Impact Of The Use Of Ambient Catalysts In Stationary Air Conditioning Systems On Houston-Galveston-Area (HGA) Air Quality

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The Federal Clean Air Act (FCAA) amendments of 1990 make Houston-Galveston-Area (HGA) classified as severe-17 for a metropolis region. Due to the severe-17 classification of HGA and prohibitive cost of further reductions by emitters, the technologies like direct ozone reduction (DOR) catalysts that could attack ozone and provide further alternative emission reductions became more urgent. This work explores implementation of ambient catalysts of stationary air conditioning compressorsby the Texas Commission on Environmental Quality (TCEQ). Further, potential usage estimated by industry professionals and the catalytic requirements impact on ambient ozone levels in HGA from 2001 through 2005 are modeled using applicable Direct Ozone Reduction (DOR) catalyst. The CAMx modeling results demonstrated that ambient DOR catalysts have an immediate impact on ozone concentrations. Survey data demonstrates that the case study DOR catalyst will have greatest impact on air quality within regions of higher population densities and lesser impact in industrial locations.

Keywords— CAMx,Ozone, Direct Ozone Reduction, Air Conditioning.

1. Intruduction

The Federal Clean Air Act (FCAA) in the United States established the National Ambient Air Quality Standards (NAAQS) for assuring air quality. The states were required to achieve the target attainment of NAAQS for limited pollutants that included carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, lead and particular matter. FCAA amendments of 1977 required states that did not have all areas comply with air quality standards to submit a state implementation plan (SIP) that would bring the pollutant concentrations under NAAQS for those regions. In November of 1979, Houston-Galveston-Area (HGA) became the first region in Texas to require a state implementation plan due to its high levels of measured ozone concentrations that exceeded the NAAQS standards. More recently, The FCAA amendments of 1990 resulted in the HGA being classified as severe for lack of ozone attainment. Currently, the HGA is classified as severe-17, the second most serious ranking given by the US EPA for a metropolis region [1]. This classification means that the HGA has an observed ozone concentration between 190 and 280 parts per billion and this concentration level mandates attainment of lower ozone concentrations than the NAAQS within 17 years. Due to this classification, the HGA must attain an eight-hour standard for ozone of 75 parts per billion by December 31, 2015.

Houston is considered the "air conditioning capital of the world" according to many of the industry experts. It is estimated that in 1991, Houston had 2 million tons of air conditioning and must be over 3 million in 2000. Based on data from the U.S. Energy Information Administration and U.S. Census Bureau, it was estimated that Houston-Galveston-Area have 4.72 million tons of air conditioning in 2010 [2-4]. The refrigerants release and gas emissions associated with energy use from these air conditioning systems during the phases of install, operation, maintenance, and ultimately disposal impose significant environmental impacts on ambient air quality. It was reported that up to 0.5% of refrigerants in air-conditioning systems are lost annually due to leakage and purge releases [5]. In a scenario model simulation study, the model prediction of alternative refrigerants annual emissions from refrigeration and air conditioning systems were expected to be 9.0 million tons of CO_2-eq from year 2008 onwards [6]. The

inventory data results of life cycle assessment (LCA) on alternative air-conditioning systems demonstrated that the lifetime emissions of a single air-conditioning system for Hydrofluorocarbons (HFC) refrigerants, NOx, and SO_x were 11 kg, 1788 kg, and 4289 kg, respectively [7]. The presence of hydrogen and C-H bond in refrigerant emissions can contribute to photochemical ozone formation in the boundary layer in a manner similar to other volatile organic compounds (VOCs). In the presence of nitrogen oxides, VOCs are oxidized in the surrounding urban boundary layer under sunlight and generate free radical fragments which result in the elevated ozone concentrations. [8]

Due to the severe-17 classification of HGA and prohibitive cost of further reductions by emitters, the role of technologies like direct ozone reduction (DOR) catalysts that could attack ozone and provide further alternative emission reductions became more urgent. Substantial flow of ambient ozone moves across air conditioning compressors to exchange heat. In the year 2000, the Texas Commission on Environmental Quality (TCEQ) proposed mandatory application of DOR catalysts on all new installations of air conditioning compressors within the region encompassing the HGA. TCEQ provided an implementation plan to regulate the use of DOR catalysts within Texas.

Within available DOR catalyst literature, The PremAir® Catalyst System has the highest reported ambient ozone conversion rate ranging between 47 and 75% conversion of contacted ozone [9]. The PremAir® Catalyst System is an expansion of the long-standing history of the Deoxo® catalytic ozone converter. Formulated to convert ambient ozone into diatomic and monatomic oxygen, the PremAir® Catalyst System is advertised as a base metal coating that when applied to high air flow surfaces will react with the ozone in the air and lower the ambient ozone concentration. The Deoxo® catalytic ozone converters are placed in high flying jets to treat cabin air and prevent ozone exposure effects such as "headache, fatigue, shortness of breath, chest pains, coughing, and irritation of eyes, nose or throat" [10]. According to the company literature, the air treatment canisters are lightweight, small, easy to install and maintain, and have a long service life with a very small pressure drop. Boeing, Lockheed, Airbus, Gulf Stream, and Falcon use Deoxo® canisters [10].

This paper studied the potential impact of a DOR catalyst, that showed the highest ozone conversion rate reported in the academic literature. Industry experts are surveyed for their estimations of their market and estimated sales data is used to show the impact of the DOR catalyst upon the HGA region. The results provide a baseline to address the societal cost of the technology's implementation. This study consists of two major sections. The first section introduces a case study of the 2000 proposal by TCEQ to implement DOR catalyst on all stationary air conditioning compressors in the HGA. The second section discusses the methodology to collect data for projected new stationary air conditioning installation within the Harris Country region through 2005 and the methodology to model the potential use of ambient air DOR catalysts on the air conditioner compressors and the corresponding impact on ozone concentrations. This included the method of data collection, the estimation of sources in calculations, the qualifiers that might impact model results, and a methodology on forecasting the impact of the technology as its rate of implementation increases.

2. Methodology

2.1 Data collection

The TCEQ monitoring sites are located throughout HGA region and the addresses of the most prominent monitoring sites in Harris County were entered into an Internet business data base search engine [11]. A list of about 250 air conditioning installers around each monitoring site is identified using typical internet search engines. Telephone and mail surveys were designed and all 250 companies were called targeting their business owner or business manager as the information source. In the survey, air conditioning installers estimated the tonnage of air conditioning they would install or did install in 2001 in the residential, commercial, and window unit areas. Installers then estimated how much of this total would be installed in the HGA area. Air conditioning installers then estimated their business growth per year through 2005. Data collected from the survey of air conditioning installers were plotted geographically using mapping software. A grid was overlaid across the Harris County area and a colored pin reported the total amount of tons present in each cell. The resulting color-coded and size charts are presented in Figure 1. TCEQ uses nested grids to focus study on defined areas. The HGA region grid is parceled into 4 km by 4 km cells and is part of two much larger Texas region grids [12]. Figure 1 displays an example of how survey data was distributed and shows the relative location of environmental monitoring devices. The darker the color assigned, the higher the sales density. The sales density is greatest in the central west area near the intersection of Highway 59 andLoop 610 a region known as the Galleria region.
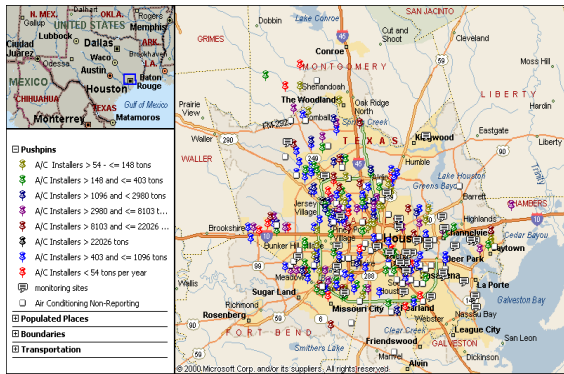
Figure 1. Two km by Two km Grid Sales in Tons of Air Conditioning Capacity 2005

2.2 Modeling process

The effect of the ozone conversion by the DOR catalyst on the ozone concentration in the atmosphere is estimated using three models in the following section. In the Initial Concentration Model (ICM) ozone destruction simulation is estimated through the modification of input files for the upper atmospheric concentrations above the model and the initial concentration for the first grid time period. In the second model, the Ground Deposition Model (GDM), the Comprehensive Air Quality Model with Extensions (CAMx) ground deposition is increased to account for the presence of DOR catalyst air conditioner within the lowest level of the grid. In the third model, the Reaction Rate Model (RRM), an additional reaction is added to the Carbon Bond IV atmospheric reactions and is activated only during daylight hours and only in the bottom layer of the model based on the grid's air conditioning sales density.

The ground deposition model modifies FORTRAN data code for CAMx inputs. The deposition rate (rate at which ozone is deposited into earth surface) is increased to simulate the impact of DOR catalyst. The impact of one year's air conditioning installation was estimated. Next the impact of 5 years of estimated air conditioning installation was input into the model varying deposition rates by varying estimated impact of DOR catalyst using low, medium and high surface deposition rates.

The reaction rate model providedthe last estimate by adding an additional chemical reaction to account for the destruction of ozone into a variety of potential products of monatomic oxygen and diatomic oxygen by DOR catalyst. This DOR catalyst reaction is combined with the existing 96 chemical reactions within the base CAMx model. These models are then run through a test case and new sets of reactions are applied to the HGA region based on an air conditioning installation data.

Comprehensive Air Quality Model with extensions (CAMx) was used to demonstrate the effectiveness of applying DOR catalysts on stationary air conditioning systems on the ozone concentration within HGA region. One method of simulating the DOR catalyst is by modifying the dry deposition V_d rates that simulate the consumption of ozone at the surface of the earth by plants, animals, and other materials. CAMx determines dry deposition using the methodology described in "Parameterization of Surface Resistances to gaseous dry deposition V_d in Regional-Scale Numerical Models" [13]CAMx model is run as described in continuous steps listed below.

- Emissions are put into the model from sources based on emission inventories and reported pollution rates.
- Chemical reactions occur throughout the grid.
- Meteorological conditions move the air mass and the effects of advection and diffusion occur.
- Pollutant deposits are made upon ground resistance.
- Process is repeated for the next time step.

To simulate the potential impact of a DOR catalyst, a simplified theoretical effect of a potential DOR catalyst is necessary as an input to the top concentration file. For this calculation, total cubic kilometers, air conditioning processing rate, assumed ozone destruction efficiency and air conditioning density in the region are the necessary inputs. To calculate air conditioning density, the tons of air conditioning in HGA region were estimated and divided by the volume of the HGA ground layer in cubic meters. Using a conservative estimate of 3 million tons of air conditioning and 1000 cfm per 3-ton air conditioning unit, we get 1,000,000 units or roughly 1 unit per every 8000 m^2 or on the lower TCEQ layer 1 unit per 271,200 m^3[14]. This would average 1933 units per 4 km by 4 km cell and 125 units per 1 km by 1 km cell.

The DOR catalyst's published ozone conversion efficiency is roughly 70% for a new unit [15]. The volume of air processed in one day by one unit is 4.077 x 10^4 m^3 of air per day [16]. For the 1 km grid, 125 units (UG4) would process 5.097 x 10^6 m^3 per day or 15% of the volume of the each cell.

To calculate the effect of the DOR catalyst on the 1 km x 1 km area (Grid 4), the study assumes no mixing of the air with other regions. With no atmospheric mixing occurring with other surrounding cells of air and assuming initial ozone concentrations of 120 ppb, 15% of the volume of the cell would contact the DOR catalyst. A portion, such as 70%, of this contacted ozone would be destroyed leaving a concentration of remaining ozone of roughly

$$(120 \times (1-.15)+120(.3 \times .15))=107 \text{ ppb.}$$ The concentration of the 1 km cell would have been reduced over a 24-hour period from 120 ppb to 107 ppb if the air in the layer had remained in place.

The HGA region has 14 layers for atmospheric modeling. Meteorological conditions cause mixing and dispersion between layers. If 13 equal layers of 33.9 meter height (a total column of 474.6 m) were fully mixed with the lower layer the resulting ozone concentration would be $$(120 \times 13 + 107)/14 = 119 \; ppb.$$ These upper layers would disperse higher levels of ozone into the processed air resulting in substantial decrease in the measurable effect of the DOR catalyst from ground monitoring sites. This establishes a base line by which model performance can be measured.

2.3 Ground Deposition Model

The ground deposition model was run to determine the possibility of simulating the DOR catalyst using land disposition rates in CAMx. No previous study was identified to calculate the ozone consumption to resistance equivalence and the modeling modification of the resistance layer. CAMx is used to calculate ground resistance with the equations reported in the literature for gaseous dry deposition V_d. There are three resistances that make up the ground layer resistance, γ_a, the aerodynamic resistance, γ_h, the quasi-laminar sublayer resistance and γ_s, the surface resistance.

This work assumes that any DOR catalyst would have a small affect on the ozone concentration due to the modeling grid size (1,000,000 m^3 and 16,000,000 m^3). Further, the impact of the DOR catalyst is reduced due to meteorological mixing as demonstrated in the initial concentration model. For these reasons, the ozone consumption was added to the deposition velocity. The factors considered in the calculation of ozone deposition are as follows.

ACS = Air Conditioning Sales (tonnage) = 3 million tons

AP = Air Conditioning Processing rate (cfm) =1000 cfm

CV = Conversion factor (4.719×10^{-4} f^3/s to m^3/s)

GS = Grid size (meters squared) = 8000 Km^2

V_d = CAMx calculated vertical deposition velocity for Ozone (m/s)

CE = Catalyst Efficiency = 70%

Therefore, the value used for the adjusted ground deposition V_{da} test case is as follows.

$$V_{da} = V_d + (ACS \times CE \times AP \times CV) \div GS \quad \textbf{(1-1)}$$

$$V_{da} = V_d + 4.130 \times 10^{-5} \; \text{m/s} \qquad \textbf{(1-2)}$$

For the HGA model run, there are two large grids covering the HGA region. Grid 3 covers the Houston Galveston region while Grid 4 covers the eastern portion of Harris County. The ACS value is drawn by CAMx from an input file developed from survey datafile which allocated estimated air conditioning installations to individual cells. Grid 3's cells (GS) are 4 km^2 or 4,000,000 m^2 while Grid 2's are 1 km^2 or 1,000,000 m^2. For the value of AP, air conditioners are assumed to run at 1000 cfm. Catalytic efficiency (CE) is estimated at 70% [15]. Equation (1-2) is used for each to calculate each varying ground deposition V_{da} for Grid 3 and Grid 4 respectively.

Using survey data, the impact of the DOR catalyst can be determined in the 5th year. Survey data revealed a total of 383,100 tons of air conditioning for the year 2000. Survey installation data projected 543,600 tons installed in year 2005. This yields a 9.16% annual growth rate (GR) for the industry. For each cell, the average total tons installed in that cell by the year 2005 are shown in the following equation.

Year 2005 air conditioning capacity in tonnage
$$\left(1+(1+GR)+(1+GR)^2+(1+GR)^3+(1+GR)^4\right)$$
$$\times \text{Year 2000 tonnage}$$

(1-3)

A range of the DOR catalyst effects can be simulated by multiplying by a high estimate of the DOR catalyst efficiency (70%), a low estimate (15%), and a mid-point value (45%) for comparison. This provides a wide variance in technology effectiveness. Base emissions input data for the HGA were obtained from the TCEQ server. As a baseline, the CAMx model was run without any air conditioning ozone consumption.

2.4 Reaction Rate Model

The reaction rate model attempts to produce more accurate estimations of the affects of DOR catalyst. Within the CAMx model various chemical reactions are included to estimate the chemical breakdown or formation of pollutants within the atmosphere. The predominant model, the Carbon Bond IV Mechanism, is a list of 96 chemical reactions that estimate the potential chemical reactions between pollutants within the atmosphere. The Carbon Bond IV mechanism lists the products, reactants, reaction rate, and activation energy of the 96 reactions. To estimate the impact of DOR catalyst within the CAMx model, the following assumptions were simulated in the model.

- Ozone (O_3) is broken down into diatomic oxygen O_2 within the Carbon Bond IV mechanism list. This study adds an additional ozone disassociation reaction to the CAMx model's atmospheric

reactions based on the ozone disassociation caused by DOR catalyst's reported reaction rate. This simulates the presence of active DOR catalyst on an air conditioning's compressor within the ground layer grids of the model. The ozone disassociation reaction rate is then proportioned to the current grid according to the cell size. It is also proportioned by the cell's estimated number of tons of air conditioning cooling capacity reported by the survey.

- The disassociation reaction of ozone breaking into a less excited ground level monatomic Oxygen (O^{3P} where 3P designates the electronic state of the O atom verses 1D at higher energy levels) is currently present in the Carbon Bond Mechanism Version IV and is stated to be first order. The DOR catalyst acts to speed the reaction of Ozone into oxygen components and therefore this catalytic reaction is assumed to be first order when ozone is broken down into only diatomic oxygen (O_2).

- The air exiting an air conditioners compressor is heated up to 20° Celsius higher than the ambient air due to diffusion of heat by the air conditioning coils. Many chemical reaction rates are temperature dependent as is the case of ozone disassociation listed in the Carbon Bond Mechanism IV. To simulate the additional heat within the air conditioning compressor, 20° Celsius was added to the current cell's temperature for the Arrhenius equation, which is used to solve for reaction rate. Heated air would rise and mix with non-ground layers of the model and DOR reaction products would be present to participate in further chemical reactions.

- Within the CAMx reaction solving mechanism, some potential DOR reaction products are listed as radicals with very short non-reactant lifespan. By adding the catalytic reaction to the Carbon Bond Mechanism Version IV reaction list, the products of DOR catalyst reactions are available to react within the cells to reform other pollutants.

- The mass of the DOR catalyst determines the reaction rate. Assuming the amount of DOR catalyst is relatively small compared to the volume of the cell, then it is assumed that doubling the amount of DOR catalyst will double the environmental ozone destruction. Therefore, a cell with more units is assumed to have a proportionally higher production rate.

The DOR catalyst reaction rate (k_4) was estimated from DOR catalyst literature [17]. A java calculator was used to solve for the reaction rate at a temperature of 298 ^oK. Reaction rate at each temperature and space velocity can be derived from the following equation.

$$Ln(1 - \text{ozone conversion}) = \frac{-k_4}{\text{space velocity}} \quad \textbf{(1-4)}$$

The following chemical reaction was assumed to describe the DOR catalyst reaction. The equation involves the production of only diatomic oxygen (O_2) suggested by some literature producing the balanced equation [18].

$$2O_3 \rightarrow 3O_2 \quad \textbf{(1-5)}$$

Since CAMx does not account for concentrations of non-pollutants such as diatomic oxygen (O_2), the reaction written into CAMx code destroys an ozone molecule without replacing its mass in the system. CAMx assumes constant initial oxygen concentrations within the grid. Further, the destruction or production of nonpollutants within all Carbon Bond IV chemical reactions are also not tracked through each cell. Two other potential chemical reactions could explain the DOR catalyst break down of ozone but are less likely due to the speed of their products reacting with other material. The catalyst could produce monatomic ground level oxygen (O^{3P}) and diatomic oxygen (O_2). Monatomic oxygen exists only for nanoseconds before reacting and its presence and fate is calculated by the CAMX radical solver.

$$O_3 \rightarrow O^{3P} + O_2 \quad \textbf{(1-6)}$$

$$O_3 \rightarrow 3O^{3P} \quad \textbf{(1-7)}$$
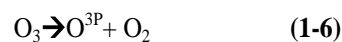
3. Results and Discussion

TCEQ estimates that around 35 tons per day of NO_x and VOCs would need to be removed from the Harris County air to attain NAAQS. The TCEQ estimates that if ambient DOR catalysts were considered to function at their highest theoretical efficiency, the equivalent of 13.5 tons per day of equivalent NO_x would be removed by ambient DOR catalyst from HGA air. The DOR catalyst studied here has the potential to lower ozone concentrations, however there might exist the possibility for migration into other media (Ground and Soil).

To prepare the HGA model, data was collected from the 23rd through the 30th of the August test case were run through the system. All modeling variations were then conducted on the data set from the 31st. Test case and HGA original files were identical output to determine the maximum concentrations that the model calculated for the cell time step. Figure 2 is a plot of the output of this file.

As shown in Figure 2, at 160 ppb concentration for the large grid and the 170 ppb concentration for the small grid, the base case HGA model estimates are higher than the 120 ppb NAAQS. Note that, as the afternoon approaches, ozone concentration nearly

doubled. This data provided the base case or original file for the study. All the HGA model variations were compared against this data to generate ozone differences.
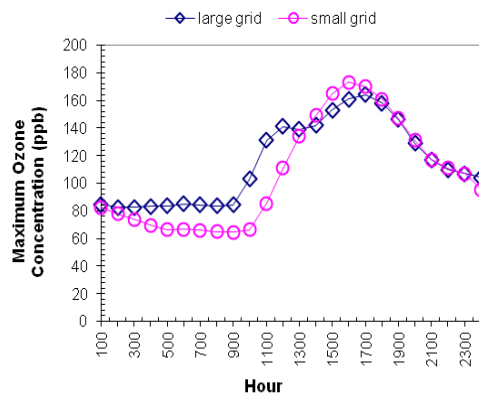

Figure 2 HGA Original Maximum Ozone Concentrations in Grid

3.1 Ground Deposition Model

The Ground deposition model was processed through the test case and the results showed reduction potential. The Ground deposition model was then run for the HGA region. Three further HGA runs estimated the difference with the anticipated growth for 5 years with the DOR catalyst at 15%, 45% and 70% effectiveness. Figure 3 graphs the maximum difference between the respective runs and the baseline run. In Figure 3, the maximum concentration values for the 70% conversion efficiency model run generated lower ozone concentrations than the 45% conversion and the 15% conversion runs, which is not anticipated. This may suggest a nonlinear relationship between the final concentration and deposition velocity. As expected, Figure 3 showed increases in ozone consumption through the afternoon similar to the trend present for the base case.

In terms of overall effectiveness, ozone consumption throughout the grid at its maximum difference from baseline can be compared to the ozone value in its parent grid to determine the maximum effectiveness of the DOR catalyst within the grid. The Ground deposition model for the 1 year data at 70% ozone conversion resulted in a spike in the ozone conversion in evening hours as well as lower conversion during the hotter hours of the day. compared to the calculations in the initial concentration model, this model and the underlying survey data tend to understate ozone conversion. The average difference in ozone concentration from the base case for both grids is between 2.4×10^{-6} ppm and 5.7×10^{-7} ppm.
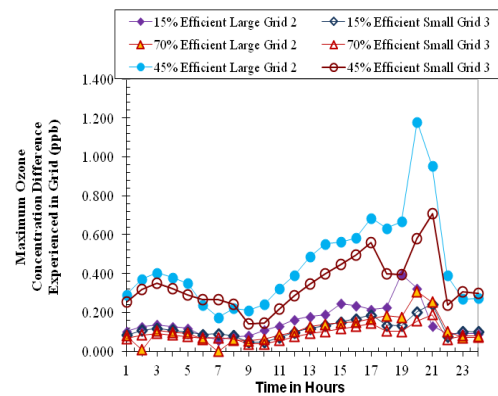

Figure 3. Ground Deposition's Hourly Ozone Concentration Differences After 5 Years of Air Conditioning Installation

3.2 Reaction Rate Model

The reaction rate model was processed through the test case and the results showed ozone reduction potential. The reaction rate model was then run for the HGA region with coding generating a reaction destroying ozone and producing only diatomic oxygen. Two further reaction rate models were run. The first was run with a reaction rate one half the Arrhenius reaction rate solution. The second run was written to produce monatomic ground level oxygen in the manner of Equation 1-7. The interaction of ozone with NO_x is extremely complex when factored with the other 96 reactions in the Carbon Bond IV system. The production of monatomic oxygen (O^{3P}) from ground level ozone is within the Carbon Bond IV reaction list and is classified as a photolysis reaction. Thus, the reaction of an ozone molecule triggered by a DOR catalyst and producing diatomic oxygen (O_2) or oxygen radicals may simply lead later to reformation of ozone.

CAMx does not vary diatomic oxygen (O_2) from cell to cell and reports diatomic oxygen (O_2) as a constant for all time periods within the model run. Since oxygen concentration is not varied in the CAMx model, an additional reaction to account for ozone destruction produces diatomic oxygen that disappears from the model mass calculations. The reaction rate model results of the DOR catalyst when producing only diatomic oxygen reports the average difference in concentration from the base case for both grids between 1.1×10^{-3} ppm and 2.2×10^{-4} ppm which is higher than the Ground deposition model values (between 2.4×10^{-6} ppm and 5.7×10^{-7} ppm). Concentration changes from the base case begin to be apparent at 6:00 AM as ozone consumption begins within the model as the sun rises.

The reaction rate model shows catalytic technology has potential for destroying ozone and possibly other criteria pollutants in areas with high density of air conditioners. But the results obtained show relatively smaller impact. This may be

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accounted for by the fact that neither grid is totally populated by Harris County with much more of grid 3 populated with air conditioning survey data than that of the larger grid 2 which stretched to Louisiana. The maximum difference experienced in grid 2 ranged between 0.7 and 0.8 ppb/grid concentration ppb and in grid 3 ranged between 0.3 and 0.2 ppb/grid concentration ppb. The values are considerably higher than ground deposition values shown in Figure 3.

For comparison purposes, the DOR catalyst reaction rate was halved. The average difference in concentration from the base case for both grids is between 2.2×10^{-1} ppb and 6.7×10^{-1} ppb. These values are lower than the original reaction rate model average difference and higher than the ground deposition model values. Radical concentrations are not reported by CAMx output programs but varying their concentrations has a direct affect on pollutant levels. In hour seven, the model concentrations for ozone exceeded 1.0 for ozone concentration and below 1×10^{-10} ppm oxides of nitrogen (N_xO_y). As a verification to ensure correct interpretation of the model reaction rate calculation, the model was run with a negative value for the activation energy (E) divided by the gas constant (R). The large concentration movement of ozone increased dramatically with highest concentration value being higher than 10.
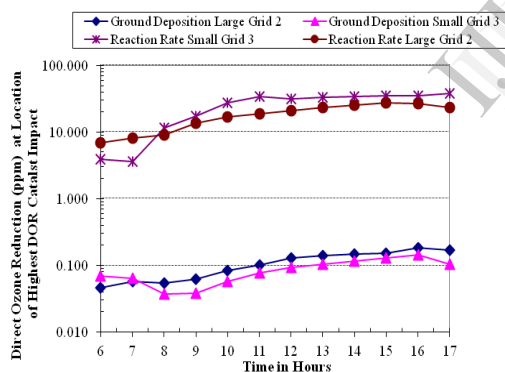

Figure 4. Comparison of Maximum Ozone Consumption between Ground Resistance and Reaction Rate Model

The ozone consumption by the DOR catalyst within grid 3 appears to be greater as the air conditioner flag is turned on during sunrise hours and large ozone concentrations are confronted by the reaction. The DOR catalyst literature does cite that the DOR catalyst has higher impact when higher concentrations of pollutants are encountered. Grid 2 also encompasses the largest concentration of air conditioners along the west central side of Harris County. Thus higher potential conversion effects from a high air conditioner dense cell are expected. In the HGA case , the maximum impacts of the DOR

catalyst is experienced in the 4 kilometer by 4 kilometer cells of grid 2 and are greater for higher reaction rates and at cells of higher estimated air conditioning installation tonnage. Determination of the effects of releases of increased radicals of oxygen remains to be demonstrated by experimental investigation. Currently, radical concentrations are not reported by emitters and the model assumes constant values for dipolar oxygen in all cases. The difference in model performance between the Ground deposition model and the reaction rate model is displayed in Figure 4. Ground Deposition is probably underestimated as survey data totals were lower than the previous estimates. Further study into the variation of the deposition term may increase its precision of simulating the DOR catalyst. Reaction rate changes in the reaction rate model seem to overstate the variations caused by ozone consumption. Sensitivity of the reaction rate to variation as well as further study on how to apply larger amounts of air conditioning density are necessary to increase model precision.

4. Conclusions

Air Quality modeling provides a method of quantifying and visually displaying atmospheric reactions in the Houston Galveston region. The modeling method was able to simulate the impact of ambient DOR catalysts on the air quality. Without field testing, the impact of the DOR catalyst in large quantities remains uncertain. Ozone destruction according to Carbon Bond IV mechanism in CAMx decreases the level of other pollutant formation. This impact is increased by assuming that the reaction produces radicals rather than simply dipolar oxygen and that these radicals become available for further atmospheric reactions. As they are in fast state relative to other atmospheric reactions, reaction rate adjustments appear to have a stronger impact than traditional ground deposition adjustments. Reaction rates are to be determined through experimental investigations. Currently, the deposition velocity method and the reaction rate results in this study differ by a factor of 1000 with the reaction rate model generating higher variances from the base case than the Ground deposition model.

Ambient DOR catalysts have an immediate impact on ozone concentrations. Survey data demonstrates that the case study DOR catalyst will have greatest impact on air quality within

regions of higher population densities and has lesser impacts in industrial locations. Ambient DOR catalysts compete with other environmental technologies in terms of their cost per ton removal of pollutant. DOR catalysts can introduce pollutant destructing potential while also introducing an element of risk to the environment. Pilot programs may be of use in providing a test for the method of binding the DOR catalyst while maximizing its ozone conversion efficiency and minimizing the energy losses from its usage.

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