Module 3

MODERATOR COVER GAS SYSTEM

OBJECTIVES:

After completing this module you will be able to:

3.1 State the lower explosive limits of D_2 and O_2 in a helium atmosphere. *⇔ Page 2*

3.2 State six factors that affect the concentration of D_2 and O_2 in the cover gas, and explain how each affects the gas concentrations. *⇔ Pages 2-3*

3.3 a) List the operating states that require cover gas circulation and explain three reasons for this circulation requirement, *⇔ Page 3*

b) Explain the three conditions that require cover gas purging, *⇔ Pages 3-4*

c) Explain the required precaution while purging the cover gas. *⇔ Page 4*

3.4 State the two methods that are used to ensure that D_2, O_2 and N_2 concentrations in the cover gas are within the allowable limits. *⇔ Page 4*

3.5 Explain the possible significant consequence and general methods to minimize or offset the consequences for each of the following abnormal conditions in the moderator cover gas:

a) D_2 concentrations between 2% and 4%, *⇔ Pages 4-5*

b) D_2 concentrations above 4%, *⇔ Page 5*

c) N_2 concentrations above 2% . *⇔ Page 5*

3.6 Explain two methods used to determine if a cover gas recombination unit is operating. *⇔ Page 4*

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INSTRUCTIONAL TEXT

INTRODUCTION

Recall from your previous R&A courses that the purpose of the moderator cover gas system is to provide a non-corrosive/non-explosive atmosphere for the calandria components. It is for these reasons that helium is used for the moderator cover gas. A typical cover gas system is shown in Figure 3.1 at the end of the module, which can be unfolded and kept in sight for easy reference.

This module will cover the cover gas circulation requirements, cover gas purging, factors affecting cover gas D_2 concentrations and consequences of high D_2 and N_2 concentrations in the cover gas.

Explosive Limits

Obj. 3.1 ⇔

* Note that the recombination units are discussed in the Chemistry 224 course. Recall also the radiolysis reaction: $2D_2O \leftrightarrow 2D_2 + O_2$

The cover gas system facilitates the recombination of D_2 and O_2 created due to radiolysis of the moderator D_2O*. The explosion hazard is eliminated by keeping D_2 and O_2 levels within operating range, which are below the **lower explosive limits** of ~8% D_2 and ~5% O_2 (ie. normal operating levels are maintained well below 1% D_2, with O_2 concentrations slightly higher to ensure a sufficient quantity of O_2 for recombination).

D_2 and O_2 concentrations in the cover gas

The rate of radiolysis and the rate at which the dissolved gases evolve from the moderator are affected by a number of factors.

Obj. 3.2 ⇔

The rate of radiolysis increases with increasing **γ radiation**. Thus, the higher the power level, the greater the rate at which radiolysis occurs. High **conductivity** or impurities (ie. nitric acid, resin fines, oils, etc.) in the moderator will cause the natural rate of D_2 and O_2 recombination to decrease.

Once these gases are produced, the rate at which they come out of solution also depends on a number of other factors:

a) As the **temperature of the moderator** increases, the water is less able to hold the dissolved gases, ie. solubility decreases. Hence, at higher temperatures the rate at which gases leave the water and enter the cover gas is greater than at lower temperatures. The moderator outlet temperature is typically maintained at ~60°C.

b) As the cover gas **pressure of the moderator** decreases, the ability of the moderator to hold the dissolved gases decreases. Again, the gas evolution rate increases as pressure in the cover gas is reduced (ie. a similar effect can be seen in carbonated drinks, as the container is opened and depressurized, the gases come out of solution). The cover gas is normally maintained at a pressure of ~10 to 25 kPa(g).

c) As the **moderator level** decreases, the D_2 and O_2 concentration in the cover gas increases. Recall from module 2 that this effect is caused by the increased surface area between the moderator and the cover gas, from which the D_2 and O_2 can evolve from the moderator to the cover gas.

d) The **concentration of D_2 and O_2 in the moderator**. As the concentration of the gases dissolved in the moderator increase, the gases will attempt to reach a new equilibrium state with the cover gas. This will result in the D_2 in the moderator evolving from the D_2O at a faster rate (as compared to a lower concentration of D_2 in the moderator) to reach the equilibrium state.

Cover gas circulation

All reactor states require the **circulation of the cover gas**. The reasons for the requirement of continuous circulation are: ⇔ *Obj. 3.3 a)*

a) High decay γ fields exist in the core during shutdowns, which will cause radiolysis to continue (hence allowing D_2 and O_2 concentrations to build up). This can be further aggravated by moderator poisons (impurities) which cause a decrease in the natural recombination rate. This is why D_2 concentrations in the cover gas increase during a reactor restart after an outage (ie. radiolysis exceeds the low rate of natural recombination).

b) Continuous circulation also ensures that any samples taken from the cover gas are representative of the cover gas.

c) The circulation also ensures that a flow is maintained to the recombination units, which will recombine the D_2 and O_2 back into D_2O.

Cover gas purging

If, during a unit shutdown, the cover gas compressors require maintenance, a helium make-up supply and a method of **purging** must be available. This is to ensure that the removal of D_2 and O_2 can occur (ie. without circulation of the cover gas through the recombination units). Purging while the cover gas compressors are shutdown is referred to as a static purge. ⇔ *Obj. 3.3 b)*

Purging the cover gas is also the only method of removing air or N_2 from the cover gas. This is of particular concern when the system has been opened for maintenance, ie. where air ingress has occurred.

Purging of the cover gas is carried out during reactor operation when concentrations of N_2 or D_2 exceed limits specified in your operating documentation. This is accomplished by bleeding off helium from the system, while making up helium to the system at the same rate (to prevent a drop in cover gas pressure). Purging while the cover gas compressors are operating is referred to as a dynamic purge.

Obj. 3.3 c) ⇔

When purging the cover gas, **care must be taken** to ensure that the **pressure** is not reduced (ie. the normal pressure is maintained at ~10-25 kPa(g)). Recall that lowering the pressure in the cover gas system can cause an increase in D_2 concentration in the cover gas (and evolution of dissolved gases in general).

We should also note that a reduction of cover gas pressure will cause the boiling point of the moderator to decrease. Hence, this will also result in the impairment in the use of the moderator as a heat sink in the event of a severe LOCA *.

* This was discussed in more detail in Module 2.

Cover gas monitoring

Obj. 3.4 ⇔

Cover gas can be monitored by two methods:

a) The first is by the **on line gas chromatograph**, which takes samples upstream and downstream of the recombination units. This will give the operator warning when D_2, O_2 and N_2 concentrations are out of specified ranges. The D_2 and O_2 readings across the recombination units will also indicate to the operator that these units are functioning properly.

b) The other method of sampling is a **manual grab sample** of the cover gas. This manual sample will require analysis by the chem lab.

Abnormal conditions

Obj. 3.5 a) ⇔

Concentration of D_2 between 2% and 4% in the cover gas requires that conditions be established to ensure D_2 levels do not increase further. This **prevents an explosive mixture of D_2 and O_2** being formed. The required methods vary from station to station, but typically include:

- Purging of the cover gas;
- Adding O_2 to ensure there is a sufficient quantity for recombination;
- Check cover gas compressor operation and place another compressor in service if required;

Obj. 3.6 ⇔

- Check **recombination unit operation**. This could be accomplished by checking that recombination unit temperature is in the correct range, ie. recombination of D_2 and O_2 produces heat. If the recombination unit catalyst becomes wet, the unit will not function (which would require the heaters to be put in service until the unit is functioning). Operation could also be confirmed by D_2 and O_2 levels at the inlet/outlet of the recombination units. If there is a fault with the unit, another unit would have to be placed in service;

- Lowering the moderator temperature;
- Increase moderator level;
- Increase purification or place fresh IX columns in service;
- Do not raise reactor power.

The reasons for these actions have been previously mentioned in this module.

At a concentration of 4% D_2 in the cover gas, the required actions are, again, to ensure that the concentration does not reach the explosive limit. Here, the actions are a bit more drastic, as the margin to the explosive limits of D_2 and O_2 is being reduced. The typical **methods** to reduce D_2 levels will be: ⇔ *Obj. 3.5 b)*

- Continue purging of the cover gas,
- Sample immediately and after the D_2 concentration has been confirmed above 4%, shut down the unit in a controlled manner.

Nitrogen in the cover gas can form **nitric acid** in the presence of moisture and radiation. This acid will also increase **radiolysis** of the moderator D_2O. This could cause a D_2 excursion, resulting in a plant shutdown. Note that this acid will also cause **corrosion** of the moderator components. The N_2 concentration is maintained $\leq$ 2% (typically $\leq$ 0.5%). When concentrations reach 2%, the typical **methods** to reduce N_2 levels will include: ⇔ *Obj. 3.5 c)*

- Purging the cover gas system until N_2 is within specifications;
- Increasing moderator purification to remove any acids that have formed.

SUMMARY OF THE KEY CONCEPTS

- D_2 concentration in the cover gas increases with:
  - Moderator temperature. As the moderator temperature increases, the D_2 solubility decreases.
  - Decreased moderator cover gas pressure. As the pressure of the cover gas decreases, the D_2 solubility decreases.
  - Decreased moderator level. As the moderator level decreases, the surface area of the moderator exposed to the cover gas increases. This increased surface area makes it easier for the D_2 gas to come out of solution.

NOTES & REFERENCES

- Increased reactor power. As reactor power increases, so do the γ and neutron fields. The increased fields increase radiolysis.
- Increased impurities in the moderator. An increase in the impurity level in the moderator will cause the rate of radiolytic recombination to reduce.
- Moderator D_2 concentration. As the moderator D_2 concentration increases, the D_2 will reach a new equilibrium with the cover gas, resulting in a higher rate of gas evolution from the moderator to the cover gas.

- The lower explosive limits for D_2 and O_2 in a helium environment are 8% D_2 and 5% O_2.
- All reactor states require cover gas circulation. Radiolysis continues during reactor shutdown due to high decay γ fields in the core.
- Purging of the cover gas is required when:
  - Cover gas N_2 or D_2 concentrations are high.
  - The system has been opened for maintenance. This is to purge air (which is mainly N_2) from the cover gas to prevent nitric acid from being formed.
  - Cover gas compressors are not available to circulate the cover gas through the recombination units.
- When purging the cover gas system, care must be taken to ensure that system pressure is not lowered, which could cause a D_2 excursion.
- D_2, O_2 and N_2 concentrations are monitored on line by the gas chromatograph. Grab samples for chem lab analysis can also be taken.
- D_2 concentrations between 2% and 4% may typically require the following to reduce concentrations:
  - Purging of the cover gas,
  - Adding O_2 to ensure there is a sufficient quantity for recombination,
  - Check and place another recombination unit in service as required,
  - Check and place another cover gas compressor in service as required,
  - Increasing the moderator level,
  - Lowering the moderator temperature,
  - Keeping reactor power constant.
- Confirmed D_2 concentrations above 4% will require a unit shutdown (while the purge continues).

- N_2 concentrations above 2% will require a cover gas purge, and may require an increased rate of moderator purification to remove nitric acid that has formed.

You can now **work on the assignment questions.**

⇔ *Page 9*

ASSIGNMENT

1. The lower explosive limits are _____% D_2 and ______% O_2 in a helium environment.

2. a) As reactor power increases, the production of D_2 in the moderator increases / decreases because ____________________

   ____

   ____

   ____.

   b) As moderator impurity levels increase, the concentration of D_2 in the moderator increases because ____________________

   ____

   ____

   ____.

   c) As moderator temperature increases, the concentration of the D_2 in the cover gas increases / decreases because __________

   ____

   ____

   ____.

   d) As cover gas pressure increases, the concentration of the D_2 in the cover gas increases / decreases because ___________

   ____

   ____

   ____.

   e) As moderator level increases, the concentration of the D_2 in the cover gas increases / decreases because ______________

   ____

   ____

   ____.

f) As the concentration of the D_2 in the moderator increases, the concentration of the D_2 in the cover gas increases / decreases because ______________________________

____

____

______________________________.

3. The cover gas must be circulated (only while operating / all the times) because ______________________________

____

______________________________.

4. a) Purging of the cover gas will be required when

i) ______________________________

____

______________________________.

ii) ______________________________

____

______________________________.

iii) ______________________________

____

______________________________.

b) The cover gas compressors can be removed from service only if ______________________________

______________________________.

5. The precaution to be taken when purging the cover gas system is

____

______________________________. This is because ______________________________

____

______________________________.

6. Gas concentrations are monitored by the ____________________ on line. The other source of gas analysis is ____________________ ____________________.

7. High concentrations of N_2 in the cover gas can lead to __________ ____________________ which will result in ____________________.

   High concentrations of D_2 in the cover gas can lead to __________ ____________________.

8. a) D_2 concentrations between 2% and 4% will typically require:

   i) ____________________.

   ii) ____________________.

   iii) ____________________.

   iv) ____________________.

   v) ____________________.

   vi) ____________________.

   vii) ____________________.

   b) D_2 concentrations above 4%, in addition to the above actions, will also require ____________________ ____________________.

   c) N_2 concentrations above 2% will require the following actions:

   i) ____________________.

   ii) ____________________.

9. Recombination unit operation can be confirmed by the following:

   a) ____

   ____

   ____

   ____

   b) ____

   ____

   ____

   ____

Before you move on, **review the objectives** and make sure that you can meet their requirements.

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