

SHELL EO/EG PROCESS MEMORANDUM 105

SUBJECT : REACTOR MECHANICAL DESIGN CONSIDERATIONS

DATE OF ISSUE : ORIGINAL : MAY 2005
Revision A : November 2005

Revision note: Revision A

Textual changes have been marked with revision marker in the margin



INTRODUCTION

This memorandum reviews the impact of extreme operating conditions on the process and mechanical design of the water-cooled EO reactor system. The EO reactor process data sheet prepared by the licensor provides data, which correspond to the normal operating conditions. Stresses imposed by abnormal and transient conditions must be assessed and taken into account by the engineering contractor and reactor vendor.

1. REACTOR CARE PRIOR TO START-UP	2
2. PREPARATION FOR INITIAL START-UP	3
3. START-UP	6
4. NORMAL OPERATION	7
5. RUNAWAY	9
6. PRE-IGNITION	12
7. POST-IGNITION	14
8. COOLING OF REACTOR AFTER SHUT-DOWN	16
9. MAINTENANCE	17
SPECIFICATIONS FOR PROCESS CHEMICALS AND MATERIALS	18
Figure 1: Typical temperature profile	20
Figure 2: Typical temperature profile during runaway	21
Figure 3: Typical temperature cycle during pre-ignition	22
Figure 4: Typical temperature cycle during post-ignition	23



1. REACTOR CARE PRIOR TO START-UP

During reactor construction the manufacturer must exercise utmost care to prevent rust formation inside the tubes because of the detrimental effect this will have on ethylene oxide yield and byproduct formation. All materials shall be free of mill scale prior to construction. For the hydrostatic pressure test, inhibited deaerated test water shall be used.

During manufacturing the reactor components are to be kept in a dry condition and condensation is to be prevented. After manufacturing and hydrostatic testing, the reactor shall be dried. The top dome and bottom dome, including the tube sheets, and all the tubes must be gritblasted completely to remove all rust. During and after gritblasting the air in the reactor must be conditioned and dried to prevent rust formation. If gritblasting is not possible, chemical cleaning must be applied. After gritblasting or chemical cleaning, the reactor is to be kept dry and rust formation on the process side of the reactor it is to be prevented by providing nitrogen to both the tube side and the shell side of the reactor and by maintaining the nitrogen pressure above atmospheric.

The nitrogen is to be applied on the reactor during shipping and construction, while taking proper safety measures to eliminate any nitrogen asphyxiation hazards for the construction workers and other personnel involved. As soon as piping connections are made, the nozzle blinds required to preserve the nitrogen environment in the reactor are to be replaced by line blinds to exclude moisture entering the reactor. Preferably, the nitrogen environment should be restored but only if that can be done in a manner that guarantees the safety of the construction workers.

In case of reactor entry for inspection or catalyst loading activities the nitrogen is to be replaced by dry air. Proper safety procedures are to be applied to ensure proper oxygen concentrations before reactor entry. During work in the reactor for catalyst loading the reactor air supply is to be dried and conditioned to prevent condensation. Prior to catalyst loading the reactor tubes will be inspected to verify if final gritblasting is required.



2. PREPARATION FOR INITIAL START-UP

Before charging the EO catalyst it is recommended that the reactors and coolant system be heated to near operating temperature to check the mechanical operation of the coolant system and to test tube/tube sheet joints. Indication of new rust spots at tube/tube sheet joints could indicate possible leakage points. The following operations are required before the EO catalyst is charged:

1. All lines and drains are thoroughly cleaned by flushing with water, steam or nitrogen. At some opportune time it is recommended to pressurise the recycle gas loop, excluding reactor, with nitrogen and release it quickly via an open flange just upstream of the reactors. It is recommended to keep a nitrogen purge through the oxygen mixing nozzle sparger during this operation. Equipment and piping are hydrostatically tested as required by local code and by the licensee, then drained as completely as practicable. Test water should be inhibited.
2. The reactor shell-side should be degreased by circulating an alkaline cleaning solution.

After the shell side is cleaned, care must be taken to prevent corrosion and oxygen pitting by using one of the following alternatives:

- a. Completely fill the system with deaerated boiler feed water
 - b. Dry completely and store under nitrogen
3. To prepare the system for heating, the reactor shells must be completely filled with deaerated boiler feed water at ambient temperature. If the boiler feed water supply is more than 10°C above ambient temperature, fill the system via the condensate shutdown coolers. Monitor the cooler outlet temperature to avoid thermal shock in the reactor. The HP steam drum and MP steam drum must be filled to the minimum operation level to allow room for the expansion of water during heating. The operating company and engineering contractor are responsible for providing suitable water feed for this system. The typical boiling feed water properties are given in table 1.



4. Coolant circulation through the reactors is established by drawing water at ambient temperature from the HP steam drum with the condensate circulation pump. The coolant enters the bottom of the reactor shells, passes up around the tubes, and overflows into the HP steam drum and then back to the pump suction.
5. The reactors and HP steam drum are heated to around 230 °C to impose normal stresses on equipment and piping. Before heat is added to the circulating coolant stream, however, complete filling of the reactor shells should be verified to ensure good heat transfer to the top tube sheet. This may be best accomplished by putting the HP steam drum level controller into service to hold the proper level in the vessel. The cold circulating coolant is heated by careful steam sparging in the HP steam drum and the heating rate shall be limited to avoid excessive thermal stresses in the reactors. As no steam is generated yet, the level in the HP steam drum will rise and the normal continuous blowdown to the MP steam drum is not sufficient to get rid of the additional condensate. During heating of the EO reactors the operators must periodically blowdown the condensate from the HP steam drum to the MP steam drum through the discontinuous blowdown operated by a handvalve. The maximum allowable heating rate is typically 10 °C/hr. The engineering contractor and reactor vendor must define the maximum allowable heating rate.

During the heating period it is necessary to control the heat input in order not to overstress the reactors. Excessive thermal gradients across either the tube sheets, the shells, between individual tubes, or between tube bundle average temperature and the shell can overstress the reactor components, or cause tube to tube sheet leaks

6. The reactors are cooled slowly to a temperature slightly above ambient to avoid condensation in the tubes. See shutdown.
7. The reactors must be inspected for leakage of coolant into the process side and for rust deposits. Light and powdery rust on the process side may be removed by wire brushing. Heavier rust must be removed by grit blasting of the tubes. The use of a pickling solution shall be approved by Shell when pickling of the tubes is required for any reason.



Cleaning and catalyst charging are discussed in Process Memorandum 101.

8. The reactor tubes are next packed with catalyst and inerts. The bottom of each tube contains a spring to fix the catalyst. The top section of the tubes is packed with inerts or catalyst to serve as preheat section for the incoming feed gas. A top section filled with catalyst would offer the advantage of providing a buffer zone for potential catalyst poisons and would reduce the catalyst work rate, leading to improved selectivity.



3. START-UP

1. After the reaction system has been made leak tight, it is purged with nitrogen. The process side is brought to start-up composition and nearly to process design pressure but with flow bypassing the reactors.

The reactors are heated as in step 5 above.

2. During the later stages of heating and before oxygen is added to the recycle gas, reactant gas will be circulated through the reactors having a temperature approximately equal to ambient temperature. The gas will be heated to the coolant temperature in a short distance. For indication, at a typical overall coefficient is $200 \text{ kcal/m}^2\text{hr}^\circ\text{C}$, a temperature difference of 165°C will be reduced to 4°C after the gas has travelled 2.5 meters. The hot gases leaving the reactor will heat the feed-product exchanger, and the reactor feed gas temperature will soon reach the normal inlet temperature.
3. With fresh catalyst, the reaction may begin when oxygen is added. For high activity catalyst the reactor coolant temperature should be $215 - 220^\circ\text{C}$, whilst for high selectivity catalyst the reactor coolant temperature should be $230 - 260^\circ\text{C}$. At the point where the heat of reaction exceeds the heat loss plus the gain in sensible heat by the gas as it passes through the reactor, the reaction becomes self-sustaining.

The feed gas flow is then gradually brought up to design, normal thermosyphon coolant flow through the reactor shell and the primary product cooler is established and the coolant circulation pump is stopped. The heat of reaction will provide the heat required to bring the reactor and coolant to the desired temperature for normal operation. With subsequent start-ups this initiation temperature will increase, depending on the age of the catalyst.



4. NORMAL OPERATION

During normal operation, coolant is vaporised along the catalyst-containing section of the tubes. This steam rises in the shell and a portion of it is condensed in the top section to preheat the feed. The remaining steam passes out of the upper connection between the reactor shell and the HP steam drum carrying with it considerable coolant liquid. The entrained liquid is separated from the steam in the HP steam drum and, along with make-up coolant, flows back to the reactor through the lower connection in the reactor shell. The steam passes through the HP steam drum, through the pressure control valve to downstream users. The PIC controls the HP steam drum pressure and, indirectly, the reactor temperature.

The pH of the continuous blowdown from the HP steam drum to the MP steam drum must be controlled to prevent corrosion in the reactors. The pH shall be maintained above 9.5-10.5 at 25°C.

The reactant gases normally enter the top head of the reactor at about 165-175°C and are heated in the preheat section to within 2°C of the coolant temperature. Upon entering the catalyst zone, the gases react exothermally and reach a maximum temperature difference between catalyst and adjacent coolant of 4 - 6°C when the fresh catalyst is started-up. Figure 1 shows a typical initial temperature profile. As the catalyst ages, the peak temperature difference (PTD) may be 6 - 10°C.

Gas temperatures are measured by thermocouples centred in catalyst tubes. Coolant temperatures are measured by thermocouples inserted in unpacked, closed perforated reactor tubes. These temperatures are continuously recorded. The number and location of thermocouples are provided in the drawings in the reactor data sheet package and Process Memorandum 106.

The temperature difference between the reaction gases and the coolant depends on the extent of reaction and the rate of heat transfer between reactants and coolant. Adjusting the HP steam drum pressure, which in turn fixes the coolant temperature, controls the extent of reaction, or conversion in both reactors simultaneously. Although independent adjustment of reactor temperatures is not possible in case of GHSV fluctuations, any possible difference in GHSV between the reactors will be dampened overtime and the reactor system will be inherently stable.



The coolant temperature required for design conversion depends on several factors such as feed composition, space velocity, moderator addition rate, and catalyst age.

Although the gas temperature is considerably warmer than the coolant over most of its length, the tube wall is close to the temperature of the coolant. This is due to the high heat transfer coefficient from the tube wall to the boiling coolant. The coolant side coefficient normally typically exceeds 2000 kcal/m²hr°C compared with 400 - 600 kcal/m²hr°C for the gas side.

The tubes are supported by the top and bottom tubesheet. Over the length of the reactor a number of support plates are installed. They have a large number of smaller holes through which the coolant passes.



5. RUNAWAY

The term runaway is used to describe a condition in which ethylene is oxidised completely to carbon dioxide and water within the reactor bed, consuming all the available oxygen, and forming no ethylene oxide. The complete oxidation to CO_2 has a much higher heat of reaction than the partial oxidation to ethylene oxide. Therefore, runaways always involve a higher than normal amount of heat generated per unit mass of reactants.

At normal peak temperature differences of 2 - 8°C, the corresponding coolant temperature will be about 12 - 15°C below the temperature at which a runaway reaction is expected to occur in a substantial number of tubes. As the coolant temperature is increased above the normal value, the gas temperature also increases, but at a faster rate; that is, an increase in the coolant temperature above normal levels will produce a much larger temperature rise in the peak temperature of the gas.

This can be explained in the following way. Higher gas temperatures increase the rate of reaction and thus the rate of heat generation over normal levels. As the rate of reaction is increased, the extent of reaction (conversion) also increases. More carbon dioxide and less ethylene oxide is produced with increasing conversion. Hence, even more heat is generated. Since heat generation is increased over normal levels, but other factors (such as tube surface) remain essentially constant, the temperature difference between gas and coolant must increase in order to transfer the extra heat.

All tubes in a reactor are usually not identical with regard to catalyst activity and gas flow. Therefore, some tubes will be closer to runaway than others at a given coolant temperature. During normal operation, a few tubes may be in a runaway condition without noticeable effect, except for a small increase in CO and aldehyde production. If runaway should occur in a significant number of tubes however, the reactor should be shutdown, because further operation is wasteful; and because a narrow zone of catalyst in the runaway tubes is overheated and possibly deactivated. Oxygen cut-off will stop the reaction, and heat generation will cease as soon as the oxygen in the recycle system has been consumed.



In practice, the oxygen feed should be shut-off as soon as possible after a runaway is detected. A runaway reaction can be detected by high reactor outlet temperatures, high CO (higher than normal amounts are produced during runaway only) or low O₂ in the reactor product.

A high rate of reactor steam generation is also a likely indication of runaway.

Runaways have been initiated intentionally in experimental reactors using full-scale tubes and kerosene coolant. No tube damage was found after runaways of up to 30 minutes duration. No significant reduction in average catalyst activity resulted from runaways of short duration as long as the tubes were covered with coolant. Usually runaway is confined to a few tubes in the reactor unless the coolant in the shell is by accident depleted.

A typical temperature profile for runaway in a pilot plant reactor tube is shown in Figure 2. The heat transfer coefficient for the coolant increases as the heat flux and temperature differences are increased. Near the temperature peak a maximum heat flux of about 220000 kcal/m²hr is predicted for heat transfer to boiling coolant. The mean temperature difference along the tube length, between the metal tube wall and the coolant would not exceed 5°C during a runaway, due to the gas film resistance inside the tube.

The rate of heat generation and hence the heat duty on the reactor coolant system is dependent on the age of the catalyst (and thereby the prevailing operating conditions). At the onset of runaway, the rate of heat generation is many times the normal heat generated for the respective catalysts. This peak heat generation rate lasts for less than 20 seconds which is the time required to observe effect of oxygen cut-off.

Even after the supply of oxygen has been stopped, the reaction continues in a runaway condition until all the oxygen in the loop has been consumed. The expected local gas loop pressure increase during a runaway reaction is approximately 1 bar.

The limiting case for relief valve sizing has been determined to be a runaway reaction induced by a rise in coolant temperature due to blockage of the steam outlet line. In the calculation no heat sink of the coolant system is to

This document is confidential. The copyright therein is vested in Shell International Chemicals B.V. Amsterdam. The Netherlands.



be taken into account, since in practice it is feasible to operate just below the relief temperature.

Considering all the possibilities for runaway the relief case will be calculated. For the specific relief load refer to the process flow diagram.

Following a runaway, with the oxygen shut-off, gas should be re-circulated by the recycle gas compressor until the reactor is cooled to a few degrees below the normal operating temperature. Oxygen may be introduced to restart the reaction, provided the cause of the runaway has been corrected. In general, the gas loop is vented and purged to remove heavy hydrocarbons to prevent unstable catalyst operation.



6. PRE-IGNITION

Pre-ignition occurs when oxygen in the feed gas reacts to carbon dioxide and water prior to entering the reactor catalyst tubes. Pre-ignition can occur in the oxygen mixing nozzle, which is the first point at which oxygen concentrations can exceed the flammability limit for the combined gases, or, more likely, in the feed/product exchanger, where the temperature increases, or in the inlet of the reactor. Once the gas is ignited, the temperature rises rapidly and adiabatically to 800 - 900°C and all the oxygen is consumed. When this would occur the oxygen shutdown system should activate. A rise in reactor inlet pressure of approximately 1 bar will be noted.

There should be no burning backwards from the ignition source, unless the recycle gas compressor is well up on its head capacity curve, in which case the flame velocity could exceed the flow velocity. The burning will continue at high temperatures as long as make-up oxygen is fed to the reactor.

With proper selection of sensing and transmitting devices, the lag time from the initiating of flame to experiencing the effect of oxygen cut-off should be less than 20 seconds. After oxygen supply is cut-off and the high oxygen concentration zone between the oxygen mixing nozzle and reactor inlet is converged, the temperature will drop but the oxygen recycling from the rest of the loop will continue to react until the inventory is depleted. Pre-ignition can result in high temperatures in the feed lines, carbon lay-down on the inert packing and high carbon monoxide concentrations. The high temperature of the feed is attenuated through the inerts section into the coolant before it contacts the active catalyst bed.

Pre-ignition occurs less frequently than post-ignition, and is a result of faulty feed analysis, instrumentation or mechanical problems, operator judgement errors, or post-ignition problems. Several pre-ignition events have occurred and the effects of pre-ignition therefore should be considered in preparing a design. Figure 3 represents a typical first approximation time-temperature profile (process and metal walls) for a pre-ignition event. The duration of the pre-ignition shown in this figure is applicable to one reactor only. With the other reactor operating normally, the time scale will be substantially longer than shown in the figure. In that case the duration will be approximately 300 seconds.

This document is confidential. The copyright therein is vested in Shell International Chemicals B.V. Amsterdam. The Netherlands.



The engineering contractor must carry out the analysis for conditions specific to the actual design. The equipment most sensitive to process gas temperature rise is the feed piping and reactor inlet nozzle. Here the velocity is about 15 m/s, leading to a high heat transfer coefficient, the metal mass is the least and consequently the temperature rise is highest. The shell side of the feed/product exchanger, having lower velocities and heat transfer on the outer wall as well as greater metal wall thickness, responds more slowly to the process gas temperature rise. The reactor head and tube sheet are least likely to incur high temperature during the brief pre-ignition time period, because the velocity is very low (< 1 m/s) and heat transfer (conductive and radiant) is relatively low, whilst the metal mass is high.

The feed piping must be designed to provide adequate mechanical strength to withstand the system pressure and the forces due to thermal expansion at the higher temperatures temporarily encountered during a pre-ignition event. Thermal excursions due to pre-ignition must also be taken into account for the specifications of the feed/product exchanger and the oxygen mixing nozzle.

The thermocouple for high temperature shutdown must be a fast-response type and the signal transmission must be electrical such that the overall response time from the moment of detection until cut-off of the oxygen supply does not exceed 20 seconds. This includes the inventory of oxygen downstream of the oxygen mixing nozzle. The response time of heavy-walled thermowells or bulb-type detectors is too slow for this application. Therefore, a thermocouple tack-welded to a thin-walled sheath is required.



7. POST-IGNITION

Ignition of the reactor product gas in or down-stream of the reactor outlet-head, which consumes all the oxygen, is called post-ignition. Once the oxygen (about 5-6 %m/m concentration) is ignited, the temperature rises rapidly and adiabatically to about 700°C. A post ignition should be sensed by the high temperature alarm. A rise in reactor outlet pressure of approximately 1 bar will be noticed.

With proper selection of sensing and transmitting devices, the lag time from the initiating of flame until experiencing the effect of oxygen cut-off should be less than 20 seconds. The catalytic reaction will continue at a reduced rate, depending on the residual inventory of the oxygen in the recycle loop. However, burning or post-ignition will continue on the reduced oxygen concentration until all the oxygen in the loop is exhausted. Figure 4 presents a typical time-temperature profile (process gas and metal wall) for a post-ignition event when 2 reactors are in operation. The duration of a post-ignition in one reactor only, whilst the other reactor is operating normally, will be substantially longer than shown in the figure, because of partial oxygen conversion in the normally operating reactor. In that case the duration will be approximately 300 seconds.

Post-ignitions are encountered more often than pre-ignitions. Post-ignition will cause high exit gas temperatures, carbon lay-down, and high carbon monoxide levels. Post-ignitions can result from any of four conditions:

1. Too low an operating temperature, consequently conversion is too low, and outlet oxygen is too high. This situation is most common during operating upsets.
2. Front end catalyst bed deactivation, as a result of temporary under-moderation in case of the High Selectivity catalyst or in case of over-moderation in case of High Activity catalyst or a long term deactivation of the front end of the catalyst bed. This situation can be characterised by the peak temperature difference being near the exit of the bed.
3. Some tubes operating in a runaway condition. In this case some tubes are operating at high conversion and high exit temperatures. Adjacent tubes operating normally with higher exit oxygen concentration may be ignited, and spread to a general post-ignition.



4. Catalyst dust may deposit on the bottom or in piping and cause post-ignitions.

Calculations have shown that temperatures near 650°C may be reached in the reactor outlet nozzle and piping to the primary product cooler during a two-minute post-ignition event. As described above for pre-ignition, the piping must be designed to withstand the system pressure plus the additional loads due to a post-ignition temperature excursion. Calculations indicate that the reactor bottom head and bottom tube sheet temperatures do not increase significantly during a short-duration post-ignition. The inlet end of the primary product cooler is also subject to these temperature excursions.

A fast response thermocouple is required for the high temperature oxygen shutdown and must be answering the required response criteria described above. The overall response time from the start of the ignition to the closing of the oxygen shutdown valve must be of the order of 10 to 12 seconds. The response time of heavy-walled thermowells or bulb-type detectors is too slow for this application. Therefore, a thermocouple tack-welded to a thin-walled sheath is required.



8. COOLING OF REACTOR AFTER SHUT-DOWN

Unless the reactors and coolant system requires inspection or maintenance it need not be cooled down. When required, the system is cooled down in two steps:

1. The system can be cooled to ca 100 °C by gradually reducing the pressure controller setting on the HP steam drum. Boiling in the reactors and external thermosyphon circulation will continue. The depressuring rate must be limited such that the maximum allowable cooling rate and temperature gradients are not exceeded. Cooling rates should be typically in the order of 10 °C/hr, but shall be defined by the engineering contractor and reactor vendor. Feed water supply to the steam vessels must continue to maintain operating level during steam venting.
2. When the steam system pressure approaches atmospheric pressure, nitrogen must be connected to the HP steam drum to prevent formation of vacuum. This also excludes air ingress as the system cools to below 100°C. After steam generation stops, the system can be cooled further by using the condensate circulation pumps and the condensate shut-down cooler. The flow through the condensate shutdown cooler must be closely monitored and carefully controlled to avoid thermal shock since the high initial cooling rates that may be obtained could exceed the allowable cooling rates for the reactors. A decrease-and-hold procedure (normalising) may be necessary.



9. MAINTENANCE

While the reactor is shutdown nitrogen blanketing must be maintained on the shell side to exclude oxygen. For extended shutdowns the reactor must be drained, dried and kept under nitrogen, or an inhibitor will be applied as advised in the below attached specification for High Purity Boiler Feed Water.



SPECIFICATIONS FOR PROCESS CHEMICALS AND MATERIALS

High Purity Boiler Feed Water Specification to HP Steam Drum

General requirements	clear and colourless, free from dissolved matter
Conductivity at 25°C (Note 2)	< 3 μ S/cm
pH value at 15 °C (Note 6)	> 9.5
Oxygen (O ₂) (mg/kg) (Note 5)	< 0.02
Total iron content Fe (mg/kg)	< 0.02
Total copper content Cu (mg/kg)	< 0.01 (Note 1)
Silica (SiO ₂) (mg/kg)	< 0.05
Total carbon dioxide content (CO ₂) (mg/kg)	below detection limit
Hardness as CaCO ₃ (mq/kg)	below detection limit
K Mn O ₄ consumption (mg/kg)	< 5
Oil Content (mg/kg)	below detection limit
Phosphates	See Note 4
Hydrocarbons	zero

Notes:

1. Cu content preferably below 0.003 mg/kg.
2. Feed water specifications and treatment methods shall be decided by the licensee/contractor. Proposed treating chemicals shall be reviewed for process compatibility.
3. With continuous sampling measured after treatment in highly acid cat-ion exchanger (applied exclusively to water that is free from CO₂).
4. Boiler feed water and steam may not contain any hydrocarbons to prevent product quality degradation by contamination via the steam systems of the plant.
5. Phosphates other than Na₃PO₄ should not be used in view of the possible contamination of the EO catalyst. Phosphate is a severe catalyst poison because it promotes the isomerisation reaction of EO to acetaldehyde.
6. Oxygen scavenging by Hydrazine or Cor-Trol. Both scavenging agents decompose rapidly and have no influence on EO catalyst performance.
7. For pH control ammonia is preferred. Steam mate (a mixture or of different neutralizing amines with varied distribution ratios and chemical



reactivity) may be applied. Application of amines on mutual agreement to avoid deactivation of the EO catalyst performance. In case for some reason the pH of 9.5 or higher cannot be maintained for the Boiler water (see Boiler water specification below), Na_3PO_4 may be used for pH control.

Boiler Water Specification Blow-down from HP Steam Drum (Note 1)

General requirements	clear and colourless, free from dissolved matter
Conductivity at 25 °C (Note 2)	< 150 $\mu\text{S}/\text{cm}$
pH value at 15 °C (Note 6)	9.5 - 10.5
Silica (SiO_2) (mg/kg)	< 6
Total carbon dioxide content (CO_2) (mg/kg)	below detection limit
Phosphates	< 6
Hydrazine	traces

Notes:

1. Only additional requirements or requirements that differ from the high purity boiler feed water requirements are given.
2. Boiler water and steam may not contain any hydrocarbons to prevent product quality degradation by contamination via the steam systems of the plant.
3. For pH control ammonia is preferred. Steam mate (a mixture or of different neutralizing amines with varied distribution ratios and chemical reactivity) may be applied. Application of amines on mutual agreement to avoid deactivation of the EO catalyst performance. In case for some reason the pH of 9.5 or higher cannot be maintained for the Boiler water, Na_3PO_4 may be used for pH control.
4. The maximum allowable concentration (mg/kg) of phosphates depends on the pressure in the system. For a pressure below 40 barg the maximum allowable concentration is 30 mg/kg.



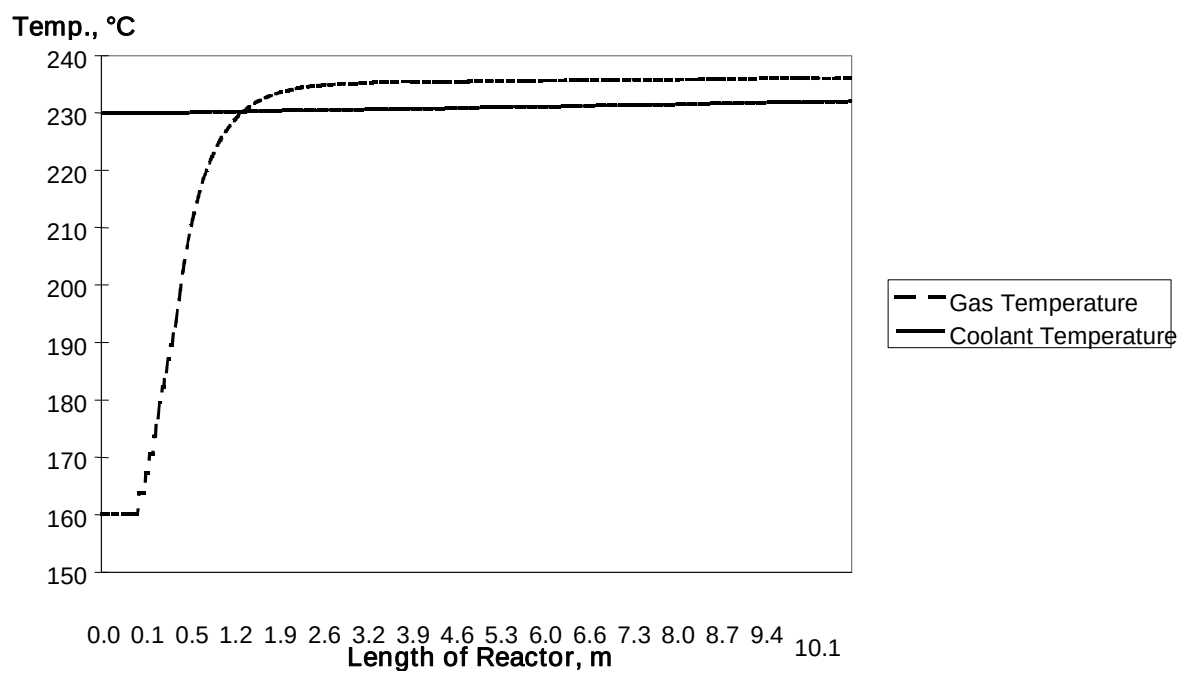


FIGURE 1: TYPICAL TEMPERATURE PROFILE AT SOC



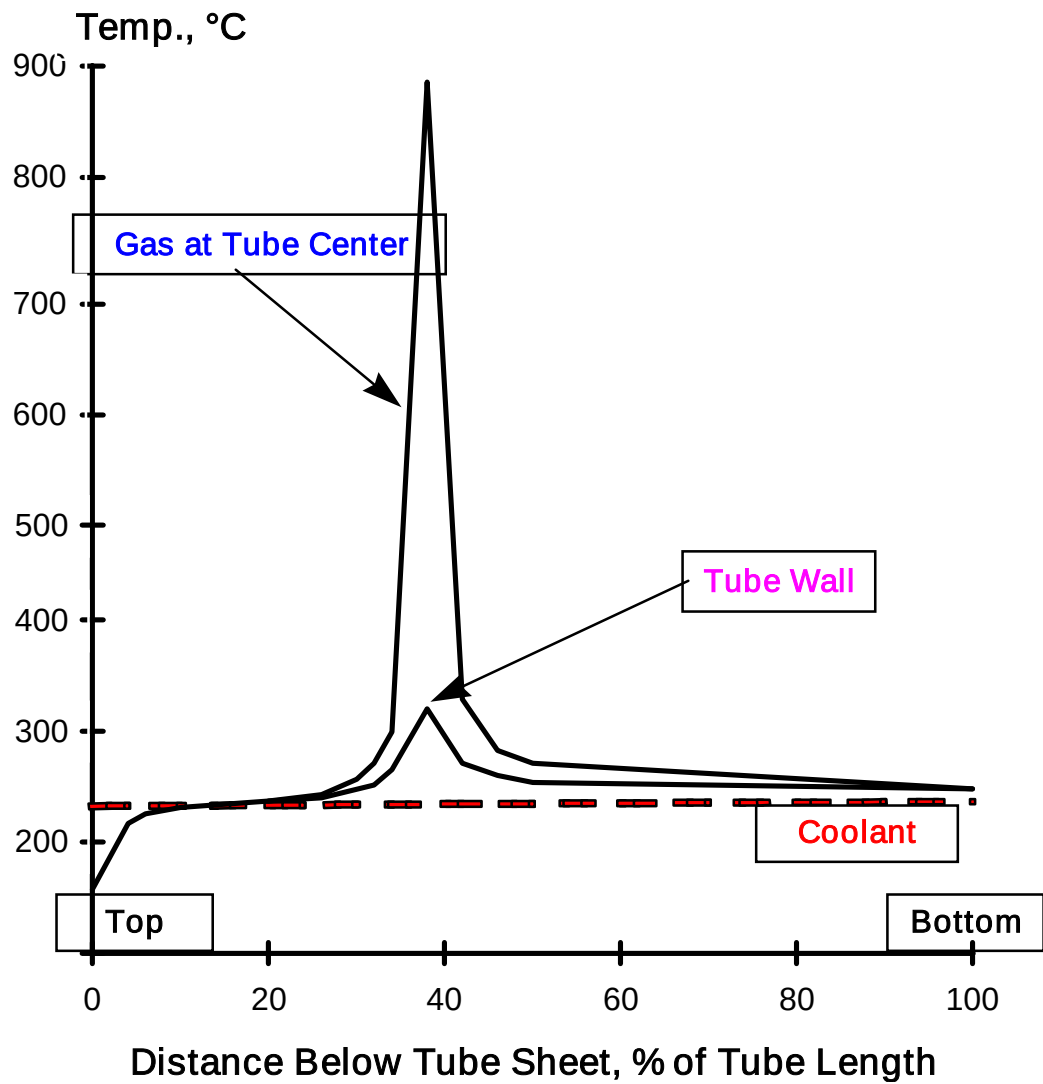


FIGURE 2. TYPICAL TEMPERATURE PROFILE DURING RUNAWAY



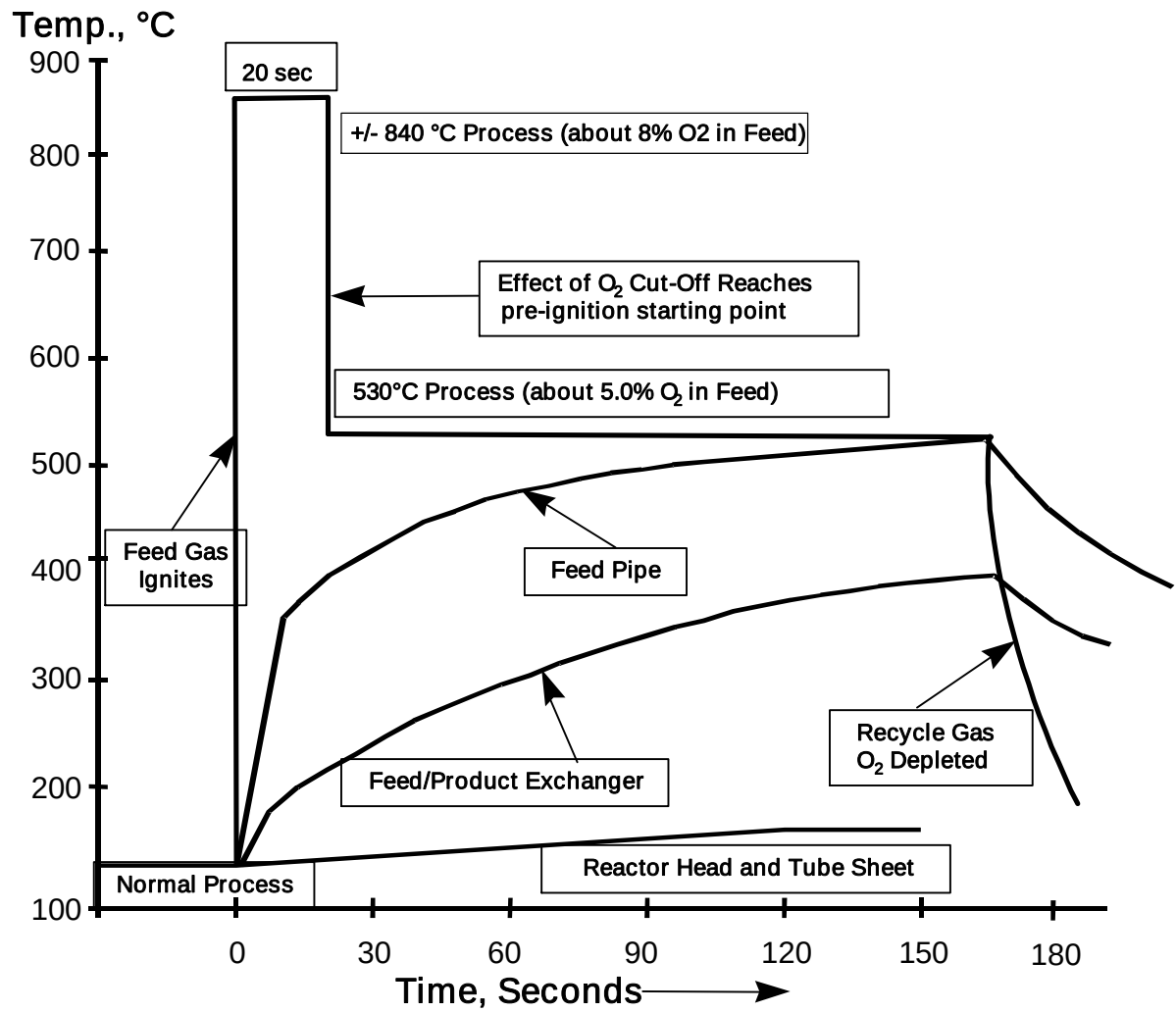


FIGURE 3. TYPICAL TEMPERATURE CYCLE FOR PRE-IGNITION IN BOTH REACTOR SECTIONS



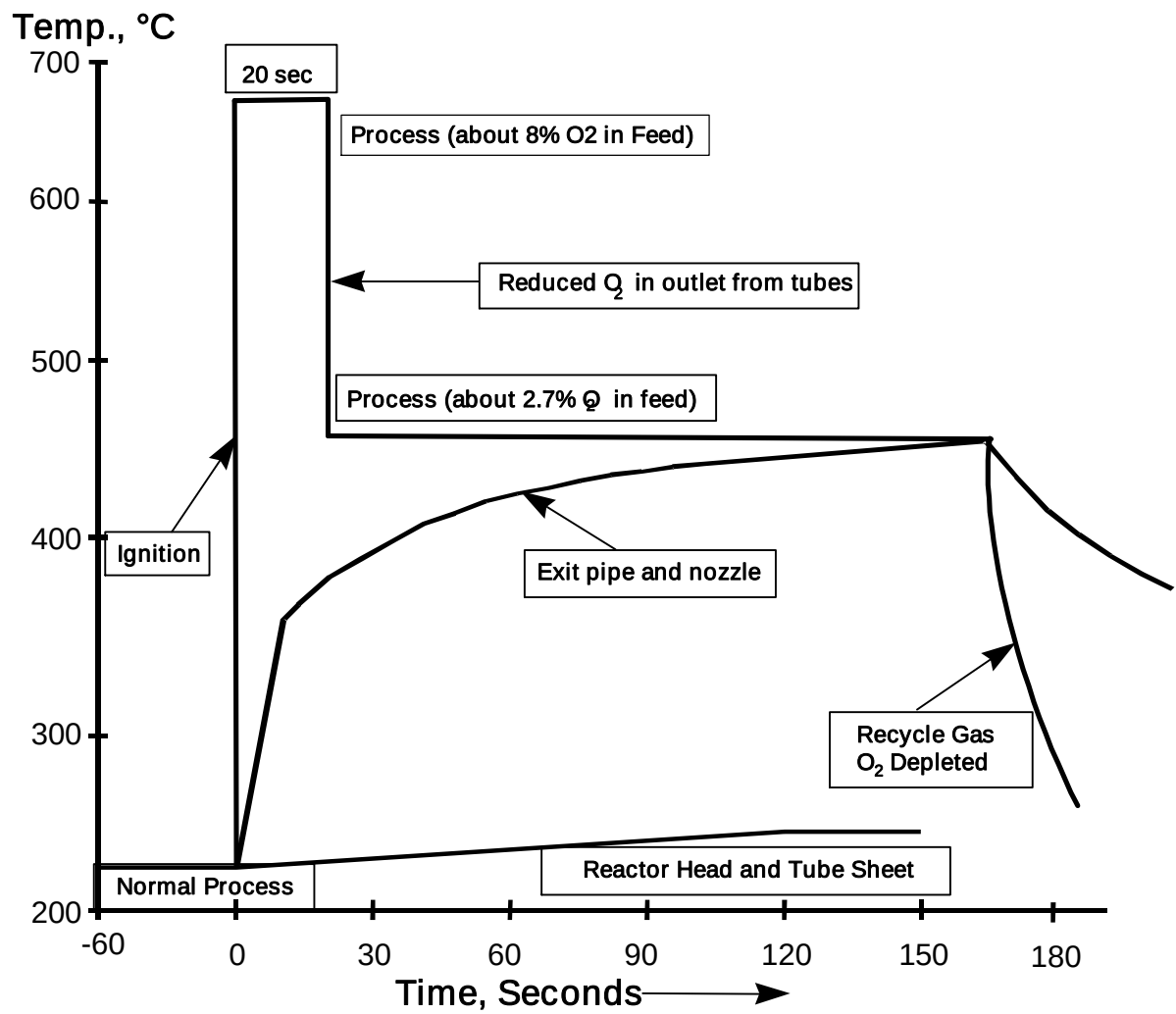


FIGURE 4. TYPICAL TEMPERATURE CYCLE FOR POST-IGNITION IN BOTH REACTOR SECTIONS

