MEMORANDUM

State of Alaska

Department of Environmental Conservation
Division of Air and Water Quality - Air Quality Maintenance

TO: John F. Kuterbach, Program Manager DATE: October 27, 2000

THRU: Bill MacClarence, Operating Permits Supervisor

FROM: Matt Wilkinson
Air Quality Maintenance

SUBJECT: Maximum SO_2 Concentration from the combustion of natural gas

EPA in their Title V permit reviews is requiring the department to demonstrate that limiting hydrogen sulfide content of the natural gas to 4000 ppmv will ensure compliance with our 500 ppmv SO_2 limit. This memorandum sets forth engineering calculations which demonstrate that combustion of natural gas containing hydrogen sulfide up to 4000 ppmv will always comply with the 500 ppmv SO_2 limit regardless of the source involved. I recommend that we reference these calculations in future "statements of basis" that we send to EPA with our draft operating permits.

Summary

This engineering calculation examined the stoichiometric combustion of natural gas and calculated the maximum sulfur dioxide content of the flue gases. The maximum sulfur dioxide concentration will result from the combustion of pure methane, whereas heavier hydrocarbons (e.g. ethane or propane) with the same volumetric hydrogen sulfide concentration will result in a lower concentration of sulfur dioxide. Typically, combustion of 4000-ppmv-hydrogen sulfide natural gas can produce up to 470 ppmv SO_2 in the flue gas and will never exceed the 500ppm limit.

I conclude that combustion of 4000-ppmv-hydrogen-sulfide natural gas with air will always comply with the 500ppmv emission limit.

Assumptions

All constituents of the fuel are burned proportionally.
Any excess air typical of combustion would tend to dilute the SO_2 concentration of the flue gas, therefore only theoretical air is considered.
Natural gas is composed of carbon, hydrogen, sulfur, and negligible amounts of water and ash.
Ignore the water because the standard is a dry standard and the water will drop out of any calculations.
The heavier hydrocarbons have a higher weight percent of hydrocarbons for a given volumetric hydrogen sulfide concentration that dilutes the SO2 concentration of the flue gas, therefore the natural gas is entirely made up of methane—the lightest hydrocarbon.

By Dalton's Law and by the Ideal Gas Law, the molar fraction is equal to the volume fraction. Therefore, for 100 moles of 4000-ppmv-hydrogen sulfide natural gas there are 100 X (4,000 / 1,000,000) = 0.4 moles of hydrogen sulfide and there are 100 – 0.4 = 99.6 moles of hydrocarbons.

By definition, the formula showing the composition of hydrocarbons is C_mH_n. Each mole of hydrocarbon supplies "m" moles C and supplies "n"/2 moles H_2. Each mole of hydrogen sulfide supplies one mole S and one mole H_2.

Therefore, the following equations can be used for 100 moles of a natural gas composed of 4000-ppmv hydrogen sulfide and only of one type of hydrocarbon:

moles C = 99.6 X m
moles H_2 = (99.6 X n / 2) + 0.4

moles S = 0.4

Using normal air for combustion (79% N_2 and 21% O_2):

For each lb-mole of Oxygen in Air, there are 3.76 lb-mole Nitrogen (1 lb-mole O_2) = (0.79/0.21) = 3.76 lb-mole N_2

The stoichiometric equations are:
$C + O_2 + 3.76\ N_2 = CO_2 + 3.76\ N_2$
$2H_2 + 0_2 + 3.76\ N_2 = 2H_2O + 3.76\ N_2$
$S + 0_2 + 3.76\ N_2 = SO_2 + 3.76\ N_2$

To calculate the dry exhaust gases (CO_2, N_2, SO_2) the following equations are used:

moles CO_2 = moles C
moles N_2 = (3.76 X moles C) + (1.88 X moles H_2) + (3.76 X moles S)
moles SO_2 = moles S

Then, by Avogadro's Law and the definition of mole:

ppmv SO_2 = 1,000,000 x [moles SO_2/(moles CO_2 + moles N_2 + moles SO_2)]

Results

Using 100 moles of fuel (i.e. 99.6 moles of hydrocarbon and 0.4 moles of hydrogen sulfide) as a basis, we examined the following three cases:

Case	Moles of Fuel		
	Carbon	Hydrogen	Sulfur
Methane = CH_4	99.6	199.6	0.4
Ethane = C_2H_6	199.2	299.2	0.4
Propane = C_3H_8	298.8	398.8	0.4

	Methane	Ethane	Propane
moles CO_2	99.6	199.2	298.8
moles N_2	751.2	1313.0	1874.7
moles SO_2	0.4	0.4	0.4
Total Dry Moles	851.2	1512.6	2173.9
ppmv SO_2	470	264	184

Conclusion

The above calculations show that 4000-ppmv-hydrogen-sulfide natural gas combusted with air will always comply with the 500 ppmv SO_2 limit. The calculations use the conservative assumptions of complete combustion and no excess air. The real-world includes partial combustion and excess air, both of which would tend to dilute the SO_2 concentration in the exhaust effluent.

The equations above can be used as an initial screening for other gaseous petroleum fuels even with a higher hydrogen sulfide content.

If you agree this memorandum has value, please share it with the rest of the AQM staff.