

MODIFIED ACTIVE GAS SAMPLING MANUAL

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1.0 INTRODUCTION AND SCOPE

Modified Active Gas Sampling (MAGS) is an assessment tool effective at rapidly detecting unsaturated soil source areas impacted by volatile organic compounds. By utilizing a typical regenerative blower fitted to a temporary soil vapor extraction well, a large volume of soil can be assessed with a limited number of samples. While lacking the resolution of traditional soil sampling methods (*e.g.*, discrete soil sampling, low flow active gas sampling, *etc.*), the statistical representativeness (in the sense of sample coverage) of MAGS results versus traditional methods is much greater. Moreover, the results of the assessment provide useful transport and exposure assessment information over traditional techniques. Lastly, MAGS is effective as both an initial site assessment and remedial assessment tool, in that MAGS directly yields data required for remedial design.

Several methods are currently available for assessing volatile organic compounds in soil. The most popular and current industry standard is discrete sampling wherein individual samples are collected and analyzed for the constituents of concern. Although easy to perform and conceptualize, the method has several limitations. Generally, approximately five grams of soil, which is handled both in the field and laboratory, is analyzed per sample. This small amount of soil is then relied upon to be statistically representative of the total area represented by the sample. For a ten-foot-by-ten-foot area that is five feet deep, the mass of soil would be approximately 50,000 pounds. Thus, considering five 5 gram samples, the sampled mass would represent approximately 0.0001% of the total mass. Likewise, when a 100-foot-by-100-foot area is considered, again with five 5 gram samples, the percentage of area sampled decreases to 0.000001%. Although five samples in this area is a large number of samples for a 10-by-10 area and adequate for a 100-by-100 area, the chance of "finding the needle in the haystack" becomes apparent.

Given that (i) soil is often heterogeneous over small scales (less than inches), (ii) the release pattern of chemicals can be complex (*e.g.*, multiple locations over time, unknown locations, *etc.*), and (iii) transport of organic compounds, especially in a pure phase, can result in large variations in concentration over small intervals (again, less than inches), discrete soil sampling has major limitations where the location of the release is not known and the contaminant distribution is not continuous between sampling locations (*i.e.*, the release size must be on the order of the sampling interval for detection). Importantly, despite their limited extent, these small releases can ultimately result in groundwater impacts well above standards. Composite sampling increases the average area sampled, thereby increasing representativeness (at the cost of resolution), but the mass sampled compared to the mass of potentially contaminated media remains small, even with this amendment. Furthermore, composite sampling is not a recommended method for evaluating the presence of volatile organics due to losses associated with volatilization.

Passive gas sampling involves the collection of discrete soil samples (generally on the order of 100 grams) and subsequent analysis of the sample's soil vapor for volatile contaminants, typically as a means of screening soil. Here again, the mass sampled is diminishingly small as compared to the mass to be assessed and volatile loss during sample collection is likely. Traditional active gas sampling typically involves creating a slight vacuum (three inches of water) over a soil boring, thereby allowing the soil vapor in the vicinity of the soil boring to be analyzed for volatile compounds. This method dramatically increases the mass sampled (with a concomitant reduction in resolution), but this dramatic increase is still small as compared to the mass to be assessed. Assuming a radius of influence (ROI) of six inches and five sampling points, only 1% and 0.01% of the volume of a 10-foot-by-10-foot area and a 100-foot-by-100-foot area, respectively, would be assessed. Importantly, if the impacts are not within six inches of the sampling point, they will not be detected by this method. In the case of MAGS, one sampling point and five sampling points are needed to sample the entire area for a 10-foot-by-10-foot plot and a 100-foot-by-100-foot plot, respectively, assuming a 25-foot radius of influence.

Previous experience at facilities such as drycleaners is that multiple localized impacts exist across a typical site (often near the location of the drycleaning machine, waste storage area, back door of the facility, and near dumpsters; however, impacts also occur near the former locations of the drycleaning machine, waste storage area, and dumpsters, which are often not known). It is also known from experience that it is difficult to detect source areas using discrete soil sampling with large grid spacing. Typically, low-level impacts (30-100 micrograms per kilogram [$\mu\text{g/kg}$] of tetrachloroethene) resulting from soil vapor transport are detected over a broad area. As a footnote, based on experience, low-level impacts such as these are generally an indication of a nearby, larger source. When the release occurred at the surface and groundwater impacts are present, an unsaturated zone source should be expected, especially in areas with a surficial seal such as asphalt or the concrete slab.

In light of these limitations to traditional methodologies, a novel technique was developed to increase the sampling volume to allow for more representative samples. In addition, the developed methodology provides detailed information for the design of a remedial system and assessment of the mass flux and potential for exposure at the site. This method allows a much larger soil volume to be sampled with a minimal number of monitoring points. Although this method forfeits resolution as compared to discrete soil sampling methods, it provides a more powerful approach to locating the source area impacts and it limits the potential for missing significant source areas. Importantly, the loss of resolution of MAGS compared to discrete soil sampling is not overly restrictive in that the remedial systems of choice, soil vapor extraction (SVE) and dual-phase extraction (DPE), require well placement on the order of resolution that MAGS provides.



2.0 GENERAL CAUTIONS

- If used to supply power, internal combustion engines (*i.e.*, gasoline-powered generators) should be placed a minimum of ten feet and downwind from the monitoring point of recovered soil vapors while conducting MAGS in order to prevent inaccurate vapor analysis. Fuel containers should be stored well away from the test area.
- The user should be cognizant of electrical safety associated with connecting the MAGS system to the power supply. Voltages should be confirmed and properly sized overload protection device(s) (*e.g.*, fuses, circuit breaker) should be utilized. Equipment amperage should be confirmed prior to the sampling event and correlated to the overload protection device(s).
- The user should be cognizant of the potential for reduced air quality in the breathing zone as a result of the use of MAGS in and around areas suspected of gross soil contamination. Safety measures per the site specific Health and Safety Plan should be taken to alleviate this risk, should monitoring reveal an Organic Vapor Analyzer (OVA) response of 200 parts per million (ppm) or greater.

3.0 EQUIPMENT AND SUPPLIES

- 2-inch diameter, 0.01-slotted Schedule 40 Poly Vinyl Chloride (PVC) well screen
- 20/30 graded silica sand
- 2.5-hp, 120/240VAC, 1 Φ regenerative blower (or equivalent)
- 120/240VAC 30/15A 1 Φ electrical source (existing utility or gasoline-powered generator)
- Moisture separator (if moisture accumulation is expected)
- Appropriately sized Flow (0-50 scfm), Temperature (0-200 °F), Pressure/Vacuum (0-100, 0-10, 0-1 inches H₂O) measurement gauges
- Flow Throttling Device (gate valve)
- Ancillary piping (2-inch PVC)
- Toxic Vapor Analyzer
- One-Liter Tedlar bags

A Process and Instrumentation Diagram is provided as **Figure 1**. Equipment specifications and photographs of MAGS equipment are provided as **Appendix A**.

4.0 PLANNING

Assessment focus areas should be associated with potential release locations typical of drycleaning facilities. These areas include the current or historical vicinity of the drycleaning machine, waste storage areas, floor drains, back door of facility, *etc.* Utilization of historical site assessment data, if available, is also useful in planning for MAGS.

Ultimately, areas where an existing surface seal is present (*e.g.*, asphalt, concrete, *etc.*) are preferred when conducting MAGS. The presence of a surface seal reduces the potential for short-circuiting near the extraction well and effectively increases the area of influence associated with each extraction well. If an existing surface seal is not present, it is preferred to install a temporary surface seal using plastic sheeting (Visqueen) in the vicinity of the area of assessment. The user should consider whether the location of the MAGS point will provide biased results. That is, if a MAGS point is placed near the edge of a concrete slab or other type of surface seal, the majority of the air will flow from the direction of the edge, with little air flowing from the other direction. The user should select locations where air will be transported across potential areas of contamination, and MAGS coverage should be confirmed by measuring vacuums in abutting MAGS points.

Figure 2 includes a site plan for the “ABC” Cleaners site. Site data gathered from this hypothetical drycleaning facility will be used throughout this document for example calculations and discussions. **Tables 1** and **2** include summaries of MAGS data and MAGS results from the ABC Cleaners site, respectively.

The hydraulic conductivity of the soil will influence the number of MAGS points required for assessment. The lower the hydraulic conductivity, the more MAGS points needed and/or the longer the time that sampling must occur. Proper spacing of multiple MAGS extraction/monitoring points is important for effective data collection. Typical radii of influence for silty sand with a surface seal are on the order of 25 to 35 feet. On the initial boring, it is preferable to install additional extraction/monitoring points within the effective ROI of the first extraction/monitoring point, which enables the user to effectively monitor subsurface vacuums at various distances from the extraction point and determine the soil permeability and subsurface flow characteristics. **Equation 1** can be used to estimate the ROI (R_I) from these initial data. **Table 3** contains an example ROI calculation. The results suggest that an average radius of influence of approximately 22 feet was achieved. Multiple monitoring points around a single suspected source area can also be used later to provide varying contaminant mass extraction rates for pinpointing source areas, allowing optimization of mass recovery in the final design if impacts are detected. Note that by placing monitoring points perpendicularly, horizontal isotropy can be estimated.



$$P_r^2 - P_w^2 = (P_{RI}^2 - P_w^2) \frac{\ln(r/R_w)}{\ln(R_I/R_w)} \quad \text{Equation 1}$$

Where:

P_r = Pressure at distance r from extraction well (M/LT²)

P_w = Pressure at extraction well (M/LT²)

P_{RI} = Pressure at radius of influence (M/LT²) = 0.1 inches of water or 101300 kg/m-s²

r = Radius from the extraction well (L)

R_w = Radius of well (L)

R_I = Radius of influence (L)

Equation 1 contains several assumptions about homogeneity and isotropy, in addition to the assumption that there are only limited energy losses across the well screen. Formulas are available that account for these assumptions, but **Equation 1** is sufficient for the estimation of the ROI in the field. Additionally, using **Equation 2**, the unsaturated soil permeability (k) can be estimated from pressure (P_w) versus flow data (Q_w), and a hydraulic conductivity (K) can be back calculated and compared to assessment data and values in the literature (*e.g.*, Table 2.2 in Freeze and Cherry, 1979) using **Equation 3**. Example permeability and hydraulic conductivity calculations are included as **Tables 4** and **5**.

$$Q_w = H \left(\frac{\pi k}{\mu} \right) \left(\frac{P_w}{\ln(R_w/R_I)} \right) \left(1 - \left(\frac{P_{RI}}{P_w} \right)^2 \right) \quad \text{Equation 2}$$

Where:

Q_w = Flow rate from extraction well (M/L³)

H = Length of well screen in extraction well (L)

k = Soil permeability (L²)

μ = Viscosity of air (M/LT) = 1.8x10⁻⁶ kg/m-s at 25°C

$$K = \frac{k \rho g}{\mu} \quad \text{Equation 3}$$

Where:

K = Hydraulic conductivity (L/T)

ρ = Density of water (M/L³) = 997.0 kg/m³ at 25°C

g = Acceleration due to gravity (L/T²) = 9.80 m/s²

μ = Viscosity of water (M/LT) = 8.9x10⁻⁴ kg/m-s at 25°C

The depth to water at the site should be used to determine the construction depth for each MAGS point and the vacuum that can be applied to the extraction well. The increase in the water table elevation in response to the decrease in the energy grade line will reduce the unsaturated zone thickness in the vicinity of the well, thereby reducing the flow rate and effective area of influence. Obviously, MAGS is not appropriate at sites where the depth to water is on the order of the anticipated vacuum (in inches of water). As a rule of thumb, MAGS may not be successful at sites where the depth to water is less than 2.5 feet (~30 inches of water). Additionally, excess moisture in extracted vapors can adversely affect vapor analysis, resulting in poor correlation between data points. The completion depth of each MAGS point should be a minimum of six to twelve inches above the static water table at the time of sampling to reduce water entrainment. Additionally, the user can adjust the wellhead vacuum to prevent water entrainment, with the knowledge that the ROI and air flow rate will concomitantly be reduced.

5.0 DATA COLLECTION

Typically, airflow rates observed from shallow soils in Florida are on the order of 10 to 50 cubic feet per minute (cfm) at vacuums between 10 to 100 inches of water. Depending upon the depth of the unsaturated soil column and the presence of a suitable surface seal, a ROI with time can be estimated based on the amount of air recovered using **Equation 4**, with the assumption of homogeneity and isotropy. At the flow rate range discussed above, between 200 and 1,000 cubic feet of air can be recovered and dynamically sampled during a twenty-minute purge period. A typical unsaturated soil zone of 5 feet and an effective air-filled porosity of 15% translates into an effective area of at least nine feet. Depending upon site conditions, the typical MAGS survey will include a sampling time interval of approximately 15 minutes. An example air recovered calculation is included in **Table 6**. This time should be increased for sites with low conductivity values (including clayey strata).

$$R_{It} = \left(\frac{Qt}{\pi H \theta_a} \right)^{1/2} \quad \text{Equation 4}$$

Where:

R_{It} = Radius of influence at time t (L)

t = Time (T)

θ_a = Effective air-filled porosity (-)

Prior to conducting MAGS sampling, data collection techniques and requirements should be evaluated. A summary of data typically required is included in **Tables 1** and **2**. Vacuum measurements should be recorded at nearby piezometers in order to confirm the vacuum ROI, which can be confirmed using **Equation 1**.



Additional data should be collected during installation of the extraction/monitoring points. Soil boring logs noting the soil lithology should be collected at each point. Additionally, soil parameters (organic fraction, porosity, bulk density, moisture content, and grain size) should be analyzed for each soil type observed. Soil samples for VOCs should also be collected at this time at locations where high readings are observed (see Data Interpretation in **Section 7.0**). That is, the MAGS results are used to direct the discrete soil sampling required to meet regulatory requirements. The use of MAGS will ensure that unneeded soil samples are not collected. The VOC samples should be held until the results of the MAGS results are available (*i.e.*, that day), at which point selected soil samples can be submitted for analysis to meet the regulatory obligations for soil sampling. It is generally recommended to focus soil sampling directly above the water table interface or the interval exhibiting highest fraction of organic material based upon visual observation.

5.1 Determining Flow Rate

The flow rate should be measured by a properly scaled flow measurement device. The point of measurement should be as near the wellhead as practical. Additionally, soil vapor temperature should be measured in proximity to the point that the flow measurement was made. The flow rate can be corrected to standard conditions (STP) by the following equation:

$$Q_{STP} = Q_w * \frac{P_A}{406.78} * \frac{298}{T_A} \quad \text{Equation 5}$$

Where:

Q_w = Measured flow rate (L^3/T)

P_A = Measured absolute pressure (inches of H_2O)

T_A = Measured actual temperature (K)

5.2 Determining Radius of Influence

Upon reached pseudo-steady state conditions (constant operation for the predetermined period of time), vacuum measurements should be collected from monitoring points surrounding the extraction point to evaluate the subsurface pressure effects of vapor extraction and determine a ROI associated with the extraction point. Given that changes in the energy grade line will occur quickly at a site with a good surface seal in silty sand, ROI measurements can be made soon after MAGS initiation. That being said, measuring the ROI at the end of MAGS sampling ensures that the system has had time to reach equilibrium with respect to air movement. A minimum of three monitoring points should be located within the anticipated ROI at varying distances from the extraction point. Recommended distances are 10, 20, and 30 feet. A semi-log plot of vacuum (y) versus distance (log x) should be used to determine the effective ROI (per **Equation**

1 and Table 3). The ROI calculation for ABC Cleaners indicated an effective ROI between 19 and 31 feet. For purposes of estimating soil permeability, influence is considered to be the distance within a vacuum level of 0.1 inches of water or greater. For purposes of estimation of pore volume calculation and purge time (Section 5.3), influence is considered to be the distance within a vacuum level of ten percent of the wellhead vacuum.

5.3 Estimating Purge Time

Next, an estimate of the required purge time to reach a new dynamic equilibrium with respect to airflow is determined. This dynamic equilibrium is achieved near the extraction point first, then it propagates as an advancing radial front to the steady-state ROI. It is important to separate the energy grade line, which is measured by pressure and propagates quickly, and mass transport, which is the movement of mass and occurs more slowly. In general, it is necessary to purge a minimum of one pore volume associated with the extraction point to obtain concentration data that will be on the order of the steady-state data. Based upon the calculated ROI associated with the distance within ten percent of the wellhead vacuum, a pore volume is determined by the following equation:

$$V_p = \pi R_I^2 H \theta_a \quad \text{Equation 6}$$

Where:

V_p = Pore volume (L^3)

The time required to purge one pore volume can be determined by the following equation:

$$t = V_p / Q \quad \text{Equation 7}$$

5.4 Measuring Soil Vapors

Initially, at startup of MAGS, an initial vacuum and flow rate measurement should be recorded at the wellhead. Soil vapors that are recovered from the temporary piezometer can either be monitored dynamically or discretely at the wellhead using a Total Vapor Analyzer (containing a PID/FID). When TVA measurements are recorded with time, the concentration of vapors can give insight as to the location of potential source areas, using Equation 4. Appendix B includes dynamically measured FID values from the ABC Cleaners site. Field GC and/or laboratory samples should be gathered in Tedlar bags at the conclusion of the MAGS operation period and prior to shutdown of the system. The samples should be gathered from as near the wellhead as possible. Vacuum pumps are recommended for sampling at the wellhead to overcome wellhead vacuum. If a vacuum pump is not available, samples may be gathered from the discharge side of the blower. Dilution air is defined as ambient air introduced into the flow stream in order to reduce the vacuum exerted at the wellhead and reduce overload to the blower. The frequency of



vapor measurement can be determined proportionally to the flow rate and affected pore volume by the equation below. It is common to collect five measurements per pore volume:

$$t = \left(\frac{1}{f} \right) V_p / Q \quad \text{Equation 8}$$

Where:

V_p = Pore volume based upon radius of influence (L^3)

Q = Flow rate (L^3/T)

f = frequency of measurements per pore volume (5)

In order to correlate TVA readings with actual contaminants of concern, a representative number of vapor samples should be collected for analysis on a field GC and/or a fixed-laboratory for Volatile Organic Compounds by EPA Method 8021. A regression line can be generated between the fixed-lab (y) data and field (x) data sets. A Pearson correlation coefficient (R) greater than 0.8 and 0.9 represents a good correlation and a strong correlation, respectively, between field and laboratory data. Accordingly, the TVA data can be used to estimate concentrations of the constituent of concern using linear regression. Based on experience, practically all of the detected species are of the parent compound. Obviously, when the constituent of concern is at low concentrations or other volatile compounds are present, or groundwater is inadvertently entrained by the system, the TVA reading can be dominated by background noise, which must be considered in the interpretation. The effects of background noise generally decrease as a dynamic equilibrium is established.

6.0 MAGS THEORY

When air is moved through the subsurface, volatile chemicals are transferred from pure, dissolved, and sorbed phases into the air-filled porosity. Prior to the initiation of MAGS, vapors in the subsurface travel along pressure gradients due to barometric pressure changes in the higher conductivity seams in the unsaturated zone soil. During MAGS, the extraction well exerts a gradient and the moving air transports vapors toward the extraction point. Given an airflow rate (Q), an air-filled porosity (θ_a), and an unsaturated zone thickness (b), an air velocity (V_r) can be calculated as a function of radius (r), assuming the subsurface is homogeneous, isotropic, and that a surface seal exists (**Equation 9**). If the average soil grain size (d) is known and it is assumed to be on the order of the average pore size, then an average time (t_p) to travel through a pore space due to the applied vacuum can be estimated for varying radii (**Equation 10**). Assuming that the chemical of concern is limited by diffusion from the pure, adsorbed, and dissolved phases, a time scale (t_{Dw} [water] and t_{Da} [air], respectively) for diffusion through the soil moisture (thickness l) and the air in the pore space can be calculated by **Equation 11**, if the Diffusion Coefficients ($D_w = 8.2e-6$ cm²/s and $D_a = 7.2e-2$ cm²/s for PCE, respectively) for a specific chemical are known. Once the mass has traveled into the pore space, it becomes

available for transport, so long as air is moving through those pores, which is likely the case for the higher transmissive zones, but may not be the case for the lower transmissive zones and pores that are within seams (*i.e.*, that are not connected). This limitation applies mainly to diffusive transport into lower transmissive zones, because the contaminant mass initially had to arrive at the pore space by density flow of pure phase or along a hydraulic gradient, implying a connection to the bulk pore space. Importantly, from an exposure perspective, this “trapped” mass is not, in general, available for transport except by diffusion, and, hence, is not available to significantly impact groundwater or be part of a completed exposure route. Importantly, it is not generally measured by traditional sampling either.

$$V(r) = \frac{Q}{2\pi r H \theta_w} \quad \text{Equation 9}$$

$$t_p(r) = \frac{d}{V(r)} \quad \text{Equation 10}$$

$$t_{D_a} = \frac{d^2}{\pi D_a} \quad \text{Equation 11}$$

$$t_{D_w} = \frac{l^2}{\pi D_w} \quad \text{Equation 12}$$

$$R_{It} = \sqrt{\frac{Q}{\theta_a b \pi}} \times t \quad \text{Equation 13}$$

Where

- V_r Air velocity (L/T); average V_r occurs at $1/3 R_{It}$
- d Average soil grain size (L)
- t_p Average time to travel through a pore space (T)
- t_{D_w} Time scale for diffusion through the soil moisture (T)
- t_{D_a} Time scale for diffusion through the air in the pore space (T)
- l Thickness of soil moisture (L)
- D_w Diffusion coefficients for chemical in water (L^2/T)
- D_a Diffusion coefficients for chemical in air (L^2/T)
- b Unsaturated zone thickness (L)
- R_{It} Radius of influence at time t (L)
- t Time after MAGS initiation (T)



By comparing t_p to t_D , a determination can be made as to whether equilibrium conditions are expected within the pore space. This determination allows insight into the meaning of the MAGS results. Importantly, heterogeneity, especially lower transmissive zones and pore spaces not connected to the bulk conductivity, will influence the MAGS analysis, as discussed above. Typically, during testing only one to two pore volumes, encompassing the radius of influence of the system, are recovered. Early in the MAGS recovery period (at start-up), the vapor recovered is from the subsurface that is at a local steady state (except during periods of significant barometric pressure changes, which should still be small as compared to the air movement generated by MAGS). During this initial phase of MAGS, mass recovery is limited by airflow rate and not boundary layer mass transfer as the vapor at equilibrium is removed sequentially with distance from the extraction point. Depending on the rate of air transfer across the pore space as compared to time to re-equilibrate, the system may return to equilibrium or may become mass transfer limited (*i.e.*, if the time for air to move across the pore space is long as compared to the time for mass to diffuse into the pore space, the system will return to equilibrium). Hence, t_p can be compared to t_D to provide insight into the local equilibrium. As mentioned above, this analysis is complicated by unconnected pore spaces, which effectively act to increase the length scale for diffusion. Additionally, up-gradient flux will affect the time to pore space equilibrium by reducing the concentration gradient.

For pure-phase and sorbed-phase mass, diffusion is through the air, whereas dissolved-phase mass diffuses through a layer of water. Mass transfer limitations may more readily occur for dissolved-phase mass due to the difference in diffusion coefficients between air and water (about 10,000 times); hence, pore spaces may remain at equilibrium for pure and sorbed-phase impacts, where air diffusion predominates, especially away from the extraction point. In either case, during the recovery of the first pore volume, significant increases or peaks in concentration generally indicate the presence of a source at radius (R_{lt}) given the air velocity and time (t) as defined by the **Equation 13**. The sequential use of numerous extraction points allows the location of the source by triangulation. An initial significant concentration followed by a decrease in concentration during this initial period indicates that the extraction point is in the vicinity of the source and air from outside of the source is diluting the source with time. An alternate interpretation is that the sampled air may be associated with vapor transport from a nearby area. Although nuanced, the two scenarios can be distinguished by a sustained but lower reading, which implies the former scenario, versus a reading of non-detect, which implies the latter. After one pore volume has been recovered, the presence of pure phase or substantial adsorbed impacts is characterized by sustained mass flux without a decrease in concentration, whereas chemical mass in the dissolved phase, from vapor transport, or mass in low transmissive zones may have mass transport limitations and hence respond through declining concentrations to near non-detect levels.

The flow through the subsurface can be further characterized by the Reynolds Number (Re) and Peclet Number (Pe). The Reynolds Number provides insight into the importance of viscosity (laminar versus turbulent flow), while the Peclet Number compares advective transport to

diffusive transport. For typical MAGS scenarios, the Reynolds Number is below 1000 and Peclet Number is below 1 (except for within about a few feet of the recovery well), meaning flow is viscous or “creeping flow” and diffusion, respectively, controls transport.

$$Re = \frac{V_r d}{\nu} \quad \text{Equation 14}$$

$$Pe = \frac{V_r d}{D} \quad \text{Equation 15}$$

Where

- Re Reynolds number (-); Average Re occurs at 1/3 of radius R_{lt}
- Pe Peclet number (-); Average Re occurs at 1/3 of radius R_{lt}
- V_r Air velocity at a distance r from extraction well (L/T)
- ν Kinematic viscosity (L^2/T)
- D Diffusion coefficient for air or water (L^2/T)

The influent concentrations measured by the MAGS technique relate to an average soil vapor concentration for the sampled volume (*i.e.*, the volume within the radius of influence of the system and the vadose zone height (H)). Thus, an average mass flow ($\dot{m}$) can be calculated from Q and an average concentration (C) from the MAGS system (**Equation 16**), where the air velocity in the effluent pipe (V_p) and cross-sectional area (A) of the MAGS effluent pipe are known or measured. This mass flow rate is equivalent to the mass loading rate needed in the design of an SVE system for sizing the vapor treatment system.

$$\dot{m} = \frac{Q}{A} \times \bar{C} = V_r \times \bar{C} \quad \text{Equation 16}$$

Where

- $\dot{m}$ Mass flow (M/T) = mass loading rate
- A Cross-sectional area of extraction well (L^2)
- $\bar{C}$ Average Concentration measured at extraction well (M/L^3)

An initial rough estimate of the minimum mass present can be calculated by multiplying the average total soil concentration (converted from the average air concentration using **Equation 24**) by the mass of soil within the radius of influence (which all soil is composed of equally impacted particles). This minimum mass is exactly that, the minimum amount of mass expected. The problem associated with using this value is that any mass that is “hidden” due to establishment of equilibrium in the pore space will not be measured, and this amount of mass is likely to be much larger than the mass that can be measured across a gradient. A more refined treatment is provided below, which includes an attempt to measure mass across the gradient.



For mass transfer from through the subsurface modeled as numerous impacted spheres, flux can be characterized by **Equations 17 and 18**. The sum of the mass flux from individual spheres equals the total mass flux. In addition, the mass flow from the MAGS technique can also be described as the mass flow from a packed bed. When the subsurface re-equilibrates faster than air moves through the pore, the mass flow is directly related to the rate at which air is removed, instead of boundary layer effects. At higher flow rates, the Peclet number increases to a point at which mass transfer limitations affect mass flow. As an example, mass transfer limitations are important for PCE in sandy soil (grain size 1 mm) with a flow rate of 50 cfm at less than approximately 3 feet from the recovery point.

$$\dot{m}_p = k(C_a^s - C_a^p) \times \text{Particle Area} \quad \text{Equation 17}$$

$$k = \frac{D}{d} Sh \quad \text{Equation 18}$$

for a packed bed Equation 19

$$Sh = 1.17 Re^{0.585} Sc^{1/3} \text{ for roughly spherical particles and } n \sim 0.4 \text{ \& } Re > 10$$

$$Sc = \frac{\nu}{D} \quad \text{Equation 20}$$

$$\dot{m} = \sum \dot{m}_p = \overline{\dot{m}_p} \frac{\text{Total Volume}}{\text{Particle Volume}} = k(C_a^s - C_a^p) \frac{\nabla}{d} \quad \text{Equation 21}$$

$$C_a^s = \frac{\dot{m}}{k} \frac{d}{\nabla} + C_a^p = \frac{\overline{C} Q d}{k \nabla} + C_a^p = \overline{C} \left(\frac{Q d}{k \nabla} + 1 \right) \quad \text{Equation 22}$$

This equations assumes $\overline{C} \sim C_a^p$, which could result in a underestimation of mass.

$$C_T = \frac{\text{Mass Chemical}}{\text{Mass Soil}} = \frac{(C_a^s / H' \theta_a) (K_{oc} f_{oc} \rho_b + \theta_w + H' \theta_a)}{\rho_b + \rho_w \theta_w} \quad \text{Equation 23}$$

$$M_T = C_T (\rho_b + \rho_w \theta_w) \nabla = \overline{C} \left(\frac{Q d}{k \nabla} + 1 \right) \frac{(K_{oc} f_{oc} \rho_b + \theta_w + H' \theta_a)}{H' \theta_a} \nabla \quad \text{Equation 24}$$

$$M_T = \overline{C} \left(\frac{Q d^2}{D Sh \nabla} + 1 \right) \frac{(K_{oc} f_{oc} \rho_b + \theta_w + H' \theta_a)}{H' \theta_a} \nabla \quad \text{Equation 25}$$

Where

$\dot{m}_p$	Mass flow from an individual sphere (M/T)
$\overline{\dot{m}_p}$	Average mass flow from an individual sphere (M/T)
k	Piston velocity (L/T)
C_a^s	Source-side air concentration gradient from sphere (M/L ³)
C_a^p	Pore-side air concentration gradient from sphere (M/L ³)
∇	Average volume sampled (L ³) $\sim 1/3 R_{lt}$
Sh	Sherwood number (-)
Sc	Schmidt number (-)
ρ_b	Dry bulk density of soil (M/L ³)
ρ_w	Density of water (M/L ³)
K_{oc}	Organic carbon:water partition coefficient (L ³ /M)
f_{oc}	Organic carbon content of soil (-)
θ_w	Water-filled porosity (-)
H'	Dimensionless Henry's Law constant (-)
C_T	Total concentration (M/M)
M_T	Total minimum mass (M)

These equations can be used to “travel back across the concentration gradient” in order to estimate a minimum mass. The mass flux from individual spheres is summed to equal the total mass recovered. The average concentration detected in the soil gas can be used as an order of magnitude estimate of the “pore-side” concentration of the gradient to the sphere. **Equation 19** can be used to estimate the “source-side” calculation, which can be used to calculate a minimum mass present in the subsurface by multiplying the “source-side” concentration by the mass of soil present. These equations are complicated by the effect of pressure and temperature on the Henry's Law constant and the assumption of equilibrium across a water film, when the mass is in water versus pure phase. These equations assume spherical particles, isotropy, and homogeneity. Once a new equilibrium is reached near the extraction well, there could be a contribution of mass from near field pore spaces coming to equilibrium along with a far field flux that is being drawn to the extraction point with time. This minimum mass measurement can be a vast underestimate due to assumptions used in the derivation of the equations above, as discussed above.

7.0 DATA INTERPRETATION

Data from MAGS prior to the time one pore volume has been extracted are of interest, but can be complicated to interpret. As the air is moved toward the extraction point, a plot of the PID/FID data with time can allow insight into the relative distance of impacts according to **Equation 4**. Several plots are provided in **Appendix B**, along with interpretations. These initial data provide insight into equilibrium conditions in the subsurface, and will be useful in identifying impacts in lower transmissive zones, if any. That being said, vapor transport can occur over significant



distances and hence low-level impacts that are not sustained above detectable levels would not necessarily indicate a nearby source. Hence, these data are examined for large peaks or sustained impacts above detectable levels, which generally can be interpreted as a nearby source at a radius given by **Equation 4**. Although the radius at which the impacts occur can be calculated if a peak or sustained hit is detected, the direction of the impact is not, and thus multiple MAGS points are used to “zero in” on the source with knowledge of its existence and estimate of its distance. Importantly, until one or more pore volumes are removed, the system is at a quasi-steady state, and stable mass flux rates have not been established against the airflow.

Use of the TVA results with time to calculate distances, followed by “zeroing in” on impacted areas using additional extraction points constitutes the best use of MAGS data. Care must be taken to confirm TVA readings with field GC readings and/or laboratory confirmation results to ensure that the TVA is responding to target analytes. Other compounds including naturally occurring compounds can cause TVA detections.

With regard to contaminant concentrations, a common sense approach utilizing all available site data has proven to be most useful in evaluating MAGS data. Typically, discrete soil sampling results in excess of the Soil Cleanup Target Level (SCTL) for Groundwater Criteria as established in Chapter 62-777, FAC are utilized for evaluating soil impacts at a site. This should be the primary level of evaluation at all sites in order to meet regulatory requirements. Nevertheless, MAGS can be utilized as an initial screening prior to developing a discrete soil sampling plan or it can be a useful tool at sites that do not have documented soil impacts, but exhibit low-level groundwater impacts. As such, the MAGS results should be evaluated with regard to the purpose of the testing.

The radius of influence, pressure versus flow curve, and mass loading rate can also be obtained during a MAGS survey, as discussed above. These data are essential to the proper design of SVE and DPE systems.

The calculations using the Sherwood number can provide some insight into the minimum mass present in the subsurface. That being said, this calculation can have significant limitations. Hence, as a rule of thumb, any sustained detection greater than the detection limit of 0.5 mg/m^3 is likely indicative of a source area that could result in impacts to groundwater. For example, case studies of two Program sites in areas of high soil permeability contained detections with results less than 1 mg/m^3 , but also had low-level groundwater impacts. After SVE remediation, the groundwater concentrations decreased below groundwater criteria. Impacts above 5 to 10 mg/m^3 are likely indicative of relatively significant impacts.

8.0 LIMITATIONS

MAGS is limited in low permeability soils and areas without a good surface seal because more sampling points are needed. Nevertheless, if a surface seal is not present or if low permeability soils exist, MAGS can be conducted and is effective. As such, the results of the MAGS should be evaluated with consideration to the limitations mentioned above. Additionally, sites with a water table elevation within 2.5 feet of land surface are not likely appropriate for MAGS. Heterogeneity does not affect interpretation of bulk results (*i.e.*, impacted or not), but it can limit the use of some of the additional data interpretation described above.

Based on HSA's experience with MAGS, several problems may be encountered during the operation of the MAGS system. Below are listed typical problems encountered and some recommendations for mediation:

Problem: Accumulation of water in the moisture separator

Recommendation: This moisture accumulation is usually a result of the combination of a shallow water table and low conductivity soils. HSA typically includes a dilution air valve between the wellhead and the blower. By manipulating the dilution valve, the wellhead vacuum can be adjusted to minimize moisture recovery. As such, caution should be used when sampling air at the discharge of the blower with dilution air being added.

Problem: Surface Seal

Recommendation: Interior-duct tape/grout
Exterior-visqueen barrier

Problem: Air Emissions

Recommendation: Granular Activated Carbon treatment of discharge vapors

Problem: Reading DS-300 flow meter (inconsistent readings)

Recommendation: Increase distance of straight pipe run

Problem: IDW (moisture separator water)

Recommendation: Granular Activated Carbon treatment of moisture separator water



9.0 REFERENCES

See also the following Standard Operating Procedures

FC 1000	Cleaning/Decontaminating Procedures
FD 1000-9000	Documentation Procedures
FM 1000	Field Planning and Mobilization
FQ 1000	Field Quality Control Requirements
FS 1000	General Sampling Procedures
FS 3000	Soil
FT 1000	General Field Testing and Measurement

Hazardous Waste Site Remediation, Grasso, 1993

Table 4, Chemical Specific Values, Final Report, Development of Soil Cleanup Target Levels (SCTLs) for Chapter 62-777, F.A.C.

Groundwater, Freeze R.A. and Cherry J.A., 1979.

Modeling of In Situ Techniques for Treatment of Contaminated Soils. David Wilson. Technomic Publishing Co. Lancaster Pennsylvania. 1995.

Unit Operations of Chemical Engineering. Warren McCabe. Julian Smith. Peter Harriott. McGraw Hill. Boston. 2001.

An Introduction to Fluid Mechanics. G.K. Batchelor. Cambridge Mathematical Library. Cambridge University Press. 2000.

Mass Transfer Correlations for Nonaqueous Phase Liquid Pool Dissolution in Saturated Porous Media. Tae-Joon Kim and Constantinos V. Chrysikopoulos WATER RESOURCES RESEARCH, VOL. 35, NO. 2, PAGES 449-459, FEBRUARY 1999

THE EFFECTS OF LOCAL HYDRODYNAMICS ON MASS TRANSFER IN DISORDERED POROUS MEDIA. Gang Guo. Louisiana State University and Agriculture and Mechanical College. May 2002.



TABLES

Table 1: Summary of Active Gas Data
ABC Cleaners
Tampa, Florida

Sample ID	Date	Time	Velocity through discharge pipe (ft/min)	Flow through discharge pipe (cfm)	Standard flow through discharge pipe (scfm)	Estimated radius of influence (feet)	PZ-1 (inches of water)	PZ-2 (inches of water)	PZ-3 (inches of water)	PZ-4 (inches of water)	PZ-5 (inches of water)
PZ-1	5/31/2001	12:15	500	10.9	9.7	21.5	72	0	0.48	0.2	0.26
PZ-2	5/31/2001	10:50	2,800	61.1	66.2	21.5	0.01	58	0	0.01	0
PZ-3	5/31/2001	11:55	2,500	54.5	59.1	21.5	0.08	0	55	0.04	0
PZ-4	5/31/2001	11:35	1,500	32.7	35.4	21.5	0.08	0	0.08	64.0	0.02
PZ-5	5/31/2001	11:10	3,000	65.4	70.9	21.5	0.04	0	0	0.0	52

Notes:

ft/min= feet per minute

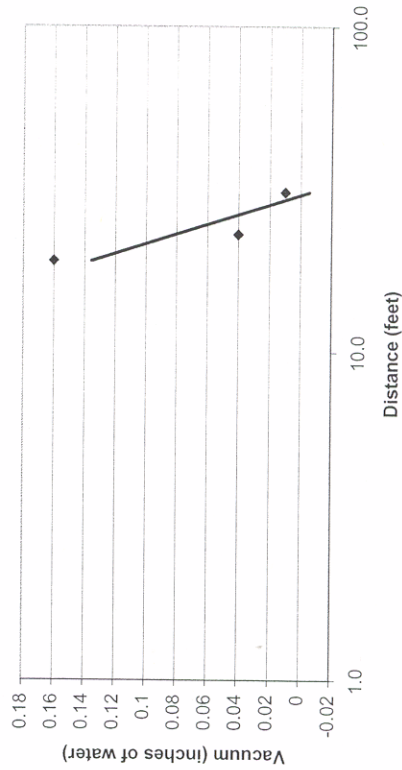
cfm= cubic feet per minute

scfm=standard cubic feet per minute

Semi-log plot of Vacuum versus Distance

$$y = -0.2883 \ln(x) + 0.9844$$

$$R^2 = 0.8033$$



slope
intercept
ROI

-0.2883
0.9844
21.49

PZ-4 (inches of water)	Distance from PZ-4 (feet)
0.16	19.0
0.01	31.0
0.04	23.0
64	0.0
0	15.0

Table 2: Summary of Active Gas Results ABC Cleaners Tampa, Florida										
Sample ID	Date	Time	Vacuum at well head (inches of water)	Velocity through discharge pipe (ft/min)	Flow through discharge pipe (cfm)	FID (Net) (ppm)	GC Results		Laboratory Confirmation	
							PCE (ppm)	TCE (ppm)	PCE (ppm)	TCE (ppm)
PZ-1	5/31/2001	12:15	72	500	10.9	14	942.5	0.299		
PZ-2	5/31/2001	10:50	58	2,800	61.1	0	3,349	BDL	4.4	BDL
PZ-3	5/31/2001	11:55	55	2,500	54.5	1.9	489	0.917		
PZ-4	5/31/2001	11:35	64	1,500	32.7	24.5	910.9	1.422	250	2.6
PZ-5	5/31/2001	11:10	52	3,000	65.4	1	20.46	BDL		

Notes:

ft/min= feet per minute

cfm= cubic feet per minute

FID= flame ionization detector

PID= photoionization detector

ppm= parts per million

Table 3: Summary of Radius of Influence Calculations (PZ-4)

ABC Cleaners

Tampa, Florida

Sample ID	Distance from PZ-4	Vacuum at piezometer	Absolute pressure at piezometer
	(meters)	(kg/m-s2)	(kg/m-s2)
PZ-1	5.8	39.9	101285
PZ-2	9.5	2.49	101323
PZ-3	7.0	9.96	101315
PZ-4	0.0	15942	85383
PZ-5	4.6	0	101325

$$R_I = R_w e^{[(P_{RI}^2 - P_w^2)/(P_r^2 - P_w^2)] \ln(r/R_w)}$$

Notes:

kg/m-s2 - Kilogram per meter second squared

where:

R_I = Radius of influence (meter)

R_w = Radius of well (meter)

P_{RI} = Pressure at radius of influence (meters of water)

P_w = Pressure at extraction well (meters of water)

r = Radius from the extraction well (meter)

Radius of Influence (meters)

	0.1 inH ₂ O	10% P _w
PZ-1	5.8	3.3
PZ-2	9.4	5.0
PZ-3	7.0	3.9

Table 4: Summary of Permeability Calculations

**ABC Cleaners
Tampa, Florida**

Sample ID	Vacuum	Vacuum	Vacuum	Flowrate	Flowrate	Screen Length	Radius of Influence	Absolute Pressure in Well	Permeability (k)
	(in. wc)	(m. wc)	(kg/m-s2)	(scfm)	(m ³ /s)	(m)	(m)	(kg/m-s2)	(m2)
PZ-1	72	1.83	17876.11	9.7	0.00458	0.9146	6.6	83449	4.14E-12
PZ-2	58	1.47	14400.20	66.2	0.03125	0.9146	6.6	86925	3.58E-11
PZ-3	55	1.40	13655.36	59.1	0.02790	0.9146	6.6	87670	3.39E-11
PZ-4	64	1.63	15889.87	35.4	0.01671	0.9146	6.6	85435	1.72E-11
PZ-5	52	1.32	12910.52	70.9	0.03347	0.9146	6.6	88414	4.32E-11
Average:									2.06E-11

Permeability Calculations

$$k = (Q/H) [\mu \ln(R_w/R_i)] / [P_w \pi (1 - (P_{atm}/P_w)^2)]$$

where:

k = permeability (Darcy)

Q = standard volumetric flow rate (m³/s)

H = Open Screen Length (m)

μ = Dynamic Viscosity of Air (kg/m s) =

1.85E-05

R_w = Radius of Well Screen (m) =

0.0254

R_i = Radius of Influence (m)

P_w = Absolute Pressure in well (kg/m-s2)

P_{atm} = Ambient Atmospheric Pressure (kg/m-s2) =

101325

(EPA/54012-91/003, Soil Vapor Extraction Technology, 1991, pp 205)

**Table 5: Summary of Hydraulic Conductivity Calculations
ABC Cleaners
Tampa, Florida**

Sample ID	k	K	
	(m ²)	(m/s)	(ft/day)
PZ-1	4.14E-12	4.55E-05	13
PZ-2	3.58E-11	3.93E-04	111
PZ-3	3.39E-11	3.72E-04	105
PZ-4	1.72E-11	1.89E-04	54
PZ-5	4.32E-11	4.74E-04	134

$$K = k\rho g / \mu$$

Notes:

m² - squared meters

m/s - meters per second

ft/day - feet per day

where:

K - Hydraulic conductivity (m/s)

k - Soil permeability (m²)

ρ - Density of water = 997.0 kg/m³

g - gravity = 9.8 m/s²

μ - Viscosity of water = 0.00089 kg/m-s

Table 6: Summary of Air Recovered Calculations ABC Cleaners Tampa, Florida				
Sample ID	Q	t	r _t	r _t
	m3/s	(min)	(m)	(ft)
PZ-1	0.0045787	17.5	2.59	8.5
PZ-2	0.0312485	19.5	7.13	23.4
PZ-3	0.0278971	19.5	6.74	22.1
PZ-4	0.0167099	19.5	5.22	17.1
PZ-5	0.0334671	19.5	7.38	24.2

$$r_t = [Qt/\pi H\theta_a]^{1/2}$$

where:

r_t - Radius of influence at time t (meters)

t - Time (seconds)

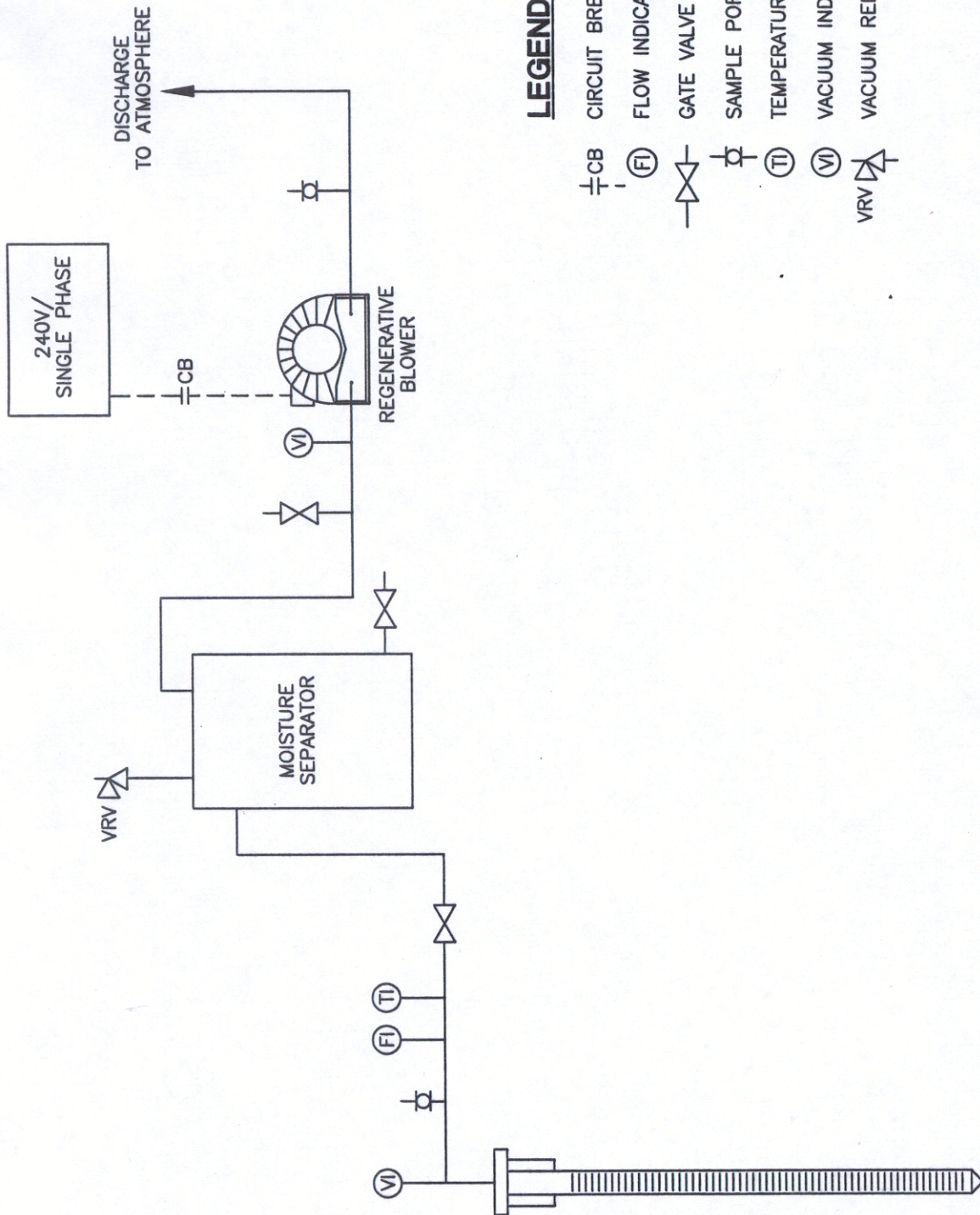
θ_a - Effective air-filled porosity

Constants:

θ_a 25 %



FIGURES



LEGEND

$\text{---} \text{CB} \text{---}$	CIRCUIT BREAKER
$\text{---} \text{FI} \text{---}$	FLOW INDICATOR
$\text{---} \text{FV} \text{---}$	GATE VALVE
$\text{---} \text{TI} \text{---}$	TEMPERATURE INDICATOR
$\text{---} \text{VI} \text{---}$	VACUUM INDICATOR
$\text{---} \text{VRV} \text{---}$	VACUUM RELIEF VALVE

NOT TO SCALE

PROCESS &
INSTRUMENTATION
DIAGRAM

FIGURE 1

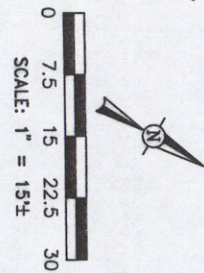
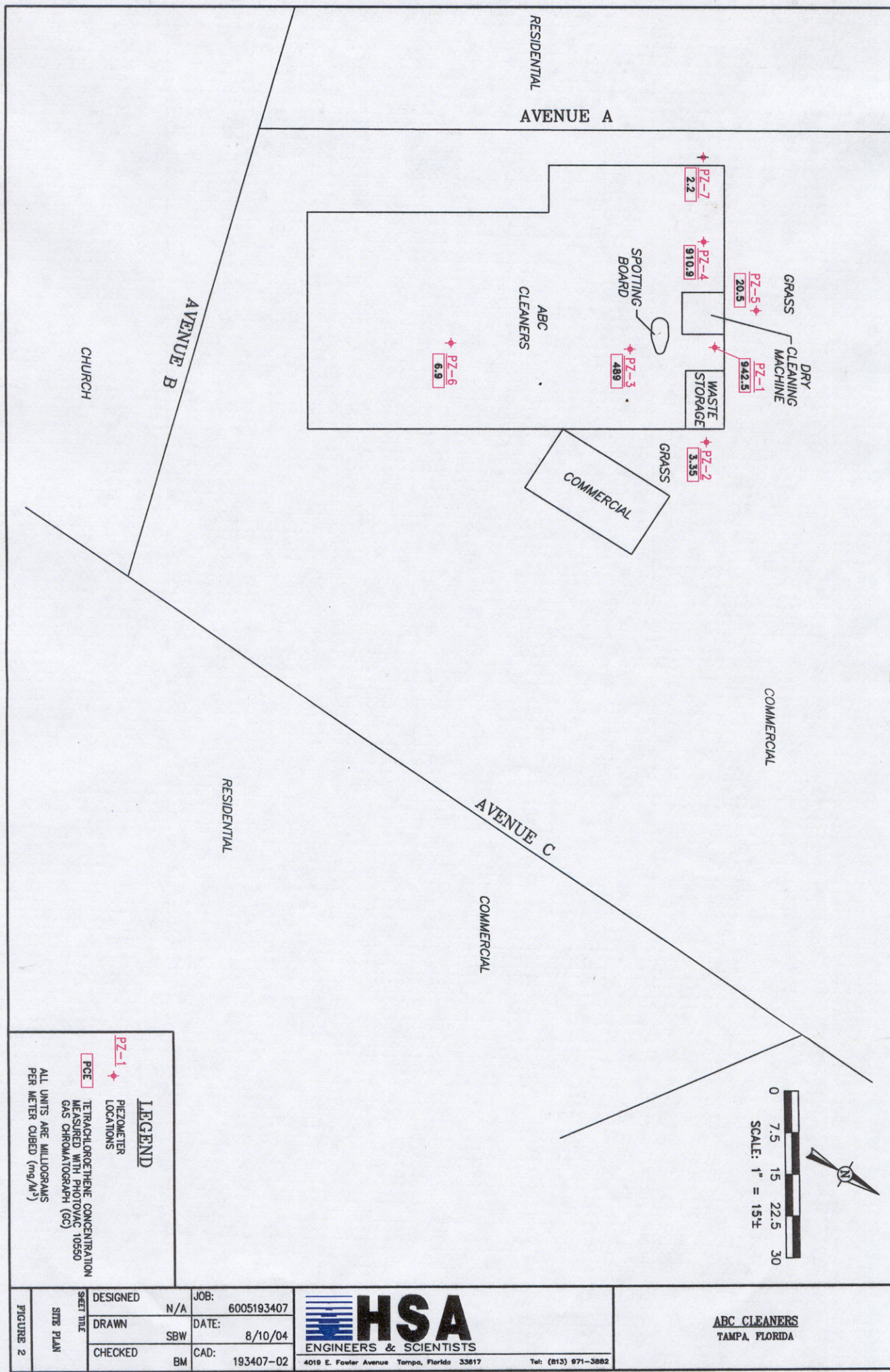
DESIGNED	SF	JOB #:	6005193407
DRAWN	SBW	DATE:	6/27/04
CHECKED	SF	CAD #:	163407-01



4019 E. Fowler Avenue Tampa, Florida 33617

Tel: (813) 971-3682

MAGS PROTOCOL



LEGEND

PZ-1 + PZ-1
PIEZOMETER LOCATIONS

PGE TETRACHLOROETHYLENE CONCENTRATION MEASURED WITH PHOTOVAC 10590 GAS CHROMATOGRAPH (GC)

ALL UNITS ARE MILLIGRAMS PER METER CUBED (mg/M³)

FIGURE 2	DESIGNED	N/A	JOB:	6005193407	 HSA ENGINEERS & SCIENTISTS 4018 E. Fowler Avenue Tampa, Florida 33617 Tel: (813) 971-3882	ABC CLEANERS TAMPA, FLORIDA
	DRAWN	SBW	DATE:	8/10/04		
	CHECKED	BM	CAD:	193407-02		



APPENDIX A

Equipment Specifications

DR 505M & CP 505M Regenerative Blower

FEATURES

- Manufactured in the USA – ISO 9001 compliant
- CE compliant – Declaration of Conformity on file
- Maximum flow: 160 SCFM
- Maximum pressure: 65 or 80 IWG
- Maximum vacuum: 5.2" Hg (70.8 IWG)
- Standard motor: 2.0 or 2.5 HP, TEFC
- Cast aluminum blower housing, impeller & cover; cast iron flanges (threaded)
- UL & CSA approved motor with permanently sealed ball bearings
- Inlet & outlet internal muffling
- Quiet operation within OSHA standards

MOTOR OPTIONS

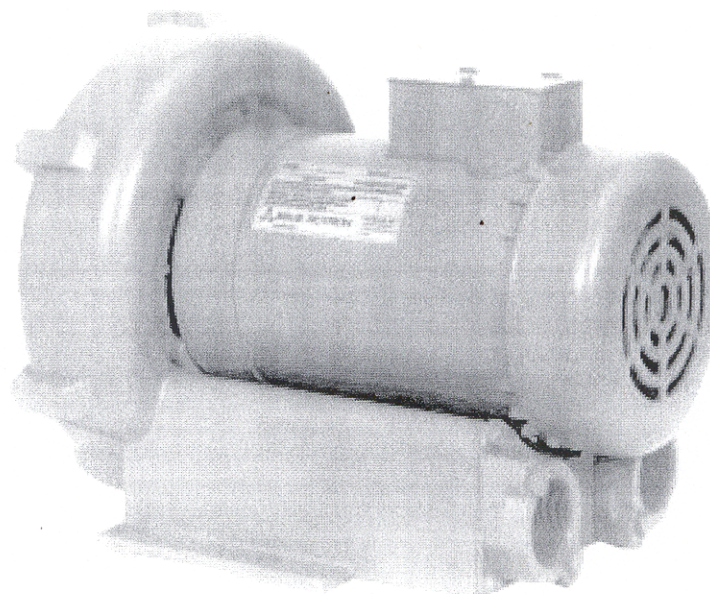
- International voltage & frequency (Hz)
- Chemical duty, high efficiency, inverter duty or industry-specific designs
- Various horsepower for application-specific needs

BLOWER OPTIONS

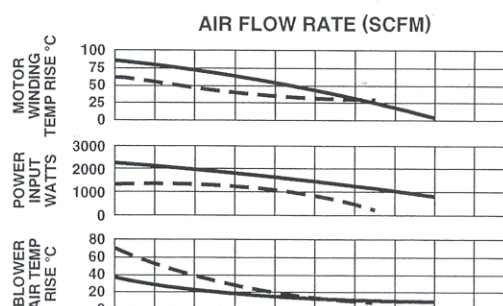
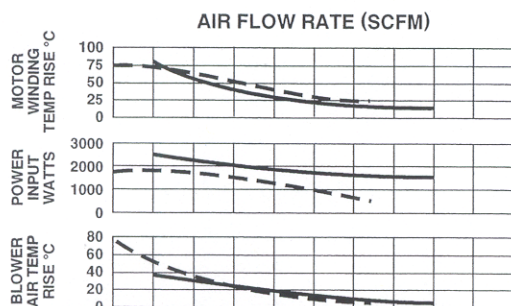
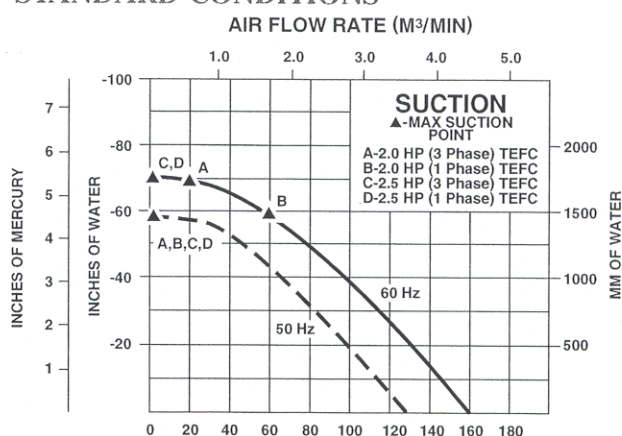
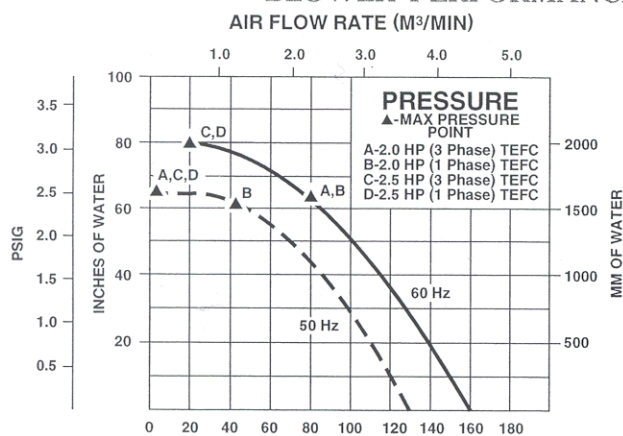
- Corrosion resistant surface treatments & sealing options
- Remote drive (motorless) models
- Slip-on or face flanges for application-specific needs

ACCESSORIES (See Catalog Accessory Section)

- Flowmeters reading in SCFM
- Filters & moisture separators
- Pressure gauges, vacuum gauges & relief valves
- Switches – air flow, pressure, vacuum or temperature
- External mufflers for additional silencing
- Air knives (used on blow-off applications)
- Variable frequency drive package



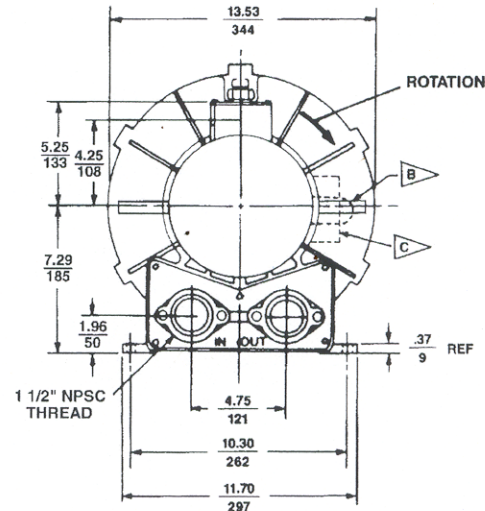
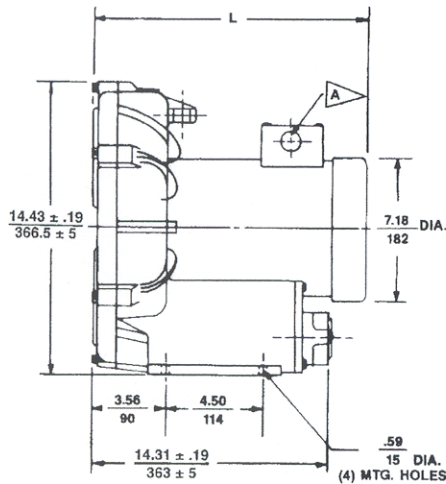
BLOWER PERFORMANCE AT STANDARD CONDITIONS



Rev. 2/01

DR 505M & CP 505M Regenerative Blower

Scale CAD drawing available upon request.



DIMENSIONS: $\frac{\text{IN}}{\text{MM}}$
TOLERANCES: $.XX \pm \frac{.08}{2}$
(UNLESS OTHERWISE NOTED)

MODEL	L (IN) $\pm .30$	L (MM) ± 8
DR505CD58M	15.28	388
DR505CD72M	13.78	350
DR505AS58M	15.28	388
DR505AS72M	13.78	350
DR505AS86M	13.78	350
CP505CT72MLR	13.78	350
CP505FE72MLR	13.78	375

- A** $\frac{.87}{22}$ DIAMETER ON TEFC MOTOR
- B** CAPACITOR LOCATION ON SINGLE PHASE MOTORS
- C** CONDUIT BOX LOCATION ON XP MOTOR. CONTAINS .75 INCH PIPE TAP

SPECIFICATIONS

MODEL	DR505AS58M	DR505AS72M	DR505AS86M	DR505CD58M	DR505CD72M	CP505FE72MLR	CP505CT72MLR
Part No.	037542	037543	037544	037546	037545	038239	038237
Motor Enclosure – Shaft Material	TEFC – CS	TEFC – CS	TEFC – CS	TEFC – CS	TEFC – CS	ChemTEFC–SS	ChemTEFC–SS
Horsepower	2.0	2.0	2.0	2.5	2.5	Same as DR505CD72M – 037545 except add Chemical Processing (CP) features from catalog inside front cover	Same as DR505AS72M – 037543 except add Chemical Processing (CP) features from catalog inside front cover
Voltage ¹	115/230	230/460	575	115/230	230/460		
Phase – Frequency ¹	Single - 60 Hz	Three - 60 Hz	Three - 60 Hz	Single - 60 Hz	Three - 60 Hz		
Insulation Class ²	F	F	F	F	F		
NEMA Rated Motor Amps	18.2/9.1	5.4/2.7	2.3	21.6/10.8	6.6/3.3		
Service Factor	1.15	1.15	1.15	1.15	1.15	Same as DR505CD72M – 037545 except add Chemical Processing (CP) features from catalog inside front cover	Same as DR505AS72M – 037543 except add Chemical Processing (CP) features from catalog inside front cover
Locked Rotor Amps	138/69	38/19	21	150/75	48/24		
Max. Blower Amps (At Cutoff) ³	24/12	7.4/3.7	3.0	26/13	10/5		
Recommended NEMA Starter Size	1/0	0/00	00	1.5/0	0/0		
Shipping Weight	83 lb (38 kg)	76 lb (35 kg)	82 lb (37 kg)	91 lb (41 kg)	82 lb (37 kg)		

¹ Rotron motors are designed to handle a broad range of world voltages and power supply variations. Our dual voltage 3 phase motors are factory tested and certified to operate on both: **208-230/415-460 VAC-3 ph-60 Hz** and **190-208/380-415 VAC-3 ph-50 Hz**. Our dual voltage 1 phase motors are factory tested and certified to operate on both: **104-115/208-230 VAC-1 ph-60 Hz** and **100-110/200-220 VAC-1 ph-50 Hz**. All voltages above can handle a $\pm 10\%$ voltage fluctuation. Special wound motors can be ordered for voltages outside our certified range.

² Maximum operating temperature: Motor winding temperature (winding rise plus ambient) should not exceed 140°C for Class F rated motors or 120°C for Class B rated motors. Blower outlet air temperature should not exceed 140°C (air temperature rise plus inlet temperature). Performance curve maximum pressure and suction points are based on a 40°C inlet and ambient temperature. Consult factory for inlet or ambient temperatures above 40°C.

³ Maximum blower amps corresponds to the performance point at which the motor or blower temperature rise with a 40°C inlet and/or ambient temperature reaches the maximum operating temperature.



APPENDIX B

FID Values and Interpretations

Interpretation of MAGS event ABC Cleaners

PZ-1

The FID plot shows a relatively flat line with little decrease over time from values between 30-40 ppm. This phenomena appears to be a result of a source that is in the direct vicinity of the sampling point which is not limited by mass transfer.

PZ-2

The FID plot shows a declining response which was relatively low at the onset (1.0-1.5 ppm), then declined to levels near the detection limit of the equipment. This phenomenon appears to be a result of a less efficient surface seal, as well as an example of vapor transport.

PZ-3

While higher in FID response initially, the FID plot follows a decline similar to PZ-2, exhibiting effects of vapor transport. This phenomenon is demonstrated more effectively at this point, given the fact that this point was beneath a more effective surface seal.

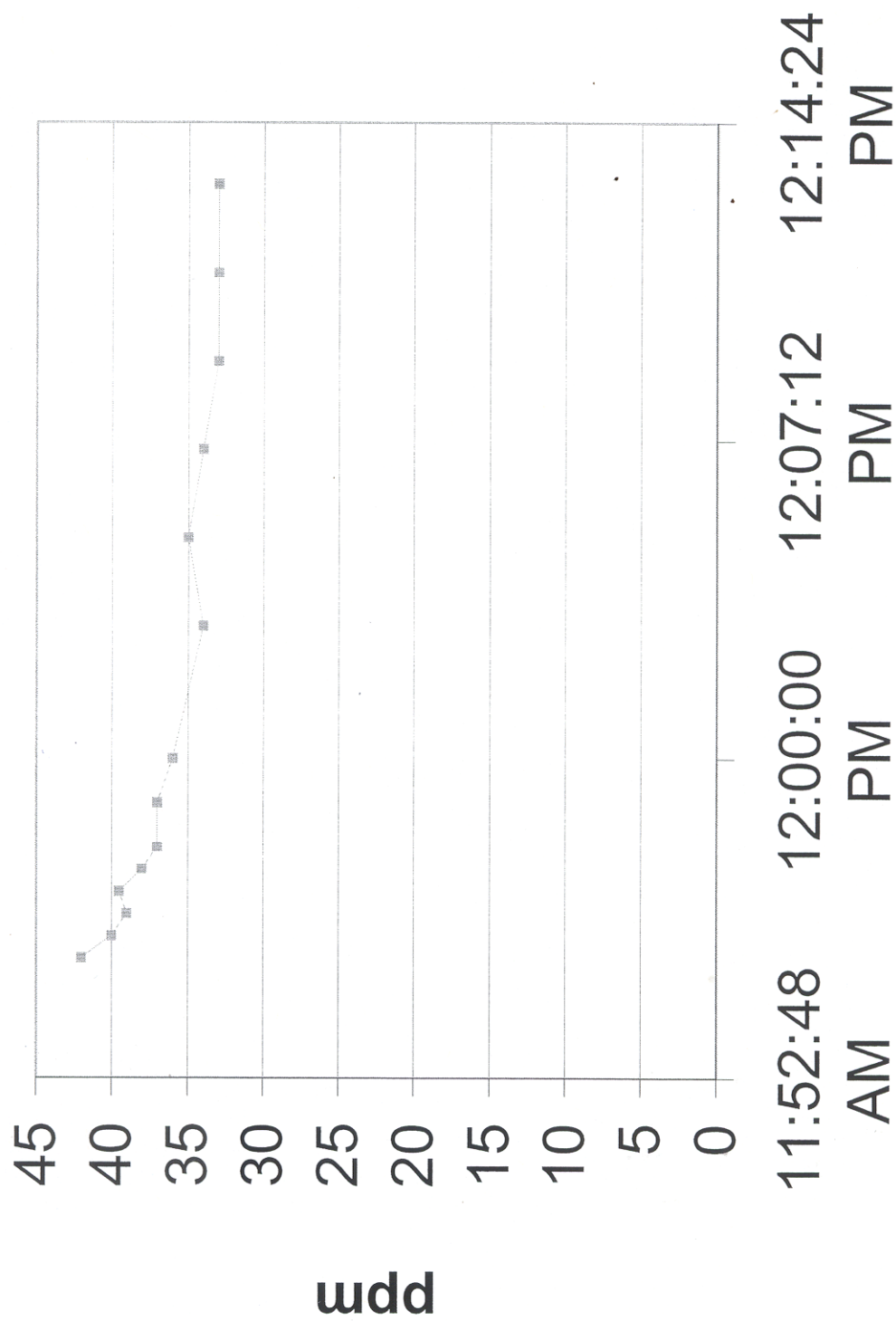
PZ-4

The FID plot follows the results similar to PZ-2, demonstrating a limited source that is not sustained throughout the test. This is also likely a result of vapor transport, albeit more substantial impacts as a result of the proximity to the source near PZ-1. In fact, due to the proximity of PZ-4 to the source area, it is likely that the plot would show asymptotic behavior at an elevated value should purging at this point have been conducted over a longer period of time.

PZ-5

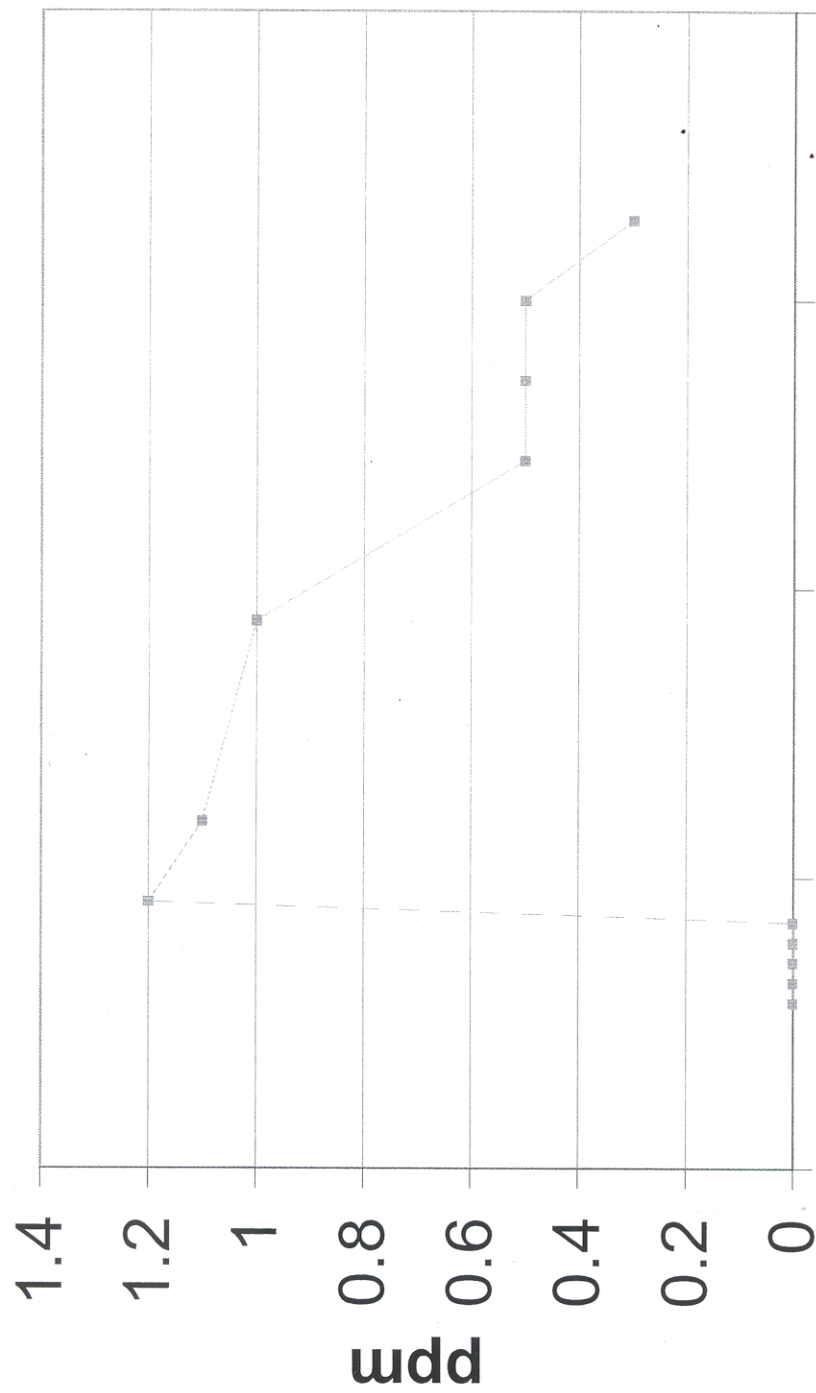
The scale of the FID results for this monitoring point suggests an unimpacted vapor stream. While some vapor transport impacts would be expected, the lack of a sufficient surface seal likely allowed short circuiting near the monitoring point and resulted in significant dilution of the vapor stream with ambient air.

PZ-1



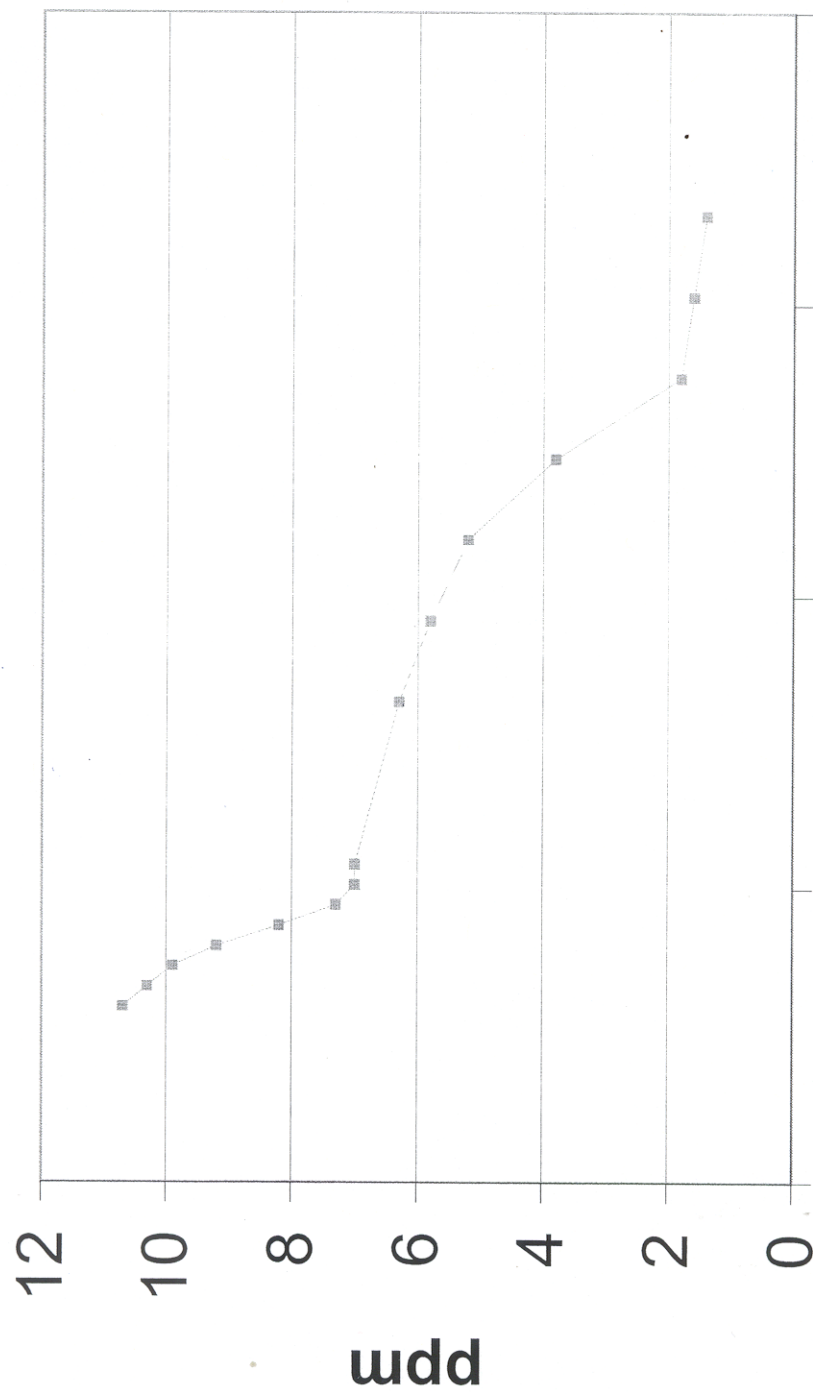
FID

PZ-2



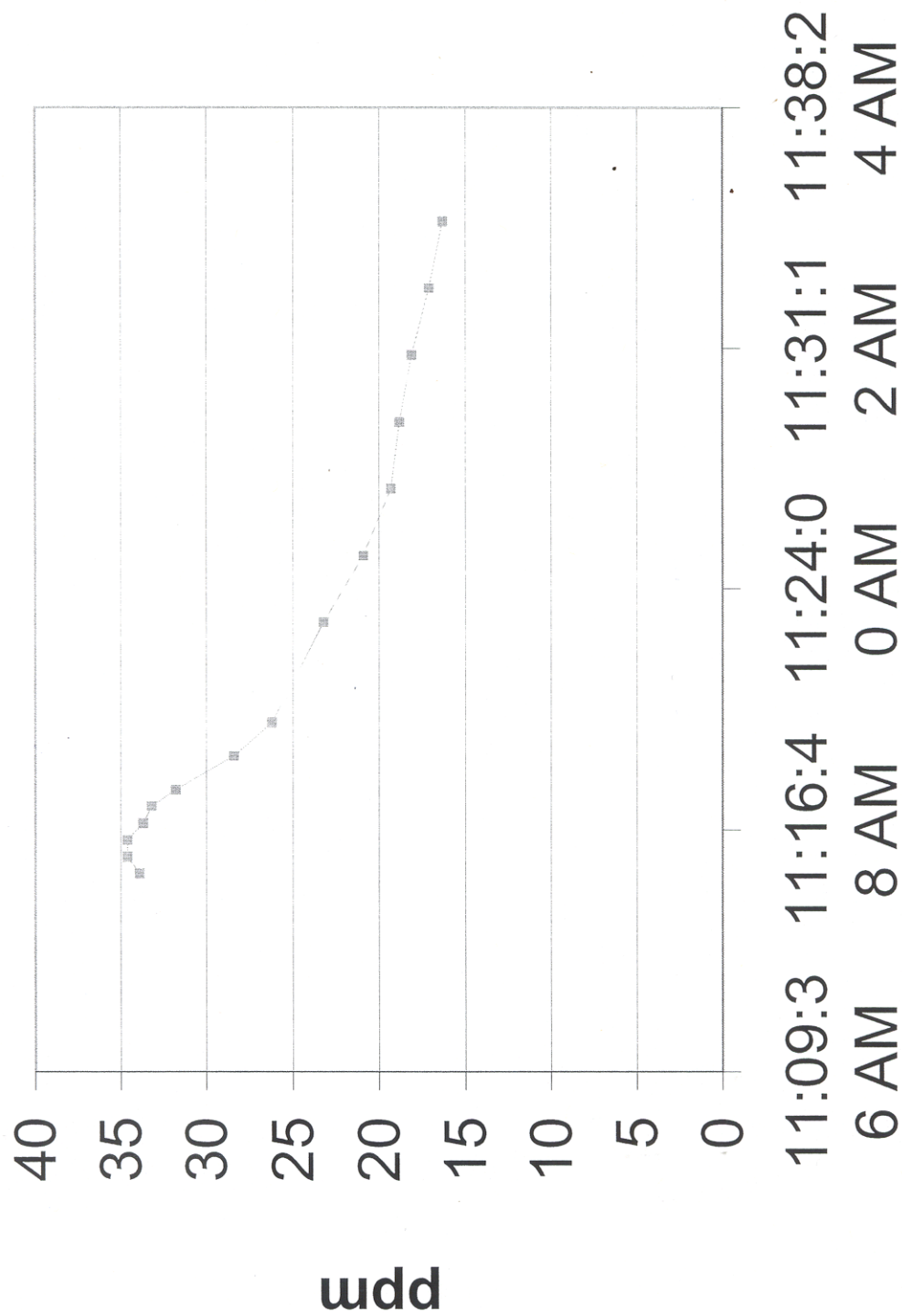
FID

PZ-3



FID

PZ-4



FID

PZ-5

