ENE-47.153 **Flue gas cleaning technology** **Exam**
Savukaasujen puhdistustekniikka **Tentti**
Gasreningsteknik för rökgaser **Tent**

16.5.2006 9:00-12:00

Please write on every page you hand in:
* ENE-47.153 Exam 16.5.2006
* Your name, department, student number

The time for this exam is **3 hours**.
Only books with tabelised data may be consulted.
The total amount of points to be scored is 50. The result will then be: 21.....26.5 points = 1, 27.....32.5 points = 2 , 33.....38.5 points = 3, 39.....44.5 points = 4, 45...50 points = 5.

There are five questions. Points: 15 + 7 + 6 + 11 + 11= 50

1. a. What is fuel-NOx? What does "NOx" mean? (3 p)
(Mitä on polttoaine- NOx? Mitä "NOx" tarkoittaa?)

b. Why does a flue gas combuster contain much less SO_3 than what is predicted by the thermodynamic equilibrium? (3 p)
(Miksi polttokammiosta tulevat savukaasut sisältävät paljon vähämmän SO_3:a kuin termodynaamisen tasapainon mukaan on ennustettu?)

c. What is the effect of HCl in flue gas on operation of FGD (flue gas desulphurisation) unit using lime (CaO)? (3 p)
(Miten HCl vaikutta savukaasuissa rikinpoistolaitokessa, joka käyttää kalkkia (CaO) ?)

d. What is the difference between a hot side" and "cold side" ESP (electrostatic precipitator)? (3 p)
(Mikä ero on "kuuman puolen" ja "kylmän puolen" sähkösuodttimilla?)

e. How the ground-level ozone formed? (3 p)
(Miten otsoni muodostuu maan tasolla?)

2. An acetone /air mixture of 1700 m^3/h, containing 29 g/s acetone is fed to a VOC combuster at 66°C, 1 bar. Acetone (C_3H_6O) has a boiling point of 56°C, molar mass 58 g/mol, LFL (Lower flammability limit) in air 2.5%-vol, UFL (Upper flammability limit) in air 12.8%-vol. VOC mixture are considered dangerous at concentrations above 0.25*LFL.

a. Calculate the %-vol of acetone in the gas? (4 p)

b. Is this considered dangerous and if so what can be done? (3 p)

3. A flue gas has the following composition:

CO_2	10 %-vol	H_2O	7 %-vol
O_2	15 %-vol	NO	100 ppm-vol
N_2	the rest		

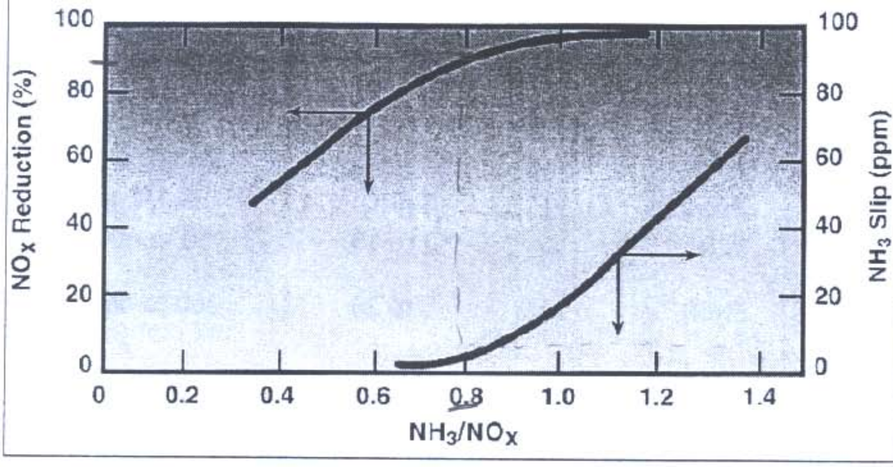
Calculate the concentration of NO (in ppm-vol) at 6 %-vol O_2 (dry). (6 p)

The following relation between stoichiometry, λ, and %-vol O_2 (dry) may be used:

$$\lambda = 21 / (21\text{-}\%\text{vol } O_2 \text{ dry})$$

Note: Gas volume V increases linearly with L, (V = a λ with constant a and concentration C is related to 1/V, C = b/V, with constant b).

4. The Figure below gives the NOx reduction efficiency of an SCR process as function of the molar ratio injected NH_3 / NOx in the gas. It also gives the ammonia slip (which is the NH_3 that did not react with the NOx) as NH_3 found in the gas downstream of the SCR unit. Assume here that NOx = NO, neglect NO_2.



The SCR is located at a coal-fired power plant, upstream of a bag filter for dust control, at a temperature of 365°C, pressure 1 bar. The incoming concentration of NO (at 365 °C, 1 bar) is 1453 ppm-vol. The concentration of water and oxygen in the flue gas are 10%-vol and 4.5 %- vol, respectively. The NO emission limit is 200 mg/m^3 STP, in 6 %-vol O_2, dry flue gas.

a. What is the NO concentration at STP conditions in this flue gas? (1 p.)

b. What is the NO concentration at STP conditions, in the dry flue gas, and what is it then when corrected to 6 %-vol oxygen, dry flue gas at STP. (1+2 = 3 p.)
Note: concentration ~ 1 / volume, volume ~ λ and $\lambda = 21 / (21 - \% O_2,$ dry) λ = combustion process stoichiometry

c. Show that the answer of b) corresponds to an NO concentration of 2000 mg /m^3_{STP} (dry gas) (3 p.)
(1 mol NO = 30 g, 1 mol gas at STP conditions is 0.0227 m^3)

d. What will be the NO reduction efficiency that is needed to comply with the emission standard, and what will be the NH_3 slip under those conditions? (1 p.)

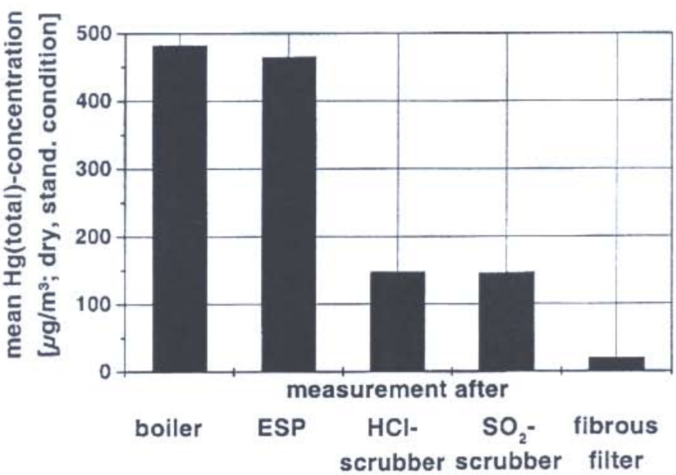
It is found that this ammonia slip will result in ammonia in the fly ashes also, and if the ammonia content of the fly ashes is too high it cannot be used in cement and concrete. The table below gives the ammonia levels found in ashes from coal-fired plants where SCR or SNCR is used as air pollution control (APC) process.

APC Process	NH_3 Slip ppm_v	NH_3 in Ash mg/kg
SCR	2 to 10	50 to 400
SNCR	5 to 20	200 to 600

e. Estimate the concentration of NH_3 you expect in the fly ash? (1 p.)

f. If ammonia costs 120 €/tonne, what are the costs of the ammonium losses with the fly ash (in € / tonne ash)? (2 p.)

5. Mercury (Hg) is emitted from a waste incinerator and is for a large part removed by the gas clean-up system, which is an electrostatic precipitator (ESP), followed by an HCl scrubber (at pH = 1), an SO_2 scrubber (at pH = 7) and a fibre filter. Before the HCl scrubber, Na_2S_4 is injected, and before the fibrous filter activated carbon is injected. The Figure below gives the concentration of Hg-species after the device that is indicated.



a. Using the figure above, Calculate the removal efficiency for Hg-species for each of the 4 gas clean-up devices, and of the total clean-up system, in % ? (4 p)

b. Explain why the Figure looks like this? (4 p)

c. What are the functions of the Na_2S_4 and the activated carbon that are injected? (3 p)

DATA for all questions :

ideal gas law: pV = nRT, where p = pressure (Pa), V = volume (m^3), n = amount (mol), R=8.314 (J/(mol K)), T = temperature (K)

molar masses:	H_2 : 2 g	N_2 : 28 g	O_2 : 32 g	Cl_2 : 71 g
	C : 12 g	S : 32 g	Ca : 40 g	Na : 23 g
	Hg : 201 g			

air: 21 %-vol O_2 + 79 %-vol N_2

STP: 1 bar, 273.15 K