Module 14

ANNULUS GAS SYSTEM

OBJECTIVES:

After completing this module you will be able to:

14.1 State three important benefits obtained by using CO_2 as the annulus gas. ⇔ *Page 3*

14.2 State the reason why the annulus gas system must be circulating in order to fulfill its purposes. ⇔ *Pages 3-4*

14.3 For each of the following parameters: ⇔ *Page 4*

a) Pressure;
b) Dew point;

State why it is monitored and give a typical range of values encountered in normal operation.

14.4 State six reasons why purging of the annulus gas system may be required. ⇔ *Page 5*

14.5 For each of the following abnormal conditions, state the indicated number of major operating concerns: ⇔ *Pages 6-7*

a) High annulus gas pressure (2),
b) Low annulus gas pressure (2),
c) Leakage of the annulus gas (2),
d) Air in the annulus gas (3),
e) High or increasing moisture levels (2).

14.6 State when the annulus gas system may be stagnant. ⇔ *Pages 7-8*

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INSTRUCTIONAL TEXT

INTRODUCTION

A general review of the annulus gas system includes:

- System purposes;
- Gas selection;
- System operation.

Following the introduction, a discussion of topics includes:

- Dew point;
- Annulus gas pressure;
- Abnormal unit conditions.

A very basic layout of an annulus gas system is shown in Figure 14.2 on fold-out page 13. This page is available for reference as you work through the module.

System Purposes

To understand the function of the annulus gas system, we should first review the location of the annuli in the calandria. Figure 14.1 indicates the location of the annulus gas as a boundary between the moderator and heat transport system.

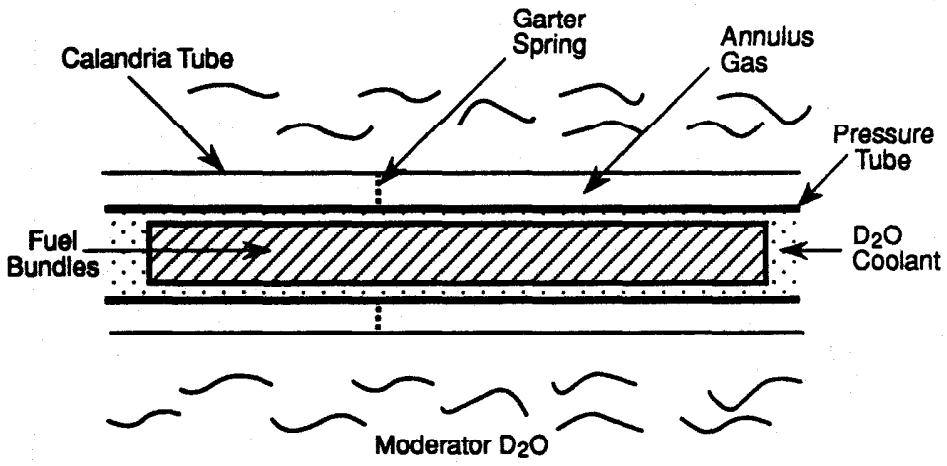

Figure 14.1 Sketch of Annulus Gas Position

Serving as a separating medium, the two main purposes of the system include:

- To provide a method to **detect** and **locate** leakage from a pressure or calandria tube.
- To provide **thermal insulation** between the hot pressure tubes and the relatively cool calandria tubes. This minimizes heat losses from the heat transport system coolant to the moderator coolant, thereby increasing the efficiency of the unit.

Secondary purposes of the annulus gas system include:

- Providing a dry gas atmosphere in the fuel channel annuli to **prevent corrosion** of fuel channel components;
- Providing a means to **drain leakage** from the heat transport, and moderator systems.

Gas Selection

To fulfill the functions required of an annulus gas, the following properties are necessary:

- **Low thermal conductivity** (good thermal insulator);
- **Low** tendency to promote **corrosion**;
- **Low radiation fields** (limited activation products).

Of the proposed annulus gases for CANDU stations, CO_2 has proven most suitable because of its good insulating properties. In the presence of water, carbonic acid (H_2CO_3) is formed. This acid is only mildly corrosive and is not a problem in the small amounts experienced. CO_2 can also form radioactive C^{14} from the neutron activation of C^{13}. Since C^{13} has a natural abundance of 1% and has a very small neutron absorption cross section, the quantity of C^{14} produced is very small.

⇔ *Obj. 14.1*

System Operation

Annulus gas flows through the fuel channel annuli, to an outlet header and then to the compressors. The compressors provide the motive force to circulate the annulus gas to the inlet header and back through the system. Circulation of the annulus gas is important for early leak detection since it ensures the **dew point readings** and **gas sampling represents all of the annuli.** Without circulation, it may take a long time (days) for a small D_2O leak to be detected. Because continuous circulation is so important, the system is designed to allow for gas flow through the channels even when the compressors are unavailable. This is achieved by supplying fresh gas from the bulk supply via the pressure

⇔ *Obj. 14.2*

regulating valve and venting to atmosphere via the purge line through contamination monitors. When a leak exists, most stations can also vent to containment for vapour recovery. This mode of circulation without the compressors is referred to as the **continuous purge** mode. The gas addition bottles through a pressure regulating valve are the normal supply to the annulus gas system.

Dew point analysers in the main outlet header determine the system dew point. These readings as well as temperature and pressure are trended in the main control room for comparison purposes. There are also sample stations, usually in the main outlet headers, which allow for manual sampling of the gas.

The system piping is arranged such that any liquid in the system drains by gravity to the drain header. A moisture beetle in this header will indicate the presence of liquid.

Some stations have an oxygen addition system connected to the header downstream of the compressors. Small amounts of oxygen gas are added to the annulus gas to promote a harder oxide layer on the outside of the pressure tubes. Most stations will be retrofitted with this system for this reason. Oxygen can also be used to purge any solid C^{14} deposits by converting them to CO_2 (this is used for decontamination purposes prior to outages, eg. O_2 concentrations used will be higher than normal operating values).

Annulus Gas Pressure

Obj. 14.3 a) ⇔

The annulus gas system should be pressurized even when the unit is shut down. Positive pressure is maintained **to prevent the ingress of air**. As air ingresses, argon activation in air can lead to high gamma fields.

With the HT system cold, the annulus gas pressure is set to a low value, typically 14 kPa(g). As reactor power increases, the annulus gas pressure increases, typically, in the range **25 to 100 kPa(g)**. When the pressure drops below setpoint, the operator can restore pressure via the pressure regulating valve.

Dew Point

Obj. 14.3 b) ⇔

A dew point analyser(s) measures the **moisture content of the annulus gas.** The signals are sent to the control room where they are trended for comparison purposes so that a **leak trend** can be established. The rate of rise of dew point can also be established as a requirement for purging.

The allowable moisture levels in the annulus gas are usually expressed as a dew point and vary from station to station. A typical dew point operating range is **- 40°C to - 10°C** with - 30°C as a normal operating value.

System Purging

⇔ *Obj. 14.4*

Whenever the moisture content of the gas approaches the dew point upper limit, the gas should be purged. Fresh dry gas is used to replace the impure gas for the following reasons:

a) To **remove accumulated moisture** which would otherwise contribute to high corrosion rates and mask small leaks. The reasons for purging include preventing build-up of corrosion products and preventing blockage of the interconnecting tubing for the channel annuli.
b) To **remove corrosive impurities**, the most critical being nitric acid formed from N_2 and O_2 via air ingress.
c) To **remove air** in the system, typically following maintenance to the system.
d) To **reduce gamma fields** in accessible areas, when Ar^{41} has formed as a result of air ingress.
e) To **lower the dew point** prior to startup of the reactor from a cold shutdown. As the reactor heats up, the temperature and pressure will increase in the annulus gas system. The partial pressure of any water vapour in the system will also increase, raising the dew point. To counter this effect, the dew point is lowered prior to heatup by a purge with dry gas.
f) To maintain **leak detection** capability by maintaining gas flow through the system when the compressors are unavailable.

SUMMARY OF THE KEY CONCEPTS

- CO_2 has the beneficial properties of:
  - low thermal conductivity;
  - low corrosion;
  - limited activation products.
- Annulus gas must be circulated or purged to ensure dew point measurements and gas sampling are representative of all of the annuli.
- System pressure should be kept above atmospheric pressure to prevent air ingress. A typical range is 25 to 100 kPa(g).
- Dew point is monitored to detect moisture from leaks. A leak tight system should have a dew point range of - 40°C to - 10°C.

- Purging may be necessary to:
  - remove accumulated moisture;
  - remove corrosive impurities such as nitric acid;
  - remove air from the system;
  - reduce gamma fields;
  - maintain leak detection capability when the compressors are unavailable;
  - lower the dew point before a cold startup.

ABNORMAL UNIT CONDITIONS

1. High Annulus Gas Pressure

Obj. 14.5 a) ⇔

Annulus gas pressure can increase due to the following causes:

- Pressure tube rupture;
- Thermal effects due to increases in reactor power;
- Pressure regulating failure.

Annulus gas overpressure can cause strain, **fatigue** or even **rupture** of the **calandria tubes** or secondly, **fatigue** or **rupture** to the **bellows seals** joining the annulus gas system to the pressure tube end fitting.

Overpressure protection is provided by pressure relief valves. Some stations use rupture discs on the compressor outlet in combination with the pressure relief valves.

2. Low Annulus Gas Pressure

Obj. 14.5 b) ⇔

Annulus gas pressure can decrease due to the following causes:

- System leakage;
- Loss of bulk gas supply;
- System shrinkage on reactor cooldown.

It is possible to draw vacuum on the system if it is isolated and cooled. **Pressure below atmospheric** in the annulus gas system **could cause the collapse of calandria tubes.** Where possible, the system should be repressured via the bulk storage and any leaks repaired. **Air in-leakage is** also **a concern** at low annulus gas pressures because of the resulting increase in radioactivity.

3. Annulus Gas Leakage

Obj. 14.5 c) ⇔

Annulus gas can escape through piping leaks or channel bellows leaks. This can present a **radiation hazard** as well as **reduce** the

NOTES & REFERENCES

or the moderator. A **stagnant mode of operation** is then used to **locate the leaking annulus.** The compressors are shut down and isolated with the purge valves closed to:

- Maximize condensation of D_2O in defective channels and;
- Reduce the spread of moisture throughout the annulus gas system.

A leak search also includes checks of channel outlet temperatures. The leaking fuel channel transfers heat from the pressure tube to the calandria tube via the leaking D_2O. If the gas space surrounding the leaking pressure tube fills with D_2O the heat transfer rate increases to effectively lower the channel outlet temperature. However, the channel outlet temperature data may not indicate the leaking pressure tube until sufficient fluid condenses and accumulates. It should be kept in mind that low channel outlet temperatures can also result from other reasons such as the pressure tube touching the calandria tube.

Note that a beetle alarm may take a long time to come in, depending upon the leak location and size. Sight glasses may also be available in some stations to detect liquid flow from individual annuli.

SUMMARY OF THE KEY CONCEPTS

- For the following conditions the operating concerns are given:

Conditions	Operating Concern(s)
High gas pressure	Failure or rupture of calandria tubes, failure or rupture of bellow seals if overpressure protection fails.
Low gas pressure	Air in-leakage, collapse of calandria tubes.
Gas leakage	Radioactive hazard, reduced ability to check P trends.
Air in system	Radioactive hazard primarily, Ar^{41}, production of corrosive nitric acid, moisture masking leaks.
High or increasing dew point	High pressure and temperature hazards with potential for a LOCA, radiological concerns.

ability to check P (pressure) trends. The escaping annulus gas from any leakage points may contain radioactivity in the form of:

- C^{14}, an activation product, as CO_2 gas or as a particulate;
- Entrained fission products and loose contamination from fission products;
- Tritium from D_2O leakage.

Annulus gas leakage can also cause low annulus gas pressure which, as mentioned in item 2 above, may lead to air in-leakage.

4. Air in the Annulus Gas

⇔ *Obj. 14.5 d)*

Maintenance work or leaks in the system cause air ingress into the annulus gas.

The presence of air leads to radioactive hazards and the production of **corrosive nitric acid** (from N_2). The predominant **radiation hazard** is Ar^{41}, an activation product. Other radiation hazards include C^{14} produced from N^{14}, and N^{16} and O^{19} from O^{16} and O^{18}. **Moisture from air** in the system **may mask leaks.**

5. High or Increasing Moisture Content

⇔ *Obj. 14.5 e)*

An increase in dew point indicates an increase in moisture content of the annulus gas.

Possible causes of high or increasing dew point may be:

- Pressure tube leak;
- Calandria tube leak;
- Air in-leakage;
- Impure annulus gas supply.

For a persistently high dew point after purging, the most probable cause is a pressure tube leak, because of HT system high pressure and temperature. Two **operational concerns** exist with increasing dew point. Firstly, that a contaminated system is leaking with **radiological concerns** and the **potential for a subsequent LOCA** with possible fuel and calandria tube damage. The leak will eventually increase over time when power changes produce temperature changes in the leaking system. Secondly, a **high temperature and pressure hazard** exist in the case of a HT system leak.

6. Leak Location

⇔ *Obj. 14.6*

To locate the leak source, a sample of condensed fluid is obtained by passing a stream of moist annulus gas through a cold finger*. The sample is then analysed to determine if the source is the HT system

* A cold finger is a trap in dry ice which freezes the moisture.

- The system may be stagnant to determine the location of a confirmed leaking annulus by maximizing condensation of D_2O in the defective channels and reducing the spread of moisture throughout the annulus gas system.

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

⇔ *Page 11*

ASSIGNMENT

1. State three desirable properties of CO_2 as an annulus gas:

   a) _____

   b) _____

   c) _____

2. The annulus gas system is normally circulating even when the unit is shut down. Why is this desirable?

   _____

   _____

3. a) Dew point is one of the most important operating parameters for the annulus gas system. Why is this the case?

   _____

   _____

   b) Why is annulus gas pressure monitored?

   _____

   _____

   c) State typical operating ranges for the following parameters.

   Dew point _____

   Pressure _____

4. Occasionally conditions warrant purging of the annulus gas system. State six reasons why purging would be required:

   a) _____

   b) _____

   c) _____

   d) _____

   e) _____

   f) _____

5. Under what operating condition would the annulus gas compressors be shut down and isolated?

   _____

   _____

6. Complete the following chart:

Conditions	Operating Concerns
High or increasing dew point	_____ _____
_____	Radioactive hazard Ar ^{41}, _____ _____
Gas leakage	_____ _____
Low pressure	_____ _____
High pressure	_____ _____

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

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Revision date: June, 1992