

Ex 6 Catalytic Converter for 4.0 Liter V6 Gasoline Engine

Given: 4.0 Liter V6 Gasoline Engine (1991 Ford Explorer)
 20 miles/gallon fuel Speed = 50 miles/hr
 Air/Fuel ratio = 14.6 lbs air/lb gasoline
 Density of liquid gasoline = 42 lbs/cubic ft at 60 deg F
 Exhaust flow = 134.065 actual cubic ft/min @ 1000 Deg F
 Catalytic hole diameter = Dia = 0.04" = 0.1016 cm
 C_7H_{13} diffusion coef. = $\Delta = 0.09$ sq cm/sec @ 0 deg C
 Uncontrolled exhaust emits 3.2 gms HC/mile traveled
 Gas velocity in cat = 20 ft/sec @ 1000 deg F
 Cat area open to flow is 77% of total x-sectional area
 HC oxidation reaction rate constant $k_r = 10$ cm/sec

$$T_{\text{cold}} := 492 \cdot R$$

$$T_{\text{hot}} := 1460 \cdot R$$

$$T_{\text{cold}} = 273.33 K$$

$$T_{\text{hot}} = 811.11 K$$

$$k_r := 10 \cdot \frac{\text{cm}}{\text{sec}}$$

$$\text{Dia} := 0.04 \cdot \text{in}$$

$$\Delta_{\text{cold}} := 0.09 \cdot \frac{\text{cm}^2}{\text{sec}}$$

$$\Delta_{\text{hot}} := \Delta_{\text{cold}} \cdot \left(\frac{T_{\text{hot}}}{T_{\text{cold}}} \right)^{1.5}$$

$$\Delta_{\text{hot}} = 0.46 \cdot \frac{\text{cm}^2}{\text{sec}}$$

$$\Delta_{\text{hot}} = \text{diffusion coefficient of } C_7H_{13} \text{ at } 1000^\circ F$$

$$K_o = \text{Overall Mass Transfer Coefficient}$$

$$\text{GasVel} = \text{gas velocity inside catalyst}$$

$$\frac{C_{\text{Inlet}}}{C_{\text{Outlet}}} := \exp\left(-\frac{\text{CatSurfaceArea} \cdot K_o \cdot \text{CatLength}}{\text{GasVel}}\right)$$

$$\text{CatSurfaceArea} = (\text{internal surface area}) / (\text{cat volume})$$

$$\frac{1}{K_o} := \frac{1}{k_m} + \frac{1}{k_r}$$

$$k_r = \text{HC oxidation reaction rate constant}$$

$$k_m = \text{gas film mass transfer coefficient}$$

1) Design (draw a sketch with length, width, and height dimensions) of catalytic converter to oxidize 99.990% of the VOCs (C_7H_{13}) in the exhaust gas stream.

$$\text{Flow} := 134.065 \cdot \text{ft}^3 \cdot \text{min}^{-1}$$

a) First calculate the gas film mass transfer coefficient k_m , then the overall mass transfer coefficient K_o

$$\text{Gas film mass transfer coef} = k_m$$

$$k_r = 10 \text{ cm} \cdot \text{sec}^{-1}$$

$$k_m := \frac{4.4 \cdot \Delta_{\text{hot}}}{\text{Dia}}$$

$$k_m = 19.924 \text{ cm} \cdot \text{sec}^{-1}$$

$$K_o = \text{Overall Mass Transfer Coefficient}$$

The mass transfer coefficient can be thought of as the "velocity" the Hydrocarbon molecules move towards the catalyst surface where they are oxidized, thus the units are cm/sec or ft/sec.

$$K_o := \frac{k_m \cdot k_r}{(k_r + k_m)}$$

$$\text{Gas Film mass transfer coefficient} = k_m = 19.924 \text{ cm/sec}$$

$$K_o = 6.658 \frac{\text{cm}}{\text{sec}}$$

b) Calculate the catalyst surface area a in units of cm^2/cm^3 & ft^2/ft^3

$$\text{Catalyst surface area} = a = 4 / \text{Cat Hole Dia}$$

This is the internal area of the small cylindrical holes

$$a := \frac{4}{\text{Dia}}$$

$$\frac{\text{cm}^2}{\text{cm}^3}$$

$$\frac{\text{ft}^2}{\text{ft}^3}$$

$$\text{Catalyst surface area} = 1200 \text{ square feet/cubic ft cat volume}$$

$$a = 39.37 \frac{\text{cm}^2}{\text{cm}^3}$$

$$a = 1200 \frac{\text{ft}^2}{\text{ft}^3}$$

c) Calculate Cat Length in direction of gas flow, x

To design a catalyst for 99.990% oxidation of the C_7H_{13} ,

$$C_{\text{in}} = 3.2 \text{ gm/mile} \quad \text{and} \quad C_{\text{out}} = .0001 C_{\text{in}} = .00032 \text{ gm/mile}$$

$$c_{\text{in}} := 3.2 \cdot \text{gm} \cdot \text{mi}^{-1}$$

$$\text{Gas vel} = \text{Vel} = 20 \text{ ft/sec}$$

$$\text{Vel} := 20 \cdot \frac{\text{ft}}{\text{sec}}$$

$$\text{GasVel} := 20 \cdot \frac{\text{ft}}{\text{sec}}$$

$$c_{\text{out}} := .0001 \cdot c_{\text{in}}$$

$$L := \frac{\text{Vel} \cdot \ln\left(\frac{c_{\text{out}}}{c_{\text{in}}}\right)}{a \cdot K_o}$$

$$\text{CatLength} := L$$

$$L = 8.433 \text{ in}$$

$$c_{\text{out}} = 3.2 \times 10^{-4} \text{ gm} \cdot \text{mi}^{-1}$$

$$\text{CatLength} = 8.433 \text{ in}$$

d) Calculate Cat surface area perpendicular to gas flow

Cat area open to flow is 77% of total x-sectional area

$$\text{Flow} = 134.065 \text{ ft}^3 \cdot \text{min}^{-1}$$

$$\text{Area} := \frac{\text{Flow}}{(\text{GasVel}) \cdot (0.77)}$$

Catalyst area perpendicular to gas flow = Area

$$\text{Area} = 0.013 \text{ m}^2$$

$$\text{Area} = 20.893 \text{ in}^2$$

cross sectional area perpendicular to flow = 20.893 sq inches

e) Calculate Cat Space Velocity Θ and Gas Residence Time in Cat

$$\text{ResTime} := \frac{\text{CatLength}}{\text{GasVel}}$$

Gas Residence Time in Cat = ResTime

Gas Space Velocity = Θ

$$\Theta := \frac{1}{\text{ResTime}}$$

$$\text{ResTime} = 0.035 \text{ s}$$

$$\Theta = 102459.49 \frac{1}{\text{hr}}$$

Gas Space Velocity = $\Theta = 102,459.5 \text{ 1/hr}$

Hydrocarbon Emissions = Emissions

$$\text{Emissions} := 0.0001 \cdot \left(3.2 \cdot \frac{\text{gm}}{\text{sec}} \right)$$

$$\text{Emissions} = 3.2 \times 10^{-4} \frac{\text{gm}}{\text{sec}}$$

US Tier 2 Bin 2 NMOG (hydrocarbon) emission standards are 0.01 gm/mile.

$$C_{\text{out}} = .0001 C_{\text{in}} = .00032 \text{ gm/mile}$$

For this catalytic converter design, the hydrocarbon emission rate out the tailpipe is much less than the 0.01 gm/mile Tier 2 Bin 2 limit.

Design Dimensions

Catalyst Length = x = 8.5 inches

cross sectional area perpendicular to flow = 20.9 sq inches

$$\text{Emissions} := \left[(0.41 + 3.4 + 1.0 + 0.2) \cdot \text{gm} \cdot \text{mi}^{-1} \right] \cdot \left(20 \cdot \text{mi} \cdot \text{gal}^{-1} \right)$$

$$\text{Emissions} = 0.221 \frac{\text{lb}}{\text{gal}}$$

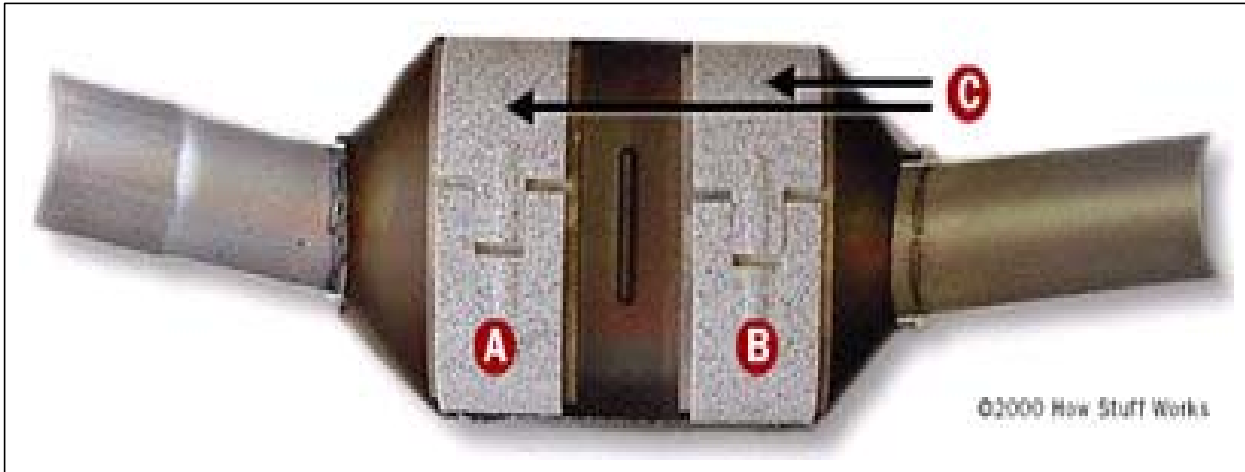
Vehicle emits 0.2209 lbs air pollutants / gallon of gasoline if it emits the pollutants at the *maximum* allowed by the Federal Vehicle Emission Standards -for older (1996) year vehicles. Most of this is CO.

The Seattle radio public service ads saying that 6 lbs of air pollutants were emitted per pound of gasoline burned were in error. Pilat phoned the radio stations & they said that the "public service ads" were sent to them by the "Washington Clean Air Society" or "Clean Air for Washington" - but no such organization could be found. The Radio station stopped broadcasting these "public service ads" (on Saturdays). This was probably related to the "politics" of public transit (Sound Transit ?) vs personal motor vehicles. Some of the information about how public transit (diesel buses, light rail) reduces air pollution emissions is based on questionable (ie false) calculations and *not measurements*.



A Reduction of NO_x
 $\text{NO} + \text{NO}_2 + \text{HC} = \text{N}_2 + \text{O}_2 + \text{H}_2\text{O} + \text{CO}$

B Oxidation of CO & hydrocarbons
 $2\text{HC} + \text{CO} + 3\text{O}_2 = 3\text{CO}_2 + \text{H}_2\text{O}$



3 Way Catalytic Converter for Gasoline Engine

