

Reactor, Boiler & Auxiliaries - Course 233

MODERATOR COVER GAS SYSTEM

I. PURPOSE OF SYSTEM

- (a) The use of a He cover gas above the moderator in the calandria (and in the dump tank if one is used) provides a non-corrosive atmosphere for the internal parts of the top of the calandria which are not submerged under moderator D₂O. In addition, the He gas will not become radioactive so that the activity of the cover gas system will be minimized. (The moderator D₂O vapour in the He cover gas will give rise to some tritium and N-16 and O-19 radiation however).
- (b) It provides a means of removing the D₂ and O₂ gases (produced by moderator radiolysis) from the gas space above the moderator. Removal is achieved by recirculating the He cover gas through recombination units.
- (c) It provides overpressure protection for the calandria and calandria tubes, in particular the lower row of calandria tubes. (The latter are subject to the highest pressure of all calandria tubes.)
- (d) It provides a vent and purge for various reactivity mechanisms.
- (e) For reactors with dump tanks, it forms part of the moderator level control system and reactor shutdown system.

This section discusses purposes (a) to (d) for reactors without dump tanks. The level control and dump aspects of purpose (e) will not be discussed in these notes.

II. EQUIPMENT DESCRIPTION (FOR COVER GAS SYSTEMS WITHOUT DUMP TANKS)

A typical simplified system is shown in Figure 1.

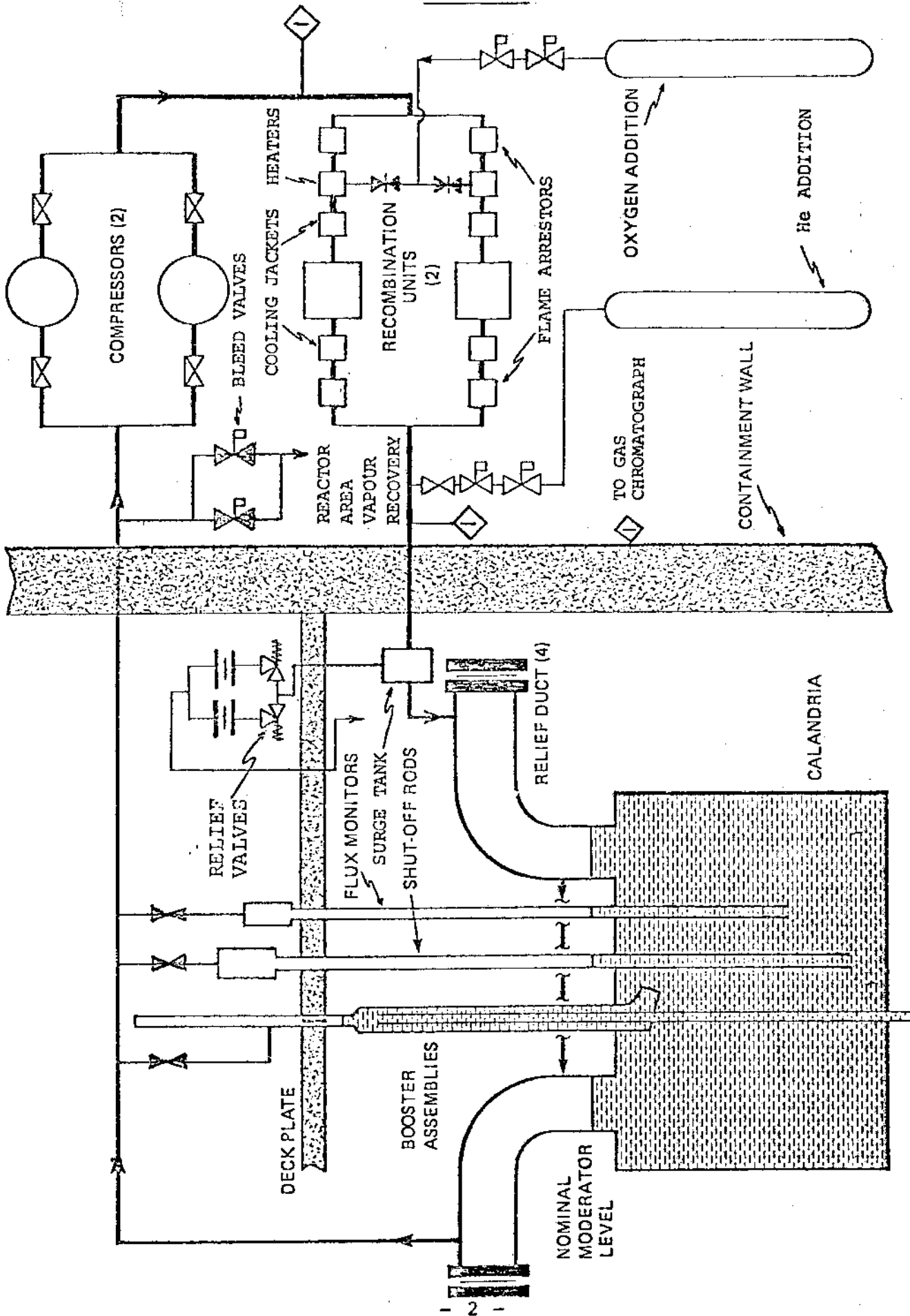


Fig. 1 MODERATOR COVER GAS SYSTEM

(a) He Compressors

The He cover gas is taken at around 110 kPa(a), from the calandria pressure relief ducts by one of 2 x 100% He compressors. The operating compressor discharges He into 2 x 100% recombination units and then back to the calandria. The ΔP across the compressors is around 10 ~ 20 kPa(d) at a typical flow of a few litres/second.

A positive pressure with respect to atmosphere is desirable to prevent air inleakage into the cover gas. Air inleakage would likely lead to the formation of corrosive nitric acid in the moderator due to the combined effect of nitrogen, oxygen and D₂O moisture in the presence of radiation. The formation of nitric acid is likely also to lead to increased moderator radiolysis and a subsequent deuterium excursion (an increase in the deuterium concentration of the cover gas). In addition, the life of the moderator IX resin would decrease due to the added burden of removing nitric acid.

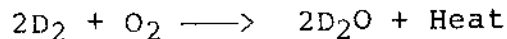
Air inleakage is also undesirable due to the production of Ar⁴¹ which would result from the absorption of a neutron by the naturally-occurring Ar⁴⁰ in air. As most of the cover gas equipment is located in accessible areas, increases in Ar⁴¹ γ fields would be undesirable.

Plants without dump tanks use diaphragm compressors. These are more suitable for the smaller flow capacities required if no dump tank is used than the liquid ring seal compressors used on units with dump tanks. The diaphragm compressors have the advantage of not requiring the moderator D₂O supply lines and N-16 delay tank which are required for the liquid ring seal compressors. Service water cooling for the oil-operated cylinder of the diaphragm compressor is, however, required. Regardless of the type of compressor used good seal integrity is very important because of the high cost of helium gas and also leakage of tritiated D₂O vapour.

Location of the compressors is usually at the highest point in the system so that no problem arises with accumulation of D₂O condensate in them. The arrangement of the cover gas piping should be such that any liquid D₂O can drain by gravity to the calandria. (Some stations may be equipped with moisture separators in the cover gas system to make D₂O drainage easier. The separators would usually drain collected D₂O into the moderator D₂O collection system tank.)

(b) Recombination Units

The recombination units consist of a palladium catalyst enclosed in a steel vessel. Their function is to maintain the cover gas deuterium concentration (produced by moderator radiolysis) to <2% under normal operation. The Pd catalyst in the units will recombine deuterium and oxygen (back into D₂O vapour) in a volume ratio of 2:1 according to the following exothermic reaction:



The D₂O vapour from recombination will then be recirculated back to the moderator in the calandria together with any other D₂O vapour being circulated by the compressors.

The units are usually equipped with electrical heaters, used to activate the units if wet by drying out the catalyst. A wet catalyst will not promote recombination. A recombination unit temperature greater than the boiling point of D₂O should be adequate to guarantee a dry catalyst. The heat from the exothermic recombination of deuterium and oxygen may be adequate during normal operation to maintain the catalyst dry without heaters. A shutdown of the He cover gas system during a reactor shutdown is likely to result in a wet catalyst requiring drying prior to start-up.

The recombination units may be considered operational when their outlet D₂ concentration is less than their inlet D₂ concentration and/or a positive ΔT is observed across the unit.

In addition to heaters, the recombination units are supplied with coolers (from service water). These cool down the outlet gas to protect downstream equipment such as valves and calandria rupture discs from high temperatures as the gas outlet temperature from the recombination unit may get as high as a few hundred °C due to the exothermic recombination.

(c) Flame Arrestors

Flame arrestors consisting of a wire mesh in a steel container are installed before and after the recombination units to stop any spread of burning gases that would result from ignition of the deuterium/oxygen mixture in the recombination unit. Ignition is possible inside this unit if potentially explosive concentrations exist, and recombiner catalyst temperature is above the auto ignition temperature for the He/D₂/O₂ mixture, ~600°C.

Damage to cover gas equipment and, more importantly, to the calandria/calandria tubes, due to ignition of the cover gas in the recombiner, is then prevented by the flame arrestor. The flame arrestor dissipates the heat produced by ignition on the recombiner side of the flame arrestor within its steel mesh. The temperature resulting from the ignition heat will then be reduced below that required for ignition on the other side of the flame arrestor.

(d) Oxygen Addition Line Equipment

Oxygen gas addition (Figure 1) is provided (manually) at the recombination unit inlet. This allows for makeup of O₂ concentrations in the cover gas when the oxygen:deuterium ratio is less than the 1:2 ratio required for complete recombination.

Reduction of the O₂ concentration relative to D₂ could be caused by corrosion of system materials, but this is probably small. More likely an O₂ deficiency will be due to oxidation reactions where O₂, from radiolysis, combines with oil or IX resin fines in the moderator.

(e) Pressure Control/He Addition

The cover gas pressure is maintained by feed from an He bottle station (or bulk He supply) through pressure-regulating valves (Figure 1). Excess pressure is bled off via an instrumented bleed valve to the reactor area (moderator) vapour recovery system.

(f) Overpressure Protection Equipment

Overpressure protection, in addition to the above mentioned bleed valve, is provided by safety valves (Figure 1). These provide overpressure protection for the calandria during the injection of moderator poison when SDS2 operates. This injects considerable extra D₂O (~0.8 Mg) into the moderator which then results in an increase in cover gas pressure as the cover gas is displaced into a reduced gas volume.

In addition to the above, rupture discs (Figure 1) on the calandria relief ducts provide extra overpressure protection for the cover gas. However, the rupture discs were primarily designed to protect the calandria following a burst calandria/pressure tube. An explosion in the cover gas system, giving a very rapid overpressure, is likely also to burst these.

(g) Reactivity Mechanisms Vent Connections

Connections from the cover gas system are provided to the reactivity mechanisms. This provides a non-corrosive, non-active atmosphere inside the out-of-core sections of these mechanisms. It also minimizes the build-up of D_2/O_2 gases from radiolysis of moderator D_2O surrounding the in-core components of the mechanisms by providing a direct vent to the cover gas system.

The reactivity mechanisms connections may include (depending on the station):

- shut-off rods
- adjusters
- control absorbers
- vertical flux monitor tubes
- horizontal flux monitor tubes
- liquid poison injection system

A typical connection to a reactivity mechanism is shown simplified in Figure 1.

(h) Instrument Air Connection

A connection (on reactors without dump tanks) is usually provided from instrument air to the calandria. This allows the calandria to be filled with air if the calandria is drained off moderator. Air filling is considerably cheaper than He filling in this case.

III ANALYSIS OF COVER GAS CONCENTRATIONS

Sample and sample return lines from the recombination unit inlets and outlets are connected to a gas chromatograph to monitor the D_2 (and O_2 and N_2) concentrations (Figure 1). A close watch should be kept on the D_2 concentrations, especially on a start up when D_2 excursions are more likely (see later). The risk of a cover gas explosion will then be reduced, especially if concentrations are measured continuously. Measurement of the O_2 and N_2 concentrations in the cover gas will provide an indication of air inleakage occurring, as air is ~20% O_2 and ~80% N_2 .

In particular, on units with no dump tanks, there are two differences from dump tank units that should be noted:

- (i) The cover gas volume is quite small so that a given amount of D_2 will produce a larger concentration, and faster, than in a dump tank cover gas system.

(ii) When the reactor is shutdown, there will still be considerable radiolysis in the moderator, which is still in the calandria. Radiolysis is mainly the result of fast neutrons and γ 's on D_2O , and there is still a large source of γ 's to maintain radiolysis, and hence D_2 production, during shutdown.

As a result of (ii) above, compressors, recombiners and gas analysis should be maintained operational on a reactor shutdown if possible. If these are not available the cover gas should be continually purged with helium to remove the D_2 continually being produced by radiolysis.

(a) Cover Gas D_2 Concentration Limits

D_2 limits vary from station to station, but typically 2% D_2 in the cover gas is an action limit at which cover gas purging may be started and moderator purification operation checked. Above about 6% D_2 , depending on the station, the reactor should be shutdown. This will reduce the radiolysis rate and decrease the rate of production of D_2 .

(b) Conditions Giving Rise to High D_2 Concentrations

Various operating conditions may give rise to high D_2 concentrations and it may not be easy to determine the prime cause of a D_2 excursion because of the numerous possible causes, especially on a start-up.

On the following page is a list of conditions which may lead to high D_2 concentrations with possible causes of these conditions listed along side.

<u>Condition</u>	<u>Possible Causes</u>
high moderator conductivity	- Gd/B in moderator - spent IX resin in service - inadequate purification flow - air inleakage - accidental addition of lithium loaded HT resin to moderator D ₂ O
resin fines in moderator	- breakthrough of resin from IX columns and/or strainers
oil/organics in moderator	- oil leakage in He compressors - oily D ₂ O added to moderator
increasing rate of radiolysis	- reactor power increasing
decreasing rate of recombination	- recombination unit catalyst waterlogged - low recombiner flow
increase release of dissolved D ₂ from moderator	- rising moderator temperature - reduction of cover gas pressure - increasing turbulence of moderator due to sprays/rapid level changes (more common on dump tank units).

ASSIGNMENTS

1. Explain why the He cover gas is circulated when the reactor is at power and explain whether it is necessary to do this on reactor shutdown.
2. From your own plant He cover gas flowsheet, find out if there are any differences between it and the simplified version in Figure 1. Discuss any reasons for differences.
3. Where are the most likely places for cover gas air inleakage to occur?
4. What are the specific actions and action limits in your own plant as cover gas D₂ concentrations rise?
5. From objectives 20-3 #5 state whether any of the effects listed above have caused D₂ excursions in your own plant. If possible state the reasons the effects happened.

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