39 2/24

Universitetet i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

EXAMINATION IN: RIS520 Technical Safety **DATE: 06.03.2015**

DURATION: 0900-1300

ALLOWED SUPPORTING MATERIAL : Valid calculator and curriculum literature:
Kuchta: Investigation of fire and explosion accidents
SINTEF NBL / Scandpower: Handbook for Fire Calculations and Fire Risk Assessment in the Process Industry
GexCon: Gas Explosion Handbook

THE EXAM CONSISTS OF 4 TASKS ON 2 PAGES

NOTE : Students are allowed to write translations, comments and corrections in the curriculum literature.

Task 1.

a) Develop a stoichiometric equation for methane in air by balancing the atoms on both sides of the equation. Calculate the stoichiometric concentration of methane in air based on this equation. Also calculate the lower and upper flammability concentrations (L_{25} and U_{25}) of methane in air.

b) Calculate the lower and the upper flammability limits as well as the stoichiometric concentration of a natural gas-air mixture at a temperature of 25°C. The gas consists of 88% methane, 8 % ethane and 4% propane.

c) Calculate the lower flammability limit for the gas-air mixture in b) above at a temperature of 100°C. The heats of combustion (ΔH_c) for methane, ethane and propane are 191.8, 341.3 and 488.5 kcal/mol, respectively.

d) The Auto Ignition Temperature (AIT) of a stoichiometric natural gas-air mixture will typically be in the range between 480 and 630 °C. A hot surface could be an ignition source for such a gas-air mixture. Would all surfaces with a temperature of AIT or higher be able to ignite the mixture? Discuss briefly. (Hint: some important parameters are size of surface, surface temperature, gas confinement).

Task 2.

a) Define the equation of state for an ideal gas. Then define the equation of state for a real gas. Under which conditions will the use of the two equations give different results?

b) Consider a 2 m^3 tank containing methane gas (CH_4). Calculate the gas densities as well as the masses of methane contained in the tank for the following three combinations of pressure and temperature (see table), by using both equations of state from task a). If the results using the two equations of state are different, discuss briefly which answer is most correct.

Pressure (bar)	Temperature (°C)
100	20
10	20
100	-40

c) Now assume that the pressure in the tank is 100 bar, and the temperature is 20°C. A leak occurs through a circular hole with a diameter of 2 cm. The universal gas constant R is 8314 J/(kmol*K) and the fraction between specific heat capacities, γ, may be set to 1.3. Calculate the initial leak rate.

d) Assume that the methane gas that leaks to atmosphere expands adiabatically to atmospheric pressure. The relationship between pressure and density for adiabatic expansion is $p\rho^{-\gamma}$=constant. Calculate the density ρ and the temperature T of the gas after it has expanded to atmospheric pressure.

e) Assume that the leaking gas has the shape of a frustum cone (i.e. the cone tip is cut off), and that the top half cone angle is 9.1degrees. Find the speed of sound in the expanded methane gas, then calculate the equivalent radius.

f) Explain the concept of equivalent radius of the leaking jet.

g) Calculate the distance from the leak point along the jet axis to the point where the concentration has dropped to the lower flammability limit of methane (use volume fraction, not per cent in the calculations!)

Task 3

Natural gas leaks into a module on an offshore platform. Assume that the gas forms a stoichiometric, uniform mixture with air which fills the module. The module is 50 m long, 20 m wide and 6 m high. It is open on one long side, otherwise closed. Equipment, pipework, cable trays, local rooms etc fill up 10% of available space inside the module. The density of natural gas at ambient temperature can be taken to be 0.8 kg/m^3.

a) The natural gas consists of 88% methane, 8 % ethane and 4% propane. What are the stoichiometric concentration and the lower and upper flammability limits of the gas-air mixture. How did you find these results?

b) The gas cloud explodes with a maximum overpressure of 4 barg. Calculate the blast overpressure at the Living Quarter on the neighbouring platform (100 m away) by using the Multi-Energy method. Also calculate the blast duration.

c) Now assume that the gas cloud explodes with a maximum overpressure of 0.2 barg. Again calculate the blast overpressure and duration at the Living Quarter on the neighbouring platform (100 m away) by using the Multi-Energy method.

d) What is the lowest explosion overpressure that would result in a blast overpressure equal to the one found in b) above?

Task 4

A tank containing 5 m^3 gasoline starts to leak. The leak rate is constant and equal to 3 kg/s until the tank is empty. The molecular weight of the gasoline is 100 kg/kmol. The density is 870 kg/m^3. The heat of combustion is 43700 kJ/kg. The regression rate of an "infinitely" large pool is $0.8 * 10^{-4}$ m/s. The density of gasoline vapor at the boiling point is 3.49 kg/m^3. Set the density of ambient air to 1.2 kg/m^3.

a) The pool ignites immediately. Calculate the equilibrium diameter D_{eq} of the pool as well as the time t_{eq} to reach the equilibrium diameter.

b) How much gasoline is burning (in kg/s) when the equilibrium diameter is reached?

c) Assume quiescent conditions (no wind), calculate the flame height L when the pool has reached its equilibrium diameter.

d) What is the duration of the leak?

39(2)/24

Universitetet i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

EXAMINATION IN: RIS520 Technical Safety **DATE: 23.02.2016**

DURATION: 0900-1300

ALLOWED SUPPORTING MATERIAL: Valid calculator and curriculum literature:
Kuchta: Investigation of fire and explosion accidents
SINTEF NBL / Scandpower: Handbook for Fire Calculations and Fire Risk Assessment in the Process Industry
GexCon: Gas Explosion Handbook

THE EXAM CONSISTS OF 4 TASKS ON 2 PAGES

NOTE : Students are allowed to write translations, comments and corrections in the curriculum literature.

Task 1.

a) Set up a stoichiometric balance equation for butane (C_4H_{10}) in air. Calculate the stoichiometric concentration for butane in air based on this equation.

b) What are the Minimum Ignition Energy (MIE) and Auto Ignition Temperature (AIT) for butane in air?

c) Explain briefly why a very smallr ignition source needs to be at a temperature higher than AIT to ignite the stoichiometric gas-air mixture?

d) Calculate the Lower and Upper Flammability Limits for the gas-air mixture based on the stoichiometric concentration.

Task 2.

A container of 3 m^3 is filled with methane gas at -30 °C (30 degrees below zero). The pressure in the container is 10 bar. The universal gas constant R is 8314 J/(kmolK). The molecular weight M of methane is 16 kg/kmol. The ratio of specific heat capacities, γ, can be set to 1.3.

a) Define the version of the equation of state that best fits the situation. Briefly justify your choice.

b) Find the density ρ of the gas in the container. Determine the mass m of the gas.

c) A pipe connection to the container is broken at the container surface and a circular hole with a diameter of 2 cm is formed. The hole is sharp edged. Which formula should be used to calculate the initial leak rate from the hole, and why? Then calculate the initial leak rate (in kg/s) from the container.

d) Assume that the methane gas that leaks to atmosphere expands isothermally to atmospheric pressure. Calculate the density ρ of the gas after it has expanded to atmospheric pressure.

e) Assume that the leaking gas has the shape of a frustum cone (i.e. the cone tip is cut off), and that the top half cone angle is 9.1degrees. Find the speed of sound in the expanded methane gas, then calculate the equivalent radius.

f) Calculate the distance from the leak point along the jet axis to the point where the concentration has dropped to the lower flammability limit of methane (use volume fraction, not per cent in the calculations!)

Task 3

A tank containing $10m^3$ of oil starts to leak. The leak rate can be assumed to be constant and equal to 5 kg/s until the tank is empty. The tank is placed on a flat area without physical barriers. The molecular weight of the liquid is 100 kg/kmol. The liquid density is 870 kg / m3. The heat of combustion is 43700 kJ / kg. The regression rate of an "infinitely" large pool is $0.8 * 10^{-4}$ m/s.

a) The pool is ignited immediately. Calculate the equilibrium diameter D_{eq} of the pool and the time t_{eq} until the equilibrium diameter is reached.

b) What is the fuel burning rate in kg/s when the equilibrium diameter is reached?

c) Assuming a no wind situation, calculate the flame height L when the pool has reached its equilibrium diameter.

d) How long does the leak last? Can you say anything (briefly) about how long the fire lasts?

Task 4

In a module which is 30 m long, 10 m wide and 10 m high, and the equipment, pipes etc. fill 6% of the module volume, enough methane leaks out to fill the module with a stoichiometric methane-air mixture. The module is open on both short sides (ends), closed otherwise. The density of of the released methane can in his case be set to 0.67 kg/m^3.

a) List three key parameters that influence the propagation of a gas explosion. Give examples of how changes in these parameters affect the pressure.

b) How many kg methane is in the gas cloud?

c) Where would you place the ignition point to get the highest possible pressure in an explosion? Explain briefly your answer.

d) The gas cloud explodes with a maximum pressure of 4 barg. Calculate the blast pressure on the neighbouring platform which is 100 m away from the module, using the Multi-Energy Method.

e) What is the duration of the shock wave when it hits the neighbouring platform?

39(2)/24

Universitetet i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

EXAMINATION IN: RIS520 Technical Safety **DATE: 27.11.2015**

DURATION: 0900-1300

ALLOWED SUPPORTING MATERIAL : Valid calculator and curriculum literature:
Kuchta: Investigation of fire and explosion accidents
SINTEF NBL / Scandpower: Handbook for Fire Calculations and Fire Risk Assessment in the Process Industry
GexCon: Gas Explosion Handbook

THE EXAM CONSISTS OF 4 TASKS ON 4 PAGES

NOTE : Students are allowed to write translations, comments and corrections in the curriculum literature.

Task 1

A tank containing 1 m^3 gasoline starts to leak. The leak rate is constant and equal to 1 kg/s until the tank is empty. The tank is placed on a flat area without any physical barriers. The molecular weight of the gasoline is 100 kg/kmol. The density is 870 kg/m^3. The heat of combustion is 43700 kJ/kg. The regression rate of an "infinitely" large pool is $0.8 * 10^{-4}$ m/s. The density of gasoline vapor at the boiling point is 3.49 kg/m^3. Set the density of air to 1.2 kg/m^3.

a) The pool ignites immediately. Calculate the equilibrium diameter D_{eq} of the pool as well as the time t_{eq} to reach the equilibrium diameter.

b) How much gasoline is burning (in kg/s) when the equilibrium diameter is reached?

c) Assume quiescent conditions (no wind), calculate the flame height L when the pool has reached its equilibrium diameter.

d) Calculate the height over the pool at which smoke production starts.

e) What is the duration of the leak? What about the duration of the fire, can you make an estimate?

f) Assume that the gasoline is collected in a circular bund with a diameter which is 50% of the calculated equilibrium diameter? What is the flame height then?

g) Calculate the fire duration for the fire in case f).

Task 2

A 3 m^3 container is filled with a gas mixture consisting of 70% methane, 10% ethane and 20% carbon dioxide (volume percent). The temperature inside the vessel is 20 degrees C. The pressure in the tank is 6 bar. The universal gas constant R is 8314 J/(kmol*K). The specific heat capacity ratio, γ, is 1.3. When deciding which equation of state to use, assume for simplicity that the gas is pure methane. Set the density of air to 1.2 kg/m^3.

a) Set up a stoichiometric balance equation for the mixture and calculate the stoichiometric concentration of the gas-air mixture based on this equation.

b) Calculate the lower and upper flammability limits for the gas mixture.

c) Calculate the average molecular weight M of the gas mixture. Calculate the density ρ and the mass m of gas in the container.

d) A leak occurs, from a circular hole with radius 2 cm. Calculate the initial leak rate (in kg/s) from the vessel. Provide a reason for the choice of formula.

e) The leak forms a jet like a frustum cone (avkuttet kjegle) with half top angle α of 9.1 degrees. Calculate based on the initial leak rate the equivalent radius r_0 and the distance from the leak location to the lower flammability limit for the jet (the "length" of the jet). Assume that the gas expands isothermally to atmospheric pressure.

f) What is the leak rate after 15 seconds?

g) Use the figure below (taken from Kuchta) to estimate the flammability limits of methane in an atmosphere consisting of

   i. Methane-air (i.e. no inert gas), and
   ii. 70% methane-air and 30% inert gas,

for the following inert gases: CO_2(carbon dioxide) and N_2 (nitrogen). Disregard any temperature deviations.

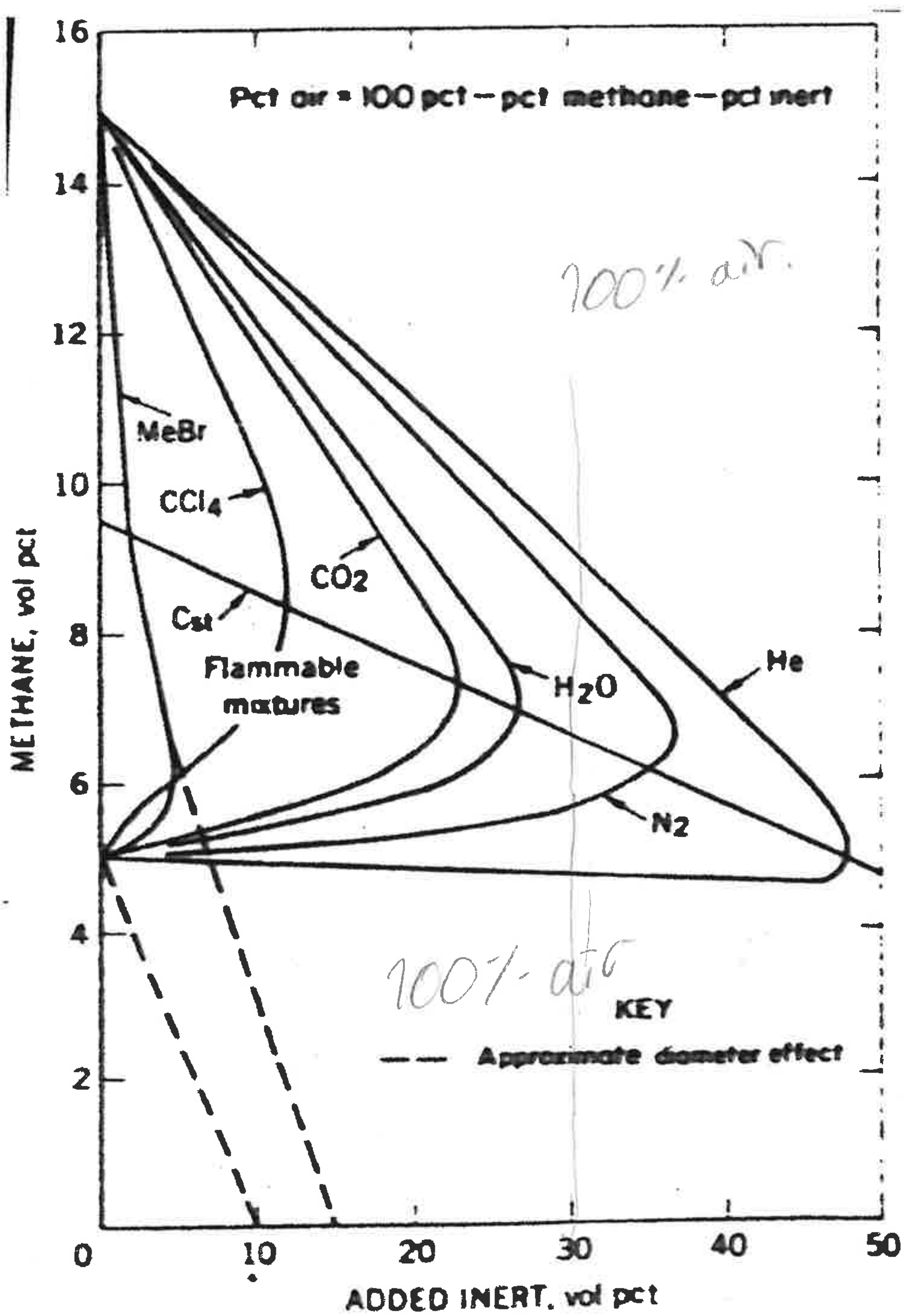

Figure 38.—Limits of flammability of various methane-air-inert gas mixtures at 25° C and 1 atm.

Task 3

This task requires you to respond qualitatively (i.e. no calculations are required) to a set of questions.

Assume that methane leaks from a gas tank. Consider the following situations and respond to the three questions given:

a) The gas is ignited immediately after the leak starts. Is the resulting combustion process a fire or an explosion? Give a brief explanation.

Fire

b) The gas is allowed to mix with air for a period, before ignition. There is no equipment, no structures or buildings in the volume occupied by the gas-air mixture. What would you call this combustion process? Explain briefly. Gas explosion ?

c) Again the gas is allowed to mix with air for a period, before ignition. Here, however, the cloud engulfs a space congested by piping and equipment. What type of combustion process would you expect here?

Task 4

Natural gas leaks into a module on an offshore platform with a leak rate of 5 kg/s. Assume that the gas forms a stoichiometric, uniform mixture with air. The module is 40 m long, 15 m wide and 6 m high. It is open on one long side, otherwise closed. Equipment, pipework, cable trays, local rooms etc fill up 15% of available space inside the module. The density of natural gas at ambient temperature (20 degrees C) can be taken to be 0.8 kg/m^3.

a) The natural gas consists of 85% methane, 10% ethane and 5% propane. Calculate the lower and upper flammability limits of the gas-air mixture, as well as the stoichiometric concentration in air of the gas mixture.

b) The gas-air cloud size increases with time. After how long (time) will the stoichiometric gas-air cloud fill the entire module?

c) At this time the gas cloud explodes with a maximum overpressure of 4 barg. Calculate the blast overpressure at the Living Quarter (LQ) on the neighbouring platform (100 m away) by using the Multi-Energy method.

d) Calculate the duration of the blast wave as it hits the LQ.

392/24

Universitetet i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

EXAMINATION IN: RIS520 Technical Safety **DATE: 19.12.2014**

DURATION: 0900-1300

ALLOWED SUPPORTING MATERIAL : Valid calculator and curriculum literature:
Kuchta: Investigation of fire and explosion accidents
SINTEF NBL / Scandpower: Handbook for Fire Calculations and Fire Risk Assessment in the Process Industry
GexCon: Gas Explosion Handbook

THE EXAM CONSISTS OF 3 TASKS ON 2 PAGES

NOTE : Students are allowed to write translations, comments and corrections in the curriculum literature.

Task 1

A container of 3 m^3 is filled with methane gas at 20° C, which is also the ambient temperature. The pressure in the vessel is 150 barg. The universal gas constant R is 8314 J/(kmol*K). The molecular weight M of methane is 16 kg/kmol, and the molecular weight of air is 29 kg/kmol. The relationship between specific heat capacities, γ, is 1.3. The atmospheric pressure is 1 bar and the air density 1.2 kg/m^3.

a) Find the density ρ of the gas. Determine the mass m of gas in the container. Explain which version of the equation of state you use, and why you use this version.

b) A pipe connection to the container breaks and a circular hole in the tank with a diameter of 3 cm is formed. Which formula should be used to calculate the initial leak rate from the hole? Calculate initial leak rate (in kg/s) from the container. What is the leak rate after 20 seconds?

c) Assume that the leaking gas expands adiabatically to atmospheric pressure. The relationship between pressure and density for adiabatic expansion is given by $p\rho^{-\gamma}$=constant. Calculate the density and temperature of the expanded methane. Is the methane lighter or heavier than air?

d) The leak is a horizontal jet, with half top angle $\alpha = 9.1°$. Calculate the speed of sound in the expanded methane. Explain the concept of equivalent radius and calculate it immediately after the leak has started.

e) How far is it from the leak source to the location along the jet axis where the concentration has dropped to 50% of stoichiometric?

f) The sonic leak is ignited immediately after it starts. Calculate lift-off s and distance L from the leak to the visible flame tip immediately after the leak is ignited.

Task 2

A pipe connection to the bottom of an atmospheric tank containing 5000 litres of gasoline is broken. The size of the resulting hole is d = 4 cm. The liquid head (the gasoline depth) is 1 m. The tank is placed on a flat area without any physical barriers. The molecular weight of the gasoline is 100 kg/kmol. The liquid density is 870 kg/m^3. The heat of combustion is 43700 kJ/kg and the heat of vapourization is 350 kJ/kg. The specific heat capacity can be set to 2.2 kJ/(kg*K). Set the density of air to 1.2 kg/m^3. The discharge coefficient is 0.62, the gravitational acceleration is 9.81 m/s^2.

a) Calculate the initial leak rate from the tank.

b) The pool ignites immediately. Calculate the regression rate (assume the pool is "infinitely" large).

c) Calculate the equilibrium diameter D_{eq} of the pool as well as the time t_{eq} to reach the equilibrium diameter.

d) How much gasoline is burning (in kg/s) when the equilibrium diameter is reached?

e) Assume quiescent conditions (no wind), calculate the flame height L when the pool has reached its equilibrium diameter.

f) Assume for this question that the leak rate is constant in time. Then what is the duration of the leak? What about the duration of the fire, can you make an estimate?

g) Then make the assumption that the gasoline is collected in a quadratic-shaped bund (dike) surrounding the tank, with a side length of 4 m. What is the flame height then? Will the fire duration be longer or shorter than the duration calculated in question f)? Is this measure (i.e. using a bund) a good or a bad measure (risk reducing or not)? Discuss briefly.

Task 3

Natural gas leaks into a module on an offshore platform with a leak rate of 5 kg/s. The natural gas consists of 85% methane and 15% propane. Assume that the gas forms a stoichiometric, uniform mixture with air and that this cloud grows with time. The module is 30 m long, 15 m wide and 8 m high. It is open on one long side, otherwise closed. Equipment, pipework, cable trays etc fill up 10% of available space inside the module. The density of natural gas at ambient temperature (20 degrees C) can be taken to be 0.8 kg/m^3.

a) Generate a stoichiometric equation for the gas-air mixture.

b) Calculate the stoichiometric concentration of the gas mixture using the stoichiometric equation.

c) Calculate the lower and upper flammability limits in air of the gas mixture at 25 degrees C.

d) How long does it take for the gas-air cloud to fill the available space in the module?

e) When the gas-air cloud fills the entire module, it explodes with a maximum overpressure of 4 barg. Calculate the blast overpressure and duration at the Living Quarter on the neighbouring platform (100 m away) by using the Multi-Energy method.

39(2)/24

Universitetet i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

EXAMINATION IN: MOS230 Technical Safety DATE: 19.02.2013

DURATION: 0900-1300

ALLOWED SUPPORTING MATERIAL : Valid calculator and curriculum literature:
Kuchta: Investigation of fire and explosion accidents
SINTEF NBL / Scandpower: Handbook for Fire Calculations and Fire Risk Assessment in the Process Industry
GexCon: Gas Explosion Handbook

THE EXAM CONSISTS OF 4 TASKS ON 2 PAGES

NOTE : Students are allowed to write translations, comments and corrections in the curriculum literature.

Task 1

Natural gas leaks into a module on an offshore platform with a leak rate of 8 kg/s. The gas forms a stoichiometric, uniform mixture with air. The module is 40 m long, 20 m wide and 8 m high. It is open on one long side, otherwise closed. Equipment, pipework, cable trays, local rooms etc fill up 10% of available space inside the module. The density of natural gas at ambient temperature (25 degrees C) can be taken to be 0.8 kg/m^3.

a) The natural gas consists of 80% methane, 12% ethane and 8% propane. What is the stoichiometric concentration in air of the gas mixture? Calculate also the lower and upper flammability limits of the gas-air mixture,

b) After how long (time) will the stoichiometric gas-air cloud fill the entire module?

c) At this time the gas cloud explodes with a maximum overpressure of 4 barg. Calculate the blast overpressure at the Living Quarter on the neighbouring platform (120 m away) by using the Multi-Energy method.

d) Calculate the duration of the pressure pulse, for the same explosion as above, for the same location.

Task 2

A pipeline with inner diameter 60 cm transports methane. At a given location the overpressure inside the pipe is 100 barg, the temperature 10 degrees C and the pressure gradient dp/dx is 60 N/m^3. Assume that the pipeline is cut (sheared) at the given location, and that on the low pressure side of the break the pipeline is closed immediately.

a) Calculate the initial leak rate from the pipe.

b) What is the leak rate after 1 minute, and how much gas has leaked out?

c) Assume that the leak ignited immediately (at time 0). The resulting flame is vertical. Calculate lift-off s and distance L from the leak to the visible flame tip.

Task 3

A 1 m^3 vessel is filled with methane gas at 0 °C. The pressure in the vessel is 120 bar. The universal gas constant R equals 8314 J/(kmol*K). The molecular weight M of methane is 16 kg/kmol. The specific heat ratio, γ, is 1.3.

a) Generate a stoichiometric balance equation for methane (CH_4) in air. Calculate stoichiometric concentration of methane in air based on the stoichiometric equation.

b) Write up the version of the equation of state that fits best for the conditions defined above. Provide a reason for your choice.

c) Find the density ρ of the gas. Calculate the mass m of gas in the vessel.

d) A pipe connection to the vessel is broken and an approximately circular, sharp-edged hole of 2 cm diameter is generated. Which formula should be used to calculate the initial leak rate from the hole – and why? Calculate the initial leak rate (in kg/s) from the vessel.

e) Calculate the equivalent radius for the leak (jet). (hint: assume isothermal expansion)

Task 4

A butane tank of 5 m^3 leaks from a circular hole with diameter 3 cm. The hole is at the bottom of the tank. The liquid head (væskehøyden) is 2 m at the start of the leak. The ambient temperature is 10 degrees C, i.e. the vapour pressure in the tank is 1,5 bar. It can be assumed to be constant. The liquid density is 589 kg/m^3. The molecular weight of butane is 58 kg/kmol. The gravitational constant is g=9.81 m/s^2.

a) How large is the regression rate in m/s for infinitely large pools when the heat of combustion is ΔH_c = 45.8 MJ/kg, and the heat of vapourization is ΔH_v = 0,37 MJ/kg? Assume for simplicity that the butane is at the boiling point.

b) How large is the initial leak rate?

c) The butane is ignited and burns as a pool which is fed from a continuous release. How large is the pool's equilibrium diameter, and at what time is the equilibrium diameter reached?

d) Assume that the fire is not affected by the presence of the tank. What is the flame height under quiescent conditions (no wind)?

39(2)/24

Universitetet i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

EXAMINATION IN: RIS520 Technical Safety **DATE: 03.12.2013**

DURATION: 0900-1300

ALLOWED SUPPORTING MATERIAL : Valid calculator and curriculum literature:
Kuchta: Investigation of fire and explosion accidents
SINTEF NBL / Scandpower: Handbook for Fire Calculations and Fire Risk Assessment in the Process Industry
GexCon: Gas Explosion Handbook

THE EXAM CONSISTS OF 3 TASKS ON 2 PAGES

NOTE : Students are allowed to write translations, comments and corrections in the curriculum literature.

Task 1

Natural gas leaks out in a module and forms a stoichiometric, uniform gas-air mixture which fills the entire module. The module is 50 m long, 20 m wide and 8 m high. It is fully open at both ends. Equipment, piping etc. occupies 5% of the module volume. The density of this natural gas is 0.8 kg/m^3, and its stoichiometric concentration is 8.5 %.

a) What is the volume of the gas-air cloud?

b) What is the volume and the mass of natural gas in the module?

c) Which ignition location results in the highest explosion overpressure? Explain briefly why.

d) Calculate the overpressure at a location 200 m from the explosion centre by the Multi-Energy (ME)-method, when the maximum explosion overpressure in the module is 4 barg.

e) If the maximum explosion overpressure is reduced from 4 to 1 barg, what is the effect on the far field overpressure (still 200 m away)? What if the maximum explosion overpressure is reduced to 0.2 barg, what is the effect on the far-field overpressure?

f) Describe (briefly) three methods by which explosion overpressure can be reduced.

Task 2.

A gasoline (petrol) tank of 5 m^3 leaks from a circular hole with diameter 4 cm. The hole is at the bottom of the tank. The liquid head (væskehøyden) is 1 m at the start of the leak. The ambient temperature is 20 degrees C, and the (absolute) vapour pressure in the tank is 170 kPa. It can be assumed to be constant. The liquid density is 750 kg/m^3. The molecular weight of gasoline is 100 kg/kmol. The gravitational constant is g=9.81 m/s^2.

a) How large is the regression rate in m/s for infinitely large pools when the heat of combustion is $\Delta H_c = 43.7$ MJ/kg, and the heat of vapourization is $\Delta H_v = 0{,}36$ MJ/kg? Assume for simplicity (for this calculation only) that the gasoline is at its boiling point.

b) How large is the initial leak rate?

c) The gasoline is ignited and burns as a pool fed from a continuous release. How large is the pool's equilibrium diameter, and at what time is the equilibrium diameter reached?

d) Assume that the fire is not affected by the presence of the tank. What is the flame height under quiescent conditions (no wind)?

Task 3

A 1 m^3 vessel is filled with methane (CH_4) gas at 20 °C. The pressure in the vessel is 100 bara. The universal gas constant R equals 8314 J/(kmol*K). The molecular weight M of methane is 16 kg/kmol. The specific heat ratio, γ, is 1.3.

a) Generate a stoichiometric balance equation for methane in air.
Calculate the stoichiometric concentration of methane in air based on the stoichiometric equation.

b) Find the minimum ignition energy (MIE) and ignition temperature (AIT) for methane. How do these parameters normally vary with increasing molecular weight of the fuel?

c) Is it likely that a spark from electrical equipment can ignite a stoichiometric methane-air mixture? Give a short explanation.

d) Write the equations of state for ideal and real gases, respectively. Describe briefly which gas properties will determine which equation of state must be applied. Which equation of state fits best for the conditions defined above?

e) Find the density ρ of the gas. Calculate the mass m of gas in the vessel.

f) A pipe connection to the vessel is broken and an approximately circular, sharp-edged hole of 3 cm radius is generated. Calculate the initial leak rate (in kg/s).

g) What is the leak rate after 10 seconds?
Make a coarse estimate of how much gas has leaked out after 10 seconds?

h) Calculate the equivalent radius for the leak (jet) based on the initial leak rate. (hint: you need to make an assumption with regard to expansion of the leaking gas.)

i) Assume that the gas jet has the shape of a frustum cone. What is the distance from the leak location, along the jet axis, to the location where the gas concentration is stoichiometric (based on initial leak rate)?

39-2/24

FACULTY OF SCIENCE AND TECHNOLOGY

EXAMINATION IN: **MOS230 Technical Safety** **DATE:** **03.12.2012**

DURATION: **0900-1300**

ALLOWED SUPPORTING MATERIAL : **Valid calculator and curriculum literature:**
Kuchta: Investigation of fire and explosion accidents
SINTEF NBL / Scandpower: Handbook for Fire Calculations and Fire Risk Assessment in the Process Industry
GexCon: Gas Explosion Handbook

THE EXAM CONSISTS OF 3 TASKS ON 2 PAGES

NOTE : Students are allowed to note translations, comments and corrections in the curriculum literature.

Task 1

A 1 m^3 vessel is filled with ethane gas at 20 °C. The pressure in the vessel is 50 bar. The universal gas constant R equals 8314 J/(kmol*K). The molecular weight M of ethane is 30 kg/kmol. The specific heat ratio, γ, is 1.3.

a) Generate a stoichiometric balance equation for ethane (C_2H_6) in air. Calculate the stoichiometric concentration of ethane in air based on the stoichiometric equation.

b) Find the minimum ignition energy (MIE) and ignition temperature (AIT) for ethane. How do these parameters normally vary with increasing or decreasing molecular weight of the fuel?

c) Is it likely that a spark from electrical equipment can ignite a stoichiometric ethane-air mixture? Give a short explanation. oftest har sparks høyere energi enn MIE, så det er sannsynlig

d) Write the equations of state for ideal and real gases, respectively. Describe briefly which gas properties will determine which equation of state must be applied. Which equation of state fits best for the conditions defined above?

e) Find the density ρ of the gas. Calculate the mass m of gas in the vessel.

f) A pipe connection to the vessel is broken and an approximately circular, sharp-edged hole of 4 cm diameter is generated. Calculate the initial leak rate (in kg/s) .

g) What is the leak rate after 1 minute, and how much gas has then leaked out?

h) Calculate the equivalent radius for the leak (jet). (hint: assume isothermal expansion)

i) Assume that the gas jet has the shape of a frustum cone. What is the distance from the leak location, along the jet axis, to the location where the gas concentration is ½ LEL?

Task 2

Natural gas leaks into a module and forms a stoichiometric, uniform gas-air mixture which fills the entire module. The module is 40 m long, 15 m wide and 5 m high. It is fully open at both ends. Equipment, piping etc. occupies 5% of the module volume. The density of natural gas can be set to 0.83 kg/m^3. The stoichiometric concentration of the natural gas is 8%.

a) What is the volume of the gas-air cloud?

b) What is the volume and the mass of natural gas in the module?

c) Which ignition location results in the highest explosion overpressure? Explain why.

Longest path of flame (Point in one end)

d) Calculate the overpressure at a location 150 m away (from the explosion centre) by the Multi-Energy (ME)-method, when the maximum explosion overpressure in the module is 4 barg.

e) If the explosion overpressure is reduced from 4 to 2 barg, what is the effect on the far field overpressure (150 m away)? What if it is reduced to 0.5 barg, what is the effect on the far-field overpressure?

f) Describe (briefly) two methods by which explosion overpressure can be reduced.

Task 3.

A gasoline (petrol) tank of 10 m^3 leaks from a circular hole with diameter 5 cm. The hole is at the bottom of the tank. The liquid head (væskehøyden) is 2 m at the start of the leak. The ambient temperature is 20 degrees C, and the vapour pressure in the tank is 70 kPa. It can be assumed to be constant. The liquid density is 750 kg/m^3. The molecular weight of gasoline is 100 kg/kmol. The gravitational constant is g=9.81 m/s^2.

a) How large is the regression rate in m/s for infinitely large pools when the heat of combustion is $\Delta H_c = 43.7$ MJ/kg, and the heat of vapourization is $\Delta H_v = 0{,}36$ MJ/kg? Assume for simplicity that the gasoline is at its boiling point (which in reality is not a unique number).

b) How large is the initial leak rate?

c) The gasoline is ignited and burns as a pool which is fed from a continuous release. How large is the pool's equilibrium diameter, and at what time is the equilibrium diameter reached?

d) Assume that the fire is not affected by the presence of the tank. What is the flame height under quiescent conditions (no wind)?