new construction or retrofitting existing installations. When a new structure is being designed, the engineer has the option of utilizing any of the above products. When adsorption applications arise in existing installations, panel filters, although they will need to be changed more frequently to offer similar capacities, offer the advantage of interchangeability, thereby eliminating the need to alter the existing air handling system.

HVAC Applications For Activated Carbon

As stated earlier, activated carbon, the universal adsorbent, will adsorb "some of almost any vapor". Detailed lists of gases and vapors – chemical compounds – are available from carbon and equipment manufacturers. The following is a partial list of gases that are of concern in the air purification systems and can be removed with carbon:

ORGANIC COMPOUNDS: Acids, Alcohols, Aldehydes.

CHLORINATED HYDROCARBONS: Esters, Ethers, Ketones, Mercaptans, Amines.

INORGANIC COMPOUNDS: Halogen Acids, Halogens, Sulphuric Acid, Sulphur Dioxide, Phosgene.

MISCELLANEOUS ODORS FROM: Humans, Animals, Foods, Cooking, and Waste Processes.

Where Are The HVAC Applications?

Odor and gaseous pollution occurs in:

- airports, libraries, hospitals, research facilities, office buildings, computer rooms.
- clean rooms, electrical rooms, microelectronic applications.
- retail stores, print shops, stadiums, auditoriums, municipal buildings, restaurants.
- homes, pet hospitals, pet groomers, medical laboratories, nursing homes and health care facilities.
- and the list goes on.

Conclusions

The removal of chemical contaminants, which affect the health and productivity of many Americans at work and at play, must and will continue to be addressed by the Air Movement Industry.

Due to the comparatively low contamination levels found in HVAC applications, adsorption has, and will continue to be, the most economical process.

Activated carbon, the universal adsorbent, has a capacity for virtually all vapor contaminants and will adsorb and retain a wide variety of chemicals at the same time.

Adsorption products utilizing activated carbon are available from a variety of sources. These products, when properly applied and maintained, can eliminate the vast majority of pollution problems caused by the gases and vapors – the chemical pollution – found in HVAC systems.



NUCON International, Inc.

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Design & Performance Characteristics of NUSORB[®] KINATM Adsorbents

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NUCON International, Inc.

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1.0 INTRODUCTION

The NUCON International Inc. (NUCON) NUSORB[®] family of adsorbents was developed for the treatment and purification of air and gas. The knowledge acquired from over twenty-five years of experience in some of the most critical air and gas treatment applications (e.g. radioactive effluent control in nuclear power plants) combined with laboratory and pilot testing facilities gives

NUCON the unique ability to make this technology available to a wide variety of industrial users. This bulletin describes typical properties, manner of operation and typical test data for NUSORB® KINATM. As is the case for all adsorptive or catalytic applications, the performance of the material depends on actual composition and conditions of the incoming air stream and the contact time between the adsorbent and the treated airflow. NUCON can assist the users in selecting the most cost effective applications of the NUSORB[®] KINATM in both once through and in recirculating air treatment systems.

NUCON uses extensive process controls and final product quality assurance to assure that the batches of special adsorbents produced are of uniform quality. NUCON's laboratory and pilot facilities are dedicated to the evaluation, characterization and testing of adsorbents. In this way, critical process operating and performance parameters can be evaluated and tailored for a particular application. Even ultra trace contaminant removal can be evaluated by taking advantage of NUCON's radio analytical techniques.

1.1 PRODUCT DESCRIPTION

The KINATM grade of the NUSORB® family of specialty adsorbents was specifically developed for the control of inorganic and organic vapors in the presence of oxygen for the most critical applications, such as space related assembly technology, computer chip manufacturing and the protection of electronic equipment in control rooms from corrosion or other deleterious contamination. The NUSORB[®] KINATM is also suitable for BIOGAS purification when undesirable inorganic compounds are present.

A technical data sheet for KINA-3TM is included in section 11. It includes a combination of specified and typical properties for the grade.

Pressure drop curves for KINA-3TM & KINA-4TM are included in section 11.

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1.2 SPECIFIC APPLICATIONS OF NUSORB[®] KINATM

The NUSORB[®] KINATM adsorbent/catalyst material is suitable for the control of combined inorganic/organic contaminants from oxygen-containing streams in the following applications:

CONTROL ROOM INTAKE FILTERS

CONTROL ROOM RECIRCULATION FILTERS

CENTRAL COMPUTER FACILITY INTAKE FILTERS

ELECTRONIC CHIP MANUFACTURING PLANT INTAKE FILTERS

SATELLITE ASSEMBLY FACILITY INTAKE FILTERS

SATELLITE ASSEMBLY FACILITY RECIRCULATION FILTERS

BIOGAS RECOVERY FACILITIES

PURIFICATION OF EXHAUST STREAMS FROM MANUFACTURING FACILITIES

CLEAN ROOM INTAKE FILTRATION

MUSEUM INTAKE FILTERS

LIBRARY INTAKE FILTERS

VISCOSE MANUFACTURING PLANT EXHAUST STREAM TREATMENT

HYDROCARBON PROCESSING (with air in bleed)

CATALYST PROTECTION SYSTEMS (ammonia plants)

Contact NUCON International, Inc or our authorized representative for additional information and/or assistance in selecting and using the NUSORB® adsorbents.

2.0 HYDROGEN SULFIDE REMOVAL

The NUSORB[®] KINATM adsorbent catalyst removes hydrogen sulfide from contaminated air streams by several different processes. While most of the steps result in the conversion of the hydrogen sulfide to elemental sulfur within the pores of the adsorbent, other surface deposited catalysts are capable of either oxidizing the hydrogen sulfide with oxygen from the air or catalyzing cross reactions with other impurities. Process conditions, the substrate activated carbon and a catalyst are chosen to avoid as far a possible those side reactions, which produce sulfuric acid.

Impurities which cross react the hydrogen sulfide are: ammonia, ozone, sulfur dioxide and nitrogen oxide (the latter is only partial). The resulting elemental sulfur is deposited (adsorbed) in the pores of the adsorbent material. The catalyst composition is very carefully selected to promote the oxidation or cross reaction of the hydrogen sulfide only to elemental sulfur and not to sulfur oxides. The chosen catalyst not only reduces unwanted side reactions but also increases the reaction rate for sulfur deposition. The deposited catalyst components do not strip from the adsorbent substrate at operating typical operating temperatures (< 180° C). While all catalytic processes perform better at elevated temperatures, the NUSORB[®] KINATM performs well on hydrogen sulfide removal at temperatures as low as -30° C inlet gas temperature.

The NUSORB[®] KINATM is capable of removing hydrogen sulfide from both high concentration and low concentration hydrogen sulfide containing streams. (Inlet concentrations from 100 vppm to a few ppb). The presence of oxygen or other oxidizing gas is required for high hydrogen sulfide removal efficiency. (For non-oxygen or oxidizer containing gas stream purification NUCON FCTM or FNTM grades are available). However, in some non-oxygen containing streams the NUSORB[®] KINATM has been successfully applied with small amounts of air bled into the treated gas stream. The NUSORB[®] KINATM also requires the presence of some water in the entering air stream (greater than 30% but less than 90% RH) for optimum performance.

Since the sulfur formed during the reaction with H₂S is deposited in the pores of the carbon, the ultimate capacity for hydrogen sulfide of the NUSORB[®] KINATM depends on the pore volume of the adsorbent and on the presence of other adsorbed impurities. Capacities as high as 30 wt. % sulfur loading can be reached from high hydrogen sulfide concentration at long residence times. The micro and macro porosity of the NUSORB[®] KINATM is in the range of 1 ml/g. Due to the high surface area and high pore volume of the NUSORB[®] KINATM the tolerance for typical organic vapor impurity presence is very high. However, in most ambient air purification systems for the prevention of contamination in clean rooms or control rooms, the life of the NUSORB[®] KINATM will be determined by the deposition (adsorption) of large molecular weight organic compounds rather than the exhaustion of hydrogen sulfide removal capacity.

When the potential exists for high organic contaminant inlet concentrations, it is advantageous to use a "guard bed" of activated carbon (NUSORB® GC 60-3) to increase the life of the NUSORB[®] KINATM.

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The NUSORB[®] KINATM is suitable for hydrogen sulfide protection both in recirculating and in inlet or exhaust air streams depending on the source of the hydrogen sulfide. In some cases the most optimum process is recirculation together with inlet air purification. NUCON can supply information for the optimum design of such systems.

Operating data for removal of hydrogen sulfide from an air stream at low concentration (1 ppmv) is shown in Figure 1 (Section 12).

Operating data for removal of H_2S from an air stream containing 1ppmv each of SO₂, H_2S , NO₂, and Cl₂ is shown in Figure 1 (Section 11). The total loading of H_2S from this 1.0 ppmv mixed input stream for KINA-3TM is shown below:

| <u>% Breakthrough</u> | Loading, g/Kg KINA TM |
|-----------------------|----------------------------------|
| 3 | 23.7 |
| 5 | 25.2 |
| 10 | >27.4 |

At concentrations above 10,000 ppmv, the capacity is 230g H₂S/Kg KINATM.

3.0 SULFUR DIOXIDE REMOVAL

The removal of sulfur dioxide by NUSORB® KINATM occurs in several different manners. The first method is neutralization of the adsorbed sulfur dioxide by the alkali material deposited on the surface. The second method is the catalyzed oxidation of the sulfur dioxide to sulfur trioxide on the catalyst surface. The adsorbed SO₂ reacts with adsorbed oxygen to produce sulfur trioxide which in turn reacts with adsorbed water to produce sulfuric acid which is neutralized by the deposited alkaline materials. If in the same incoming air stream hydrogen sulfide is also present, the NUSORB® KINATM also catalyzes the cross reaction of the hydrogen sulfide and the sulfur dioxide to elemental sulfur and water. (Two molecules of hydrogen sulfide react with one molecule of sulfur dioxide.)

Typically, when purifying incoming contaminated air all of these reactions can take place. When the incoming air also contains ozone the adsorbent collects the ozone and assists in the direct oxidation of sulfur dioxide to sulfur trioxide, which is then again converted to sulfuric acid. (And as discussed above it is then neutralized on the adsorbent surface).

The alkalinity on the NUSORB® KINATM is important for several different reasons. First, the lowest vapor pressure deposit is formed when elemental sulfur or sulfate salts are formed on the NUSORB® KINATM surface, thus the alkalinity of the catalyst material is important for maintaining the low outlet concentrations from the adsorber stage of the air purification unit. Secondly, the alkalinity of the NUSORB® KINATM also prevents the deposited sulfur from oxidizing into sulfur dioxide, which could otherwise bleed from the adsorbent, if no humidity or hydrogen sulfide were present.

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NUSORB[®] KINATM has been successfully used in diverse air purification applications both for environmental control and air pollution control systems. The retention of co-adsorbed organic compounds slows the reaction rate and the total sulfur dioxide removal capacity of any adsorbent material.

The level of organic adsorption that can be tolerated is dependent not only on the incoming air composition but also on the properties of the adsorbent substrate material. The substrate for NUSORB® KINATM has been carefully selected to result in long service life in the presence of organic compounds and it has both a very high surface area and a large pore volume (> 1.0 ml/g).

However, if elevated organic compound concentration is present in the inlet stream, it can be advantageous to place a "guard" bed of activated carbon (NUSORB[®] GC60-3) upstream of the NUSORB[®] KINATM bed to result in longer inorganic gas removal life for the NUSORB[®] KINATM carbon.

While all catalytic reactions are more efficient at higher temperatures, it is important to maintain reactant product vapor pressure as low as possible, thus the preferred operating range of the NUSORB® KINATM for sulfur dioxide removal is below 50° C.

The presence of water is beneficial for several of the sulfur dioxide removal mechanisms and it is preferable to keep the relative humidity above 30 % RH. The operation above 90 % RH should be avoided because the pore structure of the NUSORB[®] KINATM will fill up with water and the removal efficiency, by mechanisms other than oxidation to sulfur trioxide (sulfuric acid), will be lowered.

Operating data for removal of SO₂ from an air stream containing 1ppmv each of SO₂, H₂S, NO₂, and Cl₂ is shown in Figure 2 (Section 11).

The total loading of SO₂ from this 1.0 ppmv mixed input stream for KINA-3TM is shown:

| <u>% breakthrough</u> | Loading, g/Kg KINA TM |
|-----------------------|----------------------------------|
| 3 | 26.3 |
| 5 | 34.4 |
| 10 | 47.1 |

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4.0 REMOVAL OF NO_x

NO₂ is adsorbed on the NUSORB[®] KINATM surface and in the presence of adsorbed water the following chemical reaction step takes place:

 $3NO_2 + H_2O = 2HNO_3 + NO$

The generated nitric acid is neutralized by the deposited alkalinity on the adsorbent surface and thus converted to a low vapor pressure salt.

The process results in a 66% removal efficiency as NO_x because one out of three molecules can penetrate the adsorbent as NO. For this manner of NO_x control the presence of alkalinity on the surface is very important otherwise the generated nitric acid can attack (oxidize) the carbon and release additional NO_x .

In the presence of ammonia, the NUSORB[®] KINATM also catalyzes a cross reaction between nitrogen dioxide and ammonia to nitrogen and water which further reduces the NO_x in the air stream.

Because the presence of water is important for the control of nitrogen oxides, the inlet air relative humidity should be in the 30% to 90% range. Since elevated temperature is beneficial in most chemical reactions, the recommended operating temperature should be in the -20° C to $+ 80^{\circ}$ C range.

When high NO_x concentrations are present and/or carbon monoxide control is also necessary, such as in engine exhausts streams, other special grades need to be used. Contact NUCON International Inc. for special catalyst materials.

The co-adsorption of large amounts of organic material on the NUSORB[®] KINATM surface is deleterious for the removal of nitrogen oxides. In those cases, NUCON recommends a guard bed of activated carbon such as NUSORB[®] GC60-3.

Operating data for removal of NO₂ from an air stream containing 1ppmv each of SO₂, H₂S, NO₂, and Cl₂ is shown in Figure 2 (Section 11). Data showing the conversion of NO₂ to NO is given in Figure 5.

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5.0 CHLORINE REMOVAL

NUSORB[®] KINATM removes chlorine by surface physical adsorption and by chemisorption due to the presence of surface oxides on the adsorbent. The alkalinity of the adsorbent surface partially converts the adsorbed chlorine to chloride and chlorate compounds. Since the vapor pressure of the chloride and chlorate salts is much lower than that of the unreacted chlorine, the retention capacity also becomes higher at elevated alkalinity levels.

When hydrogen sulfide is also present with chlorine, the NUSORB[®] KINATM catalyzes a cross reaction with chlorine to form elemental sulfur and hydrochloric acid. The alkali present on the surface then neutralizes this acid to low vapor pressure alkali chloride. The simultaneous presence of chlorine and sulfur dioxide results in the formation of sulfuryl chloride. This reacts with adsorbed water to form hydrochloric acid and sulfuric acid which in turn are neutralized by the alkali.

While the physical adsorption (and within limits the chemisorption) of the chlorine on the NUSORB[®] KINATM surface is not humidity dependent, the formation and neutralization of the formed acids needs the presence of adsorbed water. Thus, the preferred humidity for the NUSORB[®] KINATM for mixed inlet inorganic vapor component removal is above 30 % RH. To avoid filling the microporosity of the adsorbent with water, NUSORB[®] KINATM should not be operated above 90% RH.

High organic compound concentrations in the inlet stream will retard the chlorine conversion capability of the NUSORB[®] KINATM. In such cases, a "guard bed" of activated carbon (NUSORB[®]GC60-3) should be used upstream of the NUSORB[®] KINATM bed to increase the life of the adsorbent for inorganic gas removal. A data sheet describing this product is included in section 11. The recommended operating temperature range of the NUSORB[®] KINATM for chlorine removal is -40° C to +50° C range. If the application requires operation outside these ranges NUCON International should be consulted.

Special safety note: The NUSORB® KINATM should not be used for fluorine removal above 1 vppm inlet fluorine concentration. Fluorine can violently react with the NUSORB[®] KINATM carbon substrate.

Operating data for removal of Cl₂ from an air stream containing 1ppmv each of SO₂, H₂S, NO₂, and Cl₂ is shown in Figure 4 (Section 11). The total loading of Chlorine from a 1.0 ppmv mixed input stream for KINA-3TM is shown below:

| <u>% breakthrough</u> | Loading, g/Kg KINA TM | |
|-----------------------|----------------------------------|--|
| 3 | 29.2 | |
| 5 | 30.2 | |
| 10 | 31.0 | |

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6.0 ACID GAS REMOVAL

NUSORB[®] KINATM removes acid gases such as hydrogen chloride and sulfur trioxide by physical adsorption followed by neutralization of the adsorbed acid on the surface of the adsorbent. The resulting low vapor pressure salts are retained in the pores of the adsorbent.

The capacity of the NUSORB[®] KINATM for these acid gases is dependent on the alkalinity of the adsorbent and the efficiency of the adsorbent is dependent on the contact time between the inlet air stream and the adsorbent bed.

The neutralization of the surface adsorbed acids is improved by the presence of adsorbed moisture, thus the NUSORB[®] KINATM should be operated between 30% and 90% inlet air RH.

The operating temperature of the NUSORB[®] KINATM for acid vapor removal should be below 50° C.

7.0 OZONE REMOVAL

Ozone is removed by the NUSORB® KINATM by chemical reaction between the carbon substrate and the ozone. The product of this chemical reaction is carbon dioxide. The carbon life for this reaction is very long and nearly 100% efficient. The inlet ozone concentration should be kept below 10 vppm to prevent the potential build up of solid carbon/oxygen complexes on the adsorbent surface and generation of excessive heat from the exothermic reaction. In some cases when adsorbed organic compounds are also present, a partial regeneration step can also occur, due to the oxidation of the organic compounds by the incoming ozone.

When inlet ozone concentrations are above 100 vppm, the NUSORB[®] KINATM should not be used.

The operating temperature should be kept between -20° C and $+ 80^{\circ}$ C and the inlet relative humidity between 30% and 90% for optimum performance.

The incoming ozone will also cross react with any simultaneously present hydrogen sulfide and will result in elemental sulfur deposition on the surface of the NUSORB[®] KINATM. Incoming sulfur dioxide can also be oxidized by ozone and be converted to sulfuric acid, which is again neutralized into a nonvolatile sulfate salt on the adsorbent surface. (For methods to control high concentrations of ozone, contact NUCON)

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8.0 AMMONIA REMOVAL

The NUSORB® KINATM has only limited adsorption capacity for the removal of ammonia when present alone (in the range of 10 mg/ml adsorbent).

However, the NUSORB[®] KINATM catalyzes the cross reaction between ammonia and most acid type inorganic gases, (nitric oxides, hydrogen sulfide, sulfur dioxide, chlorine, etc.). The cross-reaction results in the formation of less volatile salts on the adsorbent surface.

In some cases the ammonia acts as an additional catalyst for the conversion of inorganic compounds into strongly adsorbed forms, for example, the conversion of hydrogen sulfide to elemental sulfur.

When ammonia is present alone, other adsorbents produced by NUCON International are available. NUCON AMMOSORBTM is recommended when relatively high concentrations of ammonia need to be removed from an air or other gas stream.

For the catalytic and adsorptive process of ammonia removal -20° C to 80° C is the optimum temperature range. A relative humidity of 30% to 90% is preferred for ammonia control using NUSORB[®] KINATM.

9.0 VOLATILE ORGANIC COMPOUND REMOVAL

Since the amount of impregnant contained in NUSORB[®] KINATM adsorbent is relatively small, there is essentially no reduction in adsorption of organic vapors. The amount of a compound adsorbed by activated carbon is impacted by the physical properties of the activated carbon and the adsorption conditions (temperature, pressure, concentration). Figures 6, 7 & 8 (Section 12) are adsorption isotherms showing the capacity of NUSORB[®] KINATM adsorbents for a common paraffin, aromatic and chlorinated hydrocarbons.

Activated carbon is very effective in removing low concentrations of odorous compounds. In typical ambient air applications, the concentration of VOC's will be extremely low and the amount adsorbed on the carbon will not interfere with the performance of the impregnants for gaseous contamination control.

The NUSORB[®] KINATM adsorbent material consists of a specially impregnated activated carbon substrate specifically selected for high surface area and for high pore volume.

The retention of organic compounds on activated carbon is typically affected by the molecular weight and vapor pressure of the organic compounds. While low molecular weight compounds such as methane are not well removed under ambient temperature and pressure conditions, compounds which can deposit on critical electronic surfaces are very strongly adsorbed on the NUSORB[®] KINATM adsorbent surface.

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In many cases, applications involving critical control of atmospheres for electronic equipment require removal of both inorganic ant organic vapors at high removal efficiencies. In these saturations, it is often beneficial to use NUSORB® GC60-3 for organic vapor removal to extend the life of the NUSORB[®] KINATM. When the organic compounds are present at low concentrations, or when the inorganic compounds are present at very high concentrations, such as paper mill control rooms, there is no additional benefit from the use of an unimpregnated carbon guard bed.

The physical adsorption based organic compound removal is better at lower temperatures and at relative humidities below 70%.

If the major reason for the contamination control application is the presence of organic compounds at high concentrations, contact NUCON International Inc. for special adsorbents and systems for organic compound control.

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10.0 INSTALLATIONS

<u>Plant A</u>: The NUSORB[®] KINATM material protects a solvent recovery system from hydrogen sulfide and sulfur dioxide intrusion from viscose manufacturing plant, in the presence of carbon disulfide vapor. The plant is successfully operating with the protection system.

Inlet hydrogen sulfide conc.:2 vppmInlet sulfur dioxide conc.:periodic to 200 vppmTypical residence time:2 secondsContinuous operation.

<u>Plant B</u>: The NUSORB[®] KINATM material protects chip manufacturing plant intake air from environmental impurities. Same adsorbent bed installed and successfully operating for over 3 years.

GC60-3 guard bed installed. Typical residence time: 1.3 seconds Continuous operation There are multiple installations of this type.

<u>Plant C</u>: The NUSORB[®] KINATM protects the intake air and recirculating air of a space satellite assembly facility. Typical inorganic and organic contaminants of metropolitan area. The installation protects the satellite components from deposition/corrosion and from potential fogging of components from out gassing in vacuum.

Typical residence time of intake:0.25 secTypical residence time of recirculation:0.15 secContinuous operation.0.15 sec

<u>Plant D</u>: The NUSORB[®] KINATM protects the control room of a paper mill by filtering both intake air and partial recirculation.

Typical residence time of intake:1.0 secTypical residence time of recirculation:0.5 secThere are multiple installations of this type.

Installations using NUSORB[®] KINATM adsorbents to purify the air in many control room, library, and electronics facility operations are all performing well.

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11.0 APPLICATIONS DATA

11.1 APPLICATIONS

The NUSORB[®] KINATM can be used to treat both incoming ambient air and recirculated air with internally generated contamination. The KINATM substrate is a high surface area, very high pore volume activated carbon, specially treated with catalyst material and alkalized for additional process control. The KINATM is most commonly used in 3 mm diameter pelleted form (KINA-3TM). However for other applications it is also produced in 4 mm and 1.5 mm pellet diameters. Figure 9 (Section 12) shows the pressure drop for the 3 & 4 mm product.

While other NUSORB® grades are available for cases when no oxygen is present in the treated gas stream, the NUSORB[®] KINATM grade also works very well in hydrocarbon purification when small amounts of oxygen (a ratio of 3:1 to hydrogen sulfide) are bled into the gas stream.

11.2 LONG TERM ADSORPTION OF H₂S, SO₂, NO₂ and Cl₂

Figures 1-4 show effluent concentrations as a function of time for removal of several inorganic gases, each at 1 ppmv inlet concentration. The tests were performed at 40% relative humidity, and a residence time of 0.5 seconds. The adsorbent was NUSORB[®] KINA-3TM and KINA-8/16TM. The tests were monitored for 1800 hours.

11.3 ROUND ROBIN H₂S TESTING OF KINA-3TM

Five laboratories tested NUSORB[®] KINA-3TM as part of a round robin to verify a proposed ASTM H_2S capacity test. The test is performed by passing air containing 1% H_2S through a nine inch long column of adsorbent until the outlet concentration reaches 50 ppmv. The average capacity for H_2S of the KINA-3TM was 23 weight %.

11.4 VOC ADSORPTION DATA

Adsorption isotherms for compounds representing typical paraffin, aromatic, and chlorinated hydrocarbons are shown in Figures 6, 7 & 8.

11.5 PRESSURE DROP DATA

Figure 9 shows the pressure drop for 3 & 4 mm KINATM.

12.0 REFERENCES

12.1 Enbom, S., Hagsröm, K. and Railio J., "Sähkötilojen ilmastointi Kemiallisten suodattimien mittuasraportti", INVENT-teknologiaohjelma, Raportti 39, Maaliskuu 1994 Figure 1 Hydrogen Sulfide Removal, NUSORB KINA



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Figure 2 Sulphur Dioxide Removal, NUSORB KINA



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Figure 3 Nitrogen Dioxide Removal, NUSORB KINA



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Figure 4 Chlorine Removal, NUSORB KINA

Figure 5 NO₂ Conversion to NO, NUSORB KINA 3



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Concentration, VPPM



Velocity, ft/min

Pressure Drop, in. H₂0 / in bed depth

O-35

in the second second



Pressure Drop Curve for All NUSORB[®] Grades of 1.5 mm, 3mm and 4 mm Diameter Pelleted Carbons

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NUSORB⁷ KOGC-3 TECHNICAL DATA SHEET

TYPICAL APPLICATIONS: RAW MATERIAL: ACTIVATION METHOD: PARTICLE TYPE: IMPREGNANT H₂S removal Coal High Temperature Steam Pellet Caustic

PHYSICAL PROPERTIES:

| APPARENT DENSITY | (ASTM D2854) | 0.55 g/mL | Typical |
|---|--------------|---------------------------------|----------|
| HARDNESS | (ASTM D3802) | 98 | Typical |
| SURFACE AREA(carbon substrate) | BET | 1000 m²/g | Typical |
| MOISTURE CONTENT, as packaged | (ASTM D2867) | 15 % | Maximum |
| PARTICLE SIZE | | 3 mm | Diameter |
| CCl ₄ ACTIVITY(carbon substrate) | (ASTM D3467) | 60 % | Minimum |
| H ₂ S CAPACITY, minimum, g/mL | | 0.15 @ 300 ppm CO ₂ | |
| | | 0.14 @ 3000 ppm CO ₂ | |
| HEAD LOSS @ 50 fpm 1.6 A water/ft. | | Maximum | |

Additional ASTM or custom testing available on request

PACKAGING: Square fiber drums (150 pounds) or "tote bags"(1,000 pounds)

Information herein is accurate to the best of our knowledge. User should determine the suitability of the product for the intended use; liability consists of replacing product. NUCON INTERNATIONAL, INC., does not suggest violation of any existing patents or give permission to practice any patented invention without a license.