Ex 5 Mass Balance Air & Fuel for Gasoline Auto Engine to Obtain Exhaust Gas Flow Rate

Given: 4.0 liter V6 engine which gets 20 miles/gallon gasoline (Ford Explorer)
Vehicle 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 7.481 gallons = 1 cubic ft
Molecular weight exhaust gases (CO_2, N_2, H_2O) assume to be 29 lbs/lb mole

Note that in Mathcad, mole = gram-mole

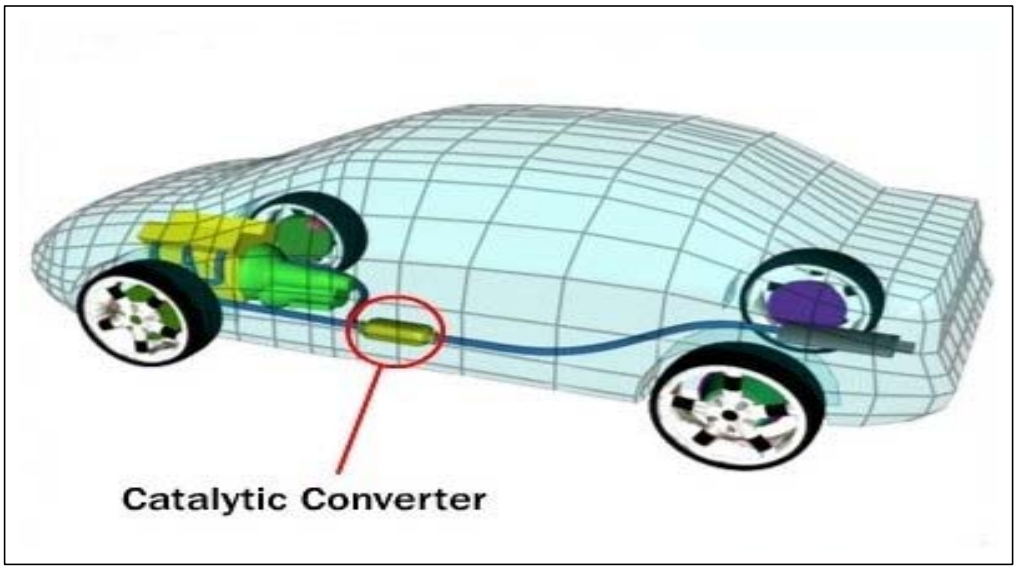
lbmole := 453.6·mole

$C_7H_{13} + 10.25\ O_2 + 38.54\ N_2$ -- $7CO_2 + 6.5\ H_2O + 38.54\ N_2$

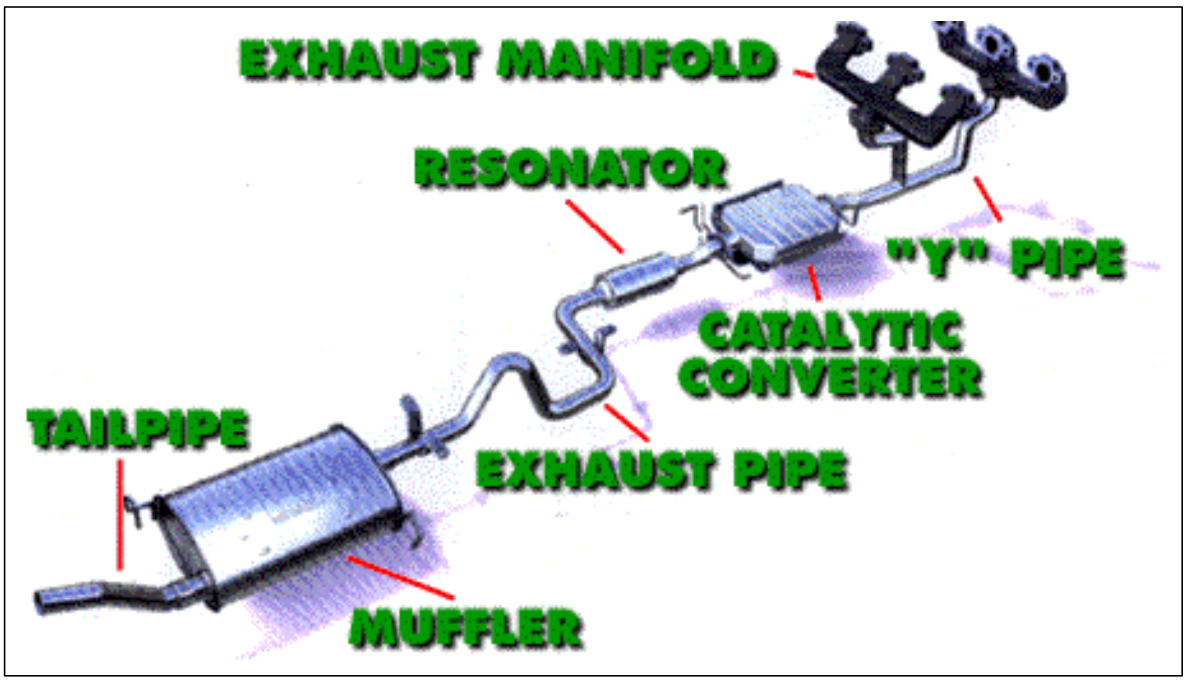
22.4 liters gas/gram-mole & 359 cubic ft gas / lbmole at 0 deg C & 1 atm

Air density = 0.07636 lb/ft^3 at 60^{o}F and 1 atm pressure

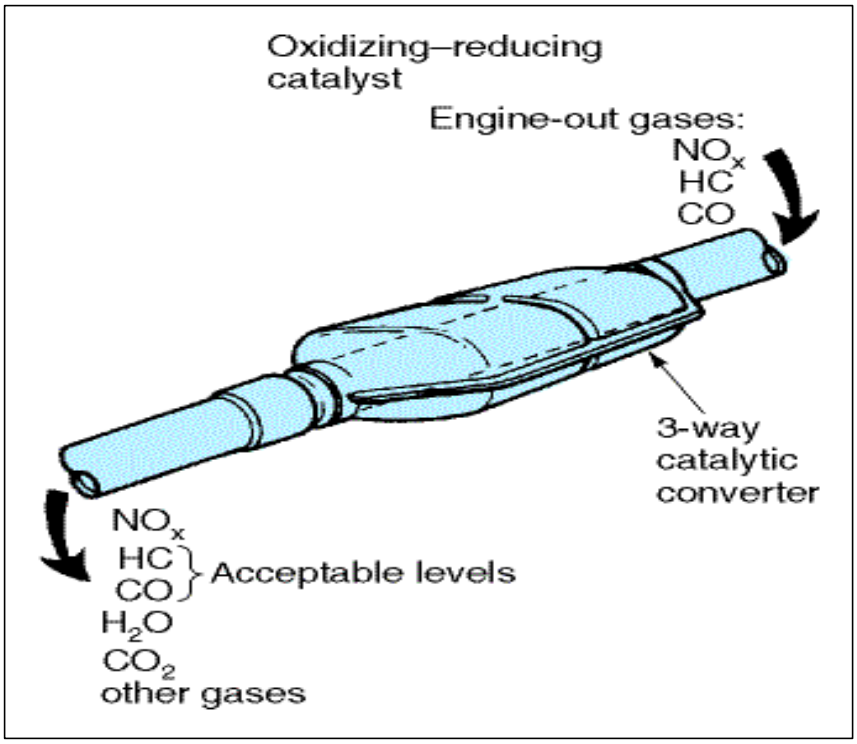
The exhausst gas volumetric flow rate at the exhaust gas conditions (temp & pressure) are needed to *design* the catalytic converter.



Catalytic Converters are commonly called "Cats" by automotive manufacturers such as Ford, GM, etc.

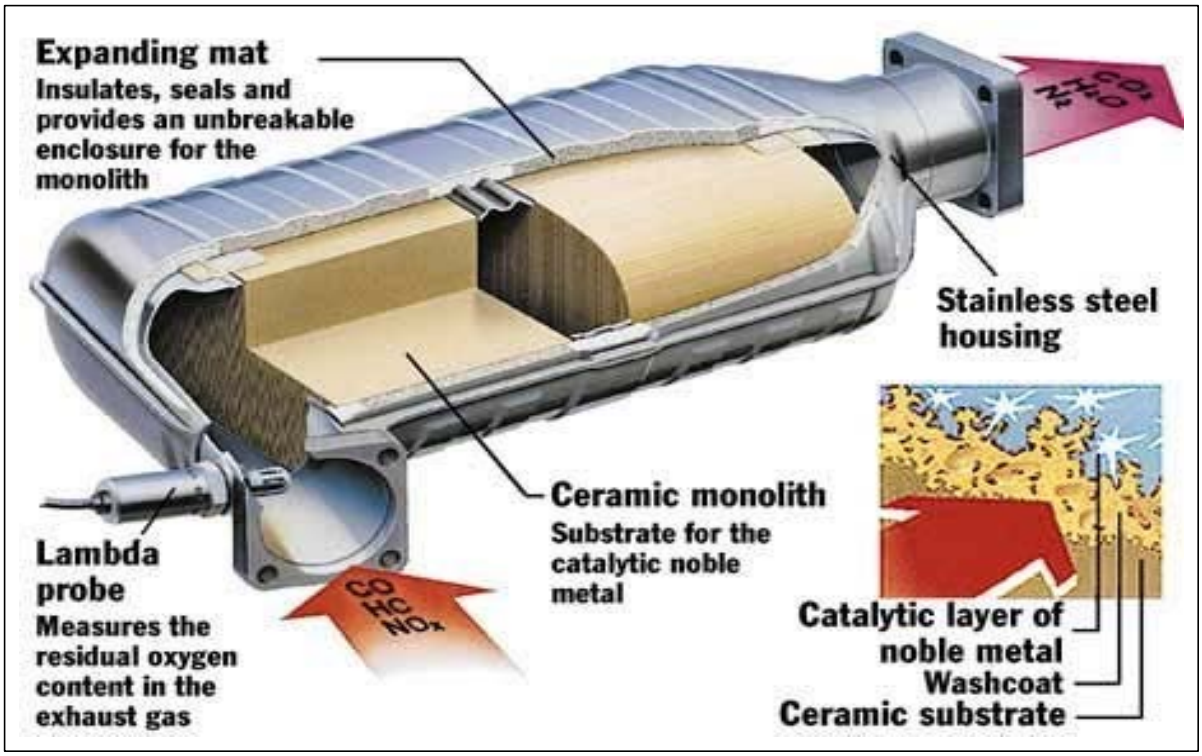


The 3 way catalytic converter reduces the NOx to nitrogen gas N_2 and oxidizes the hydrocarbons HC and carbon monoxide CO to carbon dioxide CO_2 and water vapor H_2O. The exhaust gas must not contain too much oxygen for a 3 way catalytic converter to reduce NOx and hence 3 way "Cats" have not been used on diesel engine exhaust gases which contain much more oxygen than gasoline engine exhausts.



OBD = On Board Diagnostics
OBD I has an O_2 sensor at the "Cat" gas inlet.
OBD II have O_2 sensors at the "Cat" gas inlet & outlet.
Gasoline Engine motor vehicles 1994 & earlier are OBD I and vehicles 1996 and later are OBD II. 1995 models are a mix of OBDI and OBDII.

Lambda probe measures oxygen concentration in exhaust gas; commonly called oxygen sensor.



$28.56 Bosch Oxygen Sensor - Direct OE Replacement, 4-wire, Heated, 1991 Ford Explorer XLT 6 Cyl 4.0L BOSCH OE Type Oxygen Senxor, 4-WIRE -- 18.9 in. wire length, heated; Constructed of premium ceramic technology has Zirconium or Titania & Yttrium for protection against shock; has catalytically activated fine particle filter for contamination protection & ensures precise voltage to the engines emission control computer. 2nd filter doubles protection against exhaust gas contamination for increasing oxygen sensor life; Snug fitting OE-style silicone boots ensure proper fit, Direct plug-in, no cutting or splicing required. Part Number: BS15718 Fit Note: 4 Wire, Heated, O_2 Sensor Check or Replace Interval: 60, 000 Miles (will last over 250,000 miles)

Find: a. At 20 miles/gallon, how much fuel is used at 50 mph in units of lbs gasoline/minute & gallons/min

$$FuelVolUse := \left(50 \cdot \frac{mi}{hr}\right) \cdot \left(20 \cdot \frac{mi}{gal}\right)^{-1}$$

$$FuelWtUse := FuelVolUse \cdot \left(42 \cdot \frac{lb}{ft^3}\right)$$

$$FuelVolUse = 0.042\,gal \cdot min^{-1}$$

b. At a vehicle speed of 50 miles/hr, how much air is used by the gasoline vehicle engine in units of actual cubic ft per minute (acfm) at 60°F and 1 atm pressure & units of lbs air/min .

$$FuelWtUse = 0.23394 \frac{lb}{min}$$

$$lbair := lb \qquad lbfuel := lb$$

$$AirWtUsed := \left(14.6 \cdot \frac{lbair}{lbfuel}\right) \cdot \left(0.23394 \cdot \frac{lbfuel}{min}\right)$$

$$AirWtUsed = 3.41552 \frac{lb}{min}$$

Mathcad carries many significant figures in its calculation results

$$AirVolUsed := \left(3.41552 \cdot \frac{lbair}{min}\right) \cdot \left(1 \cdot \frac{ft^3}{.07636 \cdot lb}\right)$$

$$AirVolUsed = 44.729 \frac{ft^3}{min}$$

Note that this is the volumetric air flow rate at 60 deg F & 1 atm pressure

c. Based on a mass balance at steady state conditions, lbs in = lbs out of the engine. Find the mass flow rate of the engine exhaust gases in lbs exhaust gas/minute

$$WtExhaustGasOut := AirWtUsed + FuelWtUse$$

$$WtExhaustGasOut = 3.649 \frac{lb}{min}$$

$$WtExhaustGasOut := 3.4156 \cdot \frac{lbair}{min} + 0.2339 \cdot \frac{lbfuel}{min}$$

$$WtExhaustGasOut = 3.6495 \frac{lb}{min}$$

d. Find the volumetric flow rate of exhaust gases @ 1000 deg F or 1460°R exhausting from engine and going to the catalytic converter in ft^3/min .

$$MolarGasFlow := \frac{WtExhaustGasOut}{GasMolWt}$$

$$MolarGasFlow = 0.126 \frac{lbmole}{min}$$

$$GasMolWt := 29 \cdot \frac{lb}{lbmole}$$

$$GasFlowacfm := MolarGasFlow \cdot \left(359 \cdot \frac{ft^3}{lbmole}\right) \cdot \frac{[(460 + 1000) \cdot R]}{[(460 + 32) \cdot R]}$$

Note that R = degrees Rankine
Degrees R = (1.8)(Degrees Kelvin)

$$GasFlowacfm = 134.066 \frac{ft^3}{min}$$

This 134.066 acfm is the gas flow at 1000° F

e. EPA Tier 1 Vehicle Emission Stds = 0.41 gm HC/mi, 3.4 gm CO/mi, 1.0 gm NOx/mi, 0.08gm PM/mi

$$Tier1Emissions := \left(20 \cdot mi \cdot gal^{-1}\right) \cdot \left[(0.41 + 3.4 + 1.0 + 0.08) \cdot gm \cdot mi^{-1}\right]$$

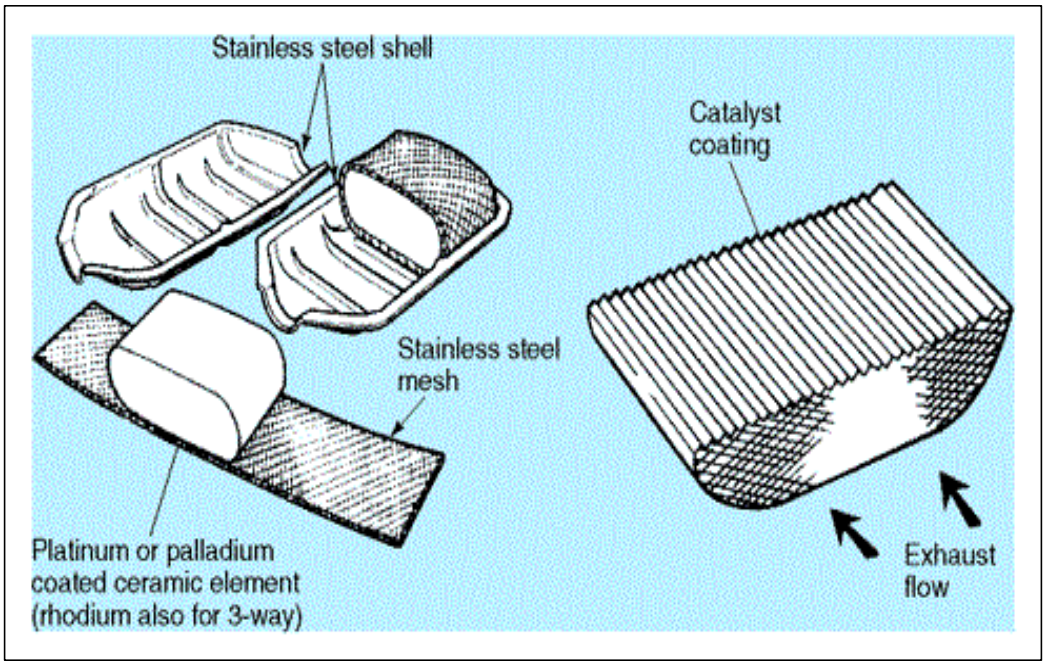
$$Tier1Emissions = 0.216\,lb \cdot gal^{-1}$$

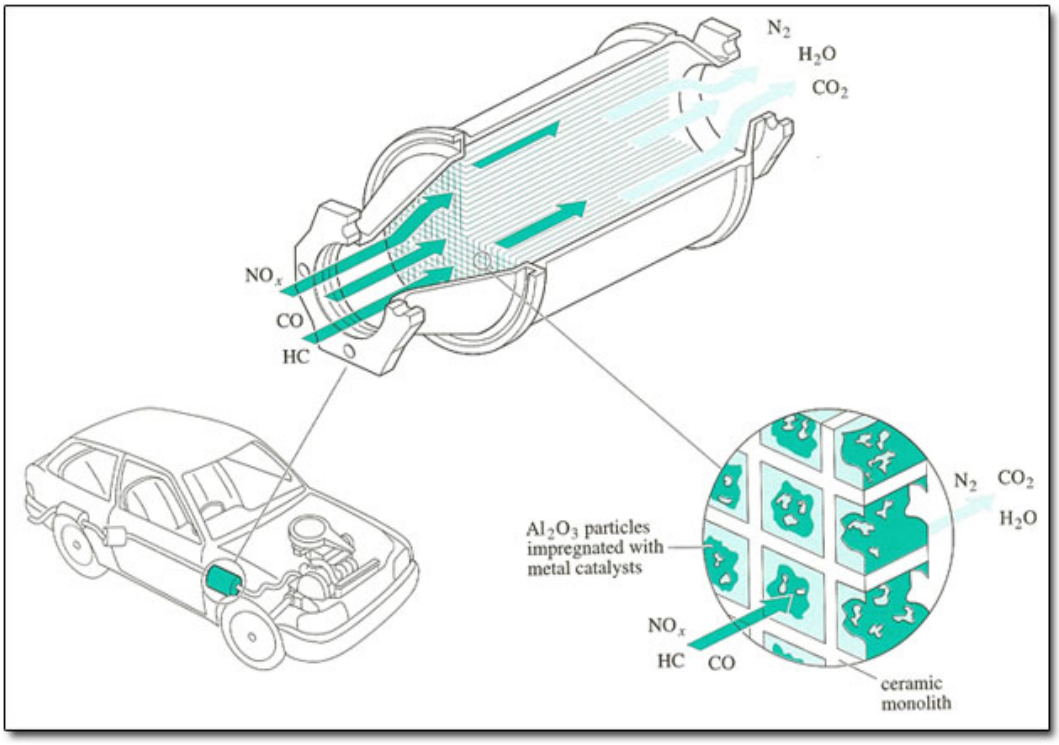
Note that carbon monoxide is 69.5% of the pollutant emissions on a mass basis for Tier 1 emissions

f. Tier 2 Vehicle Emissions Stds = 0.125 gm NMOG/mi, 3.4 gm CO/mi, 0.4 gm NOx/mi, 0.015 gm CHO/mi

$$Tier2Emissions := \left[20 \cdot \left(mi \cdot gal^{-1}\right)\right] \cdot \left[(0.125 + 3.4 + 0.4 + 0.015) \cdot \left(gm \cdot mi^{-1}\right)\right]$$

$$Tier2Emissions = 0.174\,lb \cdot gal^{-1}$$





$74.22 Eastern Catalytic Converter - Direct OE Replacement 1991 Ford Explorer XLT 6 Cyl 4.0L 49-state legal, OBDII (1991 Ford is OBD I); 3-way catalyst style; 2.5 in. inlet; 2.5 in. outlet; Single inlet and outlet configuration; 6 in. x 4.25 in. x 10 in. body, 14 in. overall length; 6,000 lb. GVW; Without air tube provision and oxygen sensor port; Ceramic honeycomb catalyst substrate; Oval body; 409 stainless steel casing; Non-directional and can be installed either way; Modification of the exhaust may be required