

FUNDAMENTALS MANUAL

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FUNDAMENTALS OF SULFUR RECOVERY

BY THE CLAUS PROCESS

*1998 Fundamentals
Session*

By

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FUNDAMENTALS OF SULFUR RECOVERY
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INTRODUCTION

There is increased awareness and concern about the potential threat of air pollution to the well being of mankind in today's society. With the continuing increase in energy consumption in the world, there is an ever increasing need to combat pollution from SO_2 . The Claus process was discovered over 100 years ago and has been used by industry to recover elemental sulfur from H_2S bearing acid gas streams for over 50 years. Until recent years, Claus plants were considered the workhorse and adequate for reducing SO_2 emissions to the atmosphere. Today, most Claus plants are considered to be potential major offenders of air pollution regulations. Several Tail Gas Clean-Up (TGCU) processes have been developed to clean-up the tail gas from Claus plants.

This paper has been prepared to provide an understanding of the basic reactions, processing steps, and equipment in a Claus plant.

DISCUSSION

The Claus Sulfur Recovery Unit (SRU) may be considered in two general sections: (1) the thermal section in which H_2S is converted to elemental sulfur at high temperature ($> 1800^\circ\text{F}$) without the aid of catalyst; and (2) the catalytic section in which sulfur is formed at much lower temperatures ($400\text{-}650^\circ\text{F}$) through the use of Claus alumina catalyst. The Claus reaction is an equilibrium reaction; the extent of reaction completion depends on the concentration of the reactants and products and operating conditions. Because the Claus reaction is limited by equilibrium, a series of conversion steps/stages is utilized to increase the overall conversion of H_2S to sulfur. A sulfur condenser is provided to condense and separate

the sulfur formed in each conversion stage. Removing sulfur, which is one of the products of reaction, from the process flow allows additional reaction to proceed in the next conversion stage. The conversion stages are a series of repetitive steps: heating, reaction, and cooling/condensing.

A simplified flow diagram of a typical SRU is shown in Figure 1. The Figure 1 flow diagram shows a once-through (straight-through) SRU with a thermal stage and three catalytic conversion stages using steam reheaters.

THERMAL SECTION

The thermal section of the SRU includes all equipment from the SRU inlet battery limit through the No. 1 Sulfur Condenser. The H_2S bearing acid gas feed stream passes through an inlet knockout drum (not shown) and flows to the Reaction Furnace Burner. Enough air is added to burn (oxidize) one-third ($1/3$) of the H_2S in the acid gas to SO_2 and burn all hydrocarbons and ammonia (NH_3), if present, to CO_2 , N_2 , and H_2O . The oxidation of H_2S is shown by reaction (1):



This reaction is highly exothermic (gives off heat) and is not limited by equilibrium.

In the Reaction Furnace, the unburned H_2S (remaining $2/3$ of H_2S) in the acid gas reacts with the SO_2 formed to yield elemental sulfur vapor. This reaction is referred to as the Claus reaction and is shown by reaction (2):



This reaction is endothermic (absorbs heat) and is limited by equilibrium.

Figure 2 shows the theoretical conversion of H_2S to elemental sulfur by the Claus reaction as a function of temperature. In the thermal region, conversion is higher at higher

temperatures. Usually, 60-70% of the total conversion of H_2S to elemental sulfur is achieved in the "thermal conversion" step.^{1,3}

The most important controllable operating variable in the SRU is the combustion air feed rate. If the conversion of H_2S to sulfur is to be maximized, the ratio of H_2S to SO_2 must be 2 to 1 to meet the stoichiometric requirements of the Claus reaction. The H_2S to SO_2 ratio is set by the amount of H_2S burned to SO_2 . If recovery is to be maximized, all Claus SRU's must have a reliable tail-gas analyzer (with feed-back trim air control) to monitor the H_2S/SO_2 ratio in the tail gas. The analyzer is necessary to permit fine adjustment of the combustion air flow to achieve the optimum ratio of 2/1 at all times even if the acid gas feed composition varies slightly.

For rich (80-90 mol% H_2S) acid gas feeds, the resulting flame temperature from combustion of H_2S is over 2000°F. Hydrocarbons and other impurities can increase the temperature significantly, possibly as high as 2400-2500°F. The endothermic thermal region Claus reaction and heat losses lower the temperature of the process gases leaving the reaction furnace.

There are many reactions, other than reactions (1) and (2) above, that are known to take place in the Reaction Furnace. Acid gases that contain significant amounts of impurities (non- H_2S components such as hydrocarbons, CO_2 , COS, NH_3 , etc.) result in many more side reactions. Some of the side reactions that are known to occur in the Reaction Furnace are shown in Figure 3. If the acid gas feed contains 80-90 mol% H_2S , very few of these side reactions proceed to any significant degree of completion.³ The reactions that have COS or CS_2 as a product typically result in a reduction in overall sulfur recovery.

The hot gases from the Reaction Furnace flow through the tubes of the Waste Heat Boiler (WHB); the gases are typically cooled to 550-600°F by generating steam on the shellside of the WHB. Low, medium, or high pressure steam may be generated in the WHB. The WHB may utilize one or two tube passes and may be a kettle type or a thermosiphon type with a steam drum. A two-pass WHB is required if hot gas bypass reheating is utilized. The first tube pass typically cools the process gases to about 1100°F. A portion of these gases are used for hot gas bypass reheating. The gases reverse and enter the second WHB tube pass where they are typically cooled from 1100°F to 550-600°F.

At reaction furnace temperatures, all sulfur vapor is in the form of S_2 . As the gases from the Reaction Furnace are cooled in the WHB, the S_2 sulfur vapor specie formed in the Reaction Furnace shifts to other sulfur species, primarily S_6 and S_8 . The shifting is actually a number of chemical reactions that may be represented as:



These reactions are all exothermic and must be considered in the design of heat exchange equipment. The cooler the temperature, less S_2 specie and more S_6 and S_8 species are present, down to about 800-900°F. Below this temperature, all S_2 specie is gone, S_6 specie begins to decrease, and S_8 specie continues to increase. Below about 400°F, the S_8 specie represents over 80% of the sulfur present in the vapor. Other sulfur vapor species (S_4 , S_6 , and S_7) are known to be present in minor amounts; but the major species are S_2 , S_6 and S_8 . Figure 4 shows the approximate equilibrium between the major sulfur vapor phase molecular species as a function of temperature.¹

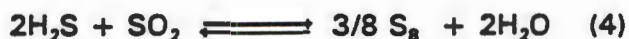
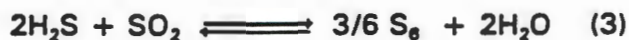
The cooled gases from the WHB are further cooled, sulfur specie shifting continues, and most of the sulfur formed in the reaction furnace is condensed in the No. 1 Sulfur Condenser^{1,3}. The condenser is a kettle type boiler that generates low pressure (40-70 psig) steam to cool the process gases. The condenser outlet temperature is typically 320-350°F. The condensed sulfur is separated from the process gas and drained from the condenser through a hydraulic seal and rundown line to the sulfur storage pit.

CATALYTIC SECTION

The unconverted sulfur in the process gas from the No. 1 Sulfur Condenser is processed further in the catalytic section of the SRU. In the catalytic section, additional sulfur is produced by the Claus reaction in the presence of Claus catalyst. The catalytic section consists of a series of three steps: reheating, conversion, and cooling/condensing. The overall conversion is improved each time a "catalytic conversion" step is performed. The sequence of steps may be repeated as many times as desired; however, three catalytic conversion steps

are normally considered optimum. With a rich acid gas feed, 96-97.5% overall conversion can be realistically achieved with one thermal stage and three catalytic conversion steps. If a TGCU process is to follow the Claus plant, only two catalytic stages are sometimes used.

The Claus reactions in the catalytic section of the SRU are slightly different than the thermal reaction. The catalytic section reactions are:



The thermal section Claus reaction in which S_2 is formed is an endothermic reaction; however, reactions (3) and (4), in which S_6 and S_8 are formed, are both exothermic. The thermal reaction equilibrium is favored by high temperature. The catalytic section Claus reaction equilibrium is favored by lower temperatures. This is shown in Figure 2.

The first step in the catalytic conversion stage is reheating. The process gas from the upstream sulfur condenser must be reheated before entering the Sulfur Converter. This is necessary to prevent sulfur condensation, and subsequent catalyst fouling of the converter catalyst beds. All three reheating steps in Figure 1 utilize Steam Reheaters (using high-pressure steam) to heat the condenser process gas outlet streams to the desired Catalytic Converter inlet temperatures (typically 400-450°F for steam heating). The reheat temperatures are kept to a practical minimum, with a safety margin above the sulfur dew point, because the Claus reaction equilibrium is favored by lower temperatures.

The heated process gas enters the Catalytic Converters and flows across fixed catalyst beds. Claus reactions (3) and (4) proceed to near equilibrium conditions if adequate active catalyst volume and good flow distribution is provided. Typical catalyst bed depths are 36-48". Normal Claus catalyst is activated alumina.

In the first Catalytic Converter, in addition to the Claus reactions, COS and CS_2 that can be formed in the Reaction Furnace are hydrolyzed to H_2S and CO_2 . Because sulfur is a component of these compounds, the hydrolysis of COS and CS_2 is very important from a recovery standpoint. Any sulfur in the form of COS and CS_2 leaving the first converter cannot

be recovered by the Claus process. Only the first converter operates at temperatures high enough to achieve significant hydrolysis of COS and CS₂. The No. 1 Catalytic Converter should be operated with the bottom bed temperature at 600-630°F to achieve high levels of COS and CS₂ hydrolysis. Specially promoted alumina Claus catalysts and TiO₂ catalysts are available that can improve the hydrolysis of COS and CS₂. To achieve bed outlet temperatures of 600°F and above, the inlet bed temperature normally must be greater than 500°F. When it is desirable to operate the first converter at a higher inlet temperature than 450-460°F, which is about the maximum practical temperature using steam, alternate reheat methods or supplemental trim reheaters can be utilized. Various reheating methods are discussed in the following section.

The process gas from the Catalytic Converters flows through the tubes of the Sulfur Condensers. In the condensers, the sulfur species are shifted and sulfur vapor is condensed. The Sulfur Condensers typically produce 45-70 psig steam on the shell side. The process gas outlet stream temperature from a Sulfur Condenser is normally between 320-350°F. The final condenser is often operated with the outlet temperature as low as 265-270°F to minimize sulfur vapor losses in the tail gas and improve the overall sulfur recovery. To achieve these low temperatures, the final condenser must generate 15-20 psig steam (preferred scheme) or be used as a boiler feedwater preheater.

MAJOR EQUIPMENT

Properly designed and installed equipment is necessary to achieve optimum performance of the sulfur recovery unit. The major equipment items are briefly discussed below.

Acid Gas Knockout Drum

The Acid Gas Knockout Drum is an inexpensive item of equipment that is often inadequately sized, poorly designed, and inadequately instrumented. The purpose of the knockout drum is to catch liquid slugs and to remove any entrained liquid from the acid gas feed stream. Entrained liquids are typically water, hydrocarbons, and amines. Liquids carried to the SRU burner can cause problems with: (1) feed metering, (2) plugging in the burner, (3)

refractory damage in the burner and Reaction Furnace, (4) undesirable side reactions in the Reaction Furnace, (5) increased air demand, and (6) reduction of SRU capacity.

Reaction Furnace Burner

The burner is probably the single most important equipment item in the SRU. The burner must provide the capability to burn 1/3 of the H_2S in the acid gas feed while completely burning of the impurities such as hydrocarbons and NH_3 in the acid gas feed at very substoichiometric air conditions (reducing conditions). It is also very important that all oxygen in the combustion air is consumed because oxygen will deactivate the downstream Claus alumina catalyst.

The Reaction Furnace Burner should be a very efficient mixing burner, have wide turndown capability, and be able to combust natural gas at substoichiometric firing conditions without forming soot during start-up and shut down operation.

Reaction Furnace

The Reaction Furnace and burner are the "heart and lungs" of the SRU. The Reaction Furnace provides the necessary residence time for the Claus reaction to proceed to near equilibrium conditions. The furnace is a horizontal, refractory lined vessel. The furnace is often equipped with a choke ring and/or a checker wall to improve mixing in the furnace. The checker wall also reflects the radiant heat to the front of the furnace and partially shields the WHB tubesheet from radiant heat. The burner, Reaction Furnace, and WHB are typically combined into a single assembly.

Waste Heat Boiler

The Waste Heat Boiler front tubesheet normally forms the outlet wall of the Reaction Furnace. The front tubesheet is refractory covered, and the tubes have ceramic ferrule tube inserts to protect the tubesheet and front section of the tubes from the high temperature process gases. The WHB is a fire-tube boiler that may be a kettle type or thermosiphon type with steam drum type, and may have one or two tube passes. The WHB typically generates 50-600 psig steam. Typical burner, Reaction Furnace, and WHB assemblies for both two-pass kettle type and one-pass thermosiphon with steam drum type WHB's are shown in Figures 5 and 6.

Sulfur Condensers

The Sulfur Condensers are horizontal, fixed tubesheet, kettle type shell and tube exchangers. The condenser shell may be a true kettle type shown in Figure 7 or a straight shell with a partially tubed tubesheet shown in Figure 8. Frequently, multiple condenser passes are combined in a common shell for SRU's below 50-60 LTPD capacity. The condensers should be designed to be free draining with the inlet channel filled with refractory up to the bottom of the tubes and sloped 1/8"/ft to the outlet end. The outlet channels from each condenser or condenser pass should be designed to allow adequate separation of the liquid sulfur from the outlet process gas flow. Outlet channel demister pads will help remove entrained liquid sulfur from the process gas flow. The liquid sulfur drain should be steam jacketed and safely rodable to break-up any plugging that can occur. Two alternate sulfur outlet channel drains are shown in Figures 9 and 10. The condenser outlet channels including the channel cover plate should be heavily insulated to prevent excessive heat losses, freezing of sulfur, and internal corrosion.

Sulfur Seals and Rundown Lines

Liquid sulfur from each condenser flows through a steam jacketed hydraulic sulfur seal. The seal isolates the process from the sulfur storage pit. A steam jacketed plug valve should be provided between the condenser drain and sulfur seal. The sulfur seal depth should be adequate to prevent blowing the seal by either the acid gas feed or combustion air blower overpressuring the SRU. A typical sulfur seal and look box for observing the sulfur production from each condenser is shown in Figure 11. The sulfur rundown lines from the sulfur seals may be collected into a common line or may each enter the sulfur pit independently.

Coalescer

A Coalescer vessel should be provided downstream of the final Sulfur Condenser. Even if the condenser outlet channel is properly designed and equipped with a demister pad, a Coalescer will aid in removal of sulfur mist before the SRU tail gas is sent to the incinerator or TGPU. The Coalescer is normally a vertical vessel with a stainless steel demister pad. The Coalescer should be heated and heavily insulated. The Coalescer liquid sulfur drain should be steam jacketed and be very similar to the condenser sulfur drain. The Coalescer liquid sulfur rundown line should have a steam jacketed plug valve between the sulfur drain and an independent sulfur seal.

In general, the direct reheat methods result in lower overall conversion than the indirect methods. Hot gas bypass reheats are inexpensive but are seldom used today because of lower conversions, control problems, and poor turndown. The in-line burners have the advantage of being able to achieve higher reheat temperatures than most of the indirect methods. The primary in-line burner disadvantage is having to closely control additional items of fired equipment with the associated burner shutdown and operating controls, and there is the potential of oxygen breakthrough and soot formation, particularly during start-up and shut down, both of which can deactivate and/or plug the catalyst beds. (Hot gas bypass and acid gas fired in-line burners bypass a portion of the acid gas around conversion steps resulting in lower overall conversion.)

The indirect methods of reheating are normally simpler to control and result in higher conversion because no acid gas bypasses any conversion steps. Steam reheaters are very reliable and the easiest to operate and control and are generally the preferred reheat method. Electric reheaters have worked very well in small SRU's and for trim heating downstream of steam reheaters. Indirect fuel gas fired reheaters, hot oil reheaters, and salt bath reheaters typically are expensive to install, have low thermal efficiency, and require operation of additional fired equipment. Gas-gas reheat exchangers are costly to install, have higher overall unit pressure drop, and do not turndown well.

AMMONIA (NH₃) DESTRUCTION

Refinery SRU's are often required to process sour water stripper (SWS) acid gas. SWS acid gas contains NH₃, which is a particularly difficult SRU impurity to handle. Ammonia reduces the sulfur processing capacity of the SRU and can react with H₂S, SO₂, CO₂, and other compounds that are found in the SRU to form solid ammonium salts under the right (really wrong) operating conditions. SWS acid gas typically contains about 1/3 H₂S, 1/3 NH₃, and 1/3 H₂O (volume basis) and is normally 180-200°F.

Two primary processing methods have been used to destruct NH₃ in SRU's: (1) the amine acid gas front/side split (split flow) system and the (2) Comprimo ammonia destruction system. The front/side split system has traditionally been used in North America, but it potentially has many problems, particularly if the NH₃ is more than a few percent of the total

acid gas stream flow. In this process, a portion of the amine acid gas is bypassed to a side port of the reaction furnace downstream of the burner. If the bypassed amine acid gas contains NH_3 and/or hydrocarbons, downstream catalyst and equipment plugging and fouling can occur. The Comprimo system utilizes a special high intensity burner that allows all of the amine acid gas and SWS gas to be processed through the burner. The Comprimo process eliminates the problems associated with the bypass stream and simplifies the overall control system. The Comprimo system has been demonstrated to successfully destroy ammonia at concentrations over 20% of the total acid gas feed. In either of these processes, the amine acid gas should be heated to prevent formation of ammonium salts that can form if NH_3 and H_2S are both present and the temperature is below about 175°F.

LEAN ACID GAS STREAMS

Acid gas feed streams containing less than about 40-45 mol% H_2S are considered "lean H_2S " streams and usually require the use of alternative flow schemes because a stable flame cannot be sustained while burning only 1/3 of the H_2S in the feed. The more CO_2 and hydrocarbons present in the stream, the greater the amounts of COS and CS_2 formed in the furnace. Also, the side reactions shown in Figure 3 proceed to a higher degree of completion. Excessive quantities of feed gas impurities can cause severe operating and sulfur recovery problems in a Claus plant.⁶

Split-Flow Thermal Stage Operation

One option for processing lean acid gas feeds is to use a split-flow scheme, as shown in Figure 24. A portion (60% max.) of the acid gas bypasses the burner. The burner then burns a much higher portion of the burner acid gas feed which results in a hotter, more stable flame. The bypassed stream normally joins the main process stream just upstream or downstream of the No. 1 Sulfur Condenser. This flow scheme results in lower conversion and can cause problems with downstream equipment plugging and catalyst fouling from the impurities in the bypassed stream that are not burned.

Selectox Process

The Selectox and Recycle Selectox Processes are used to recover elemental sulfur from lean acid gas streams (containing low concentrations of H_2S). A typical Selectox lean acid gas feed might contain 8-25 mol% H_2S , but concentrations as high as 40-60 mol% H_2S can be processed. The process uses special Selectox catalyst in the first stage to selectively oxidize H_2S to SO_2 (catalytic oxidation without the presence of a flame) and promote the Claus reaction. The Selectox catalyst bed replaces the burner and Reaction Furnace in a conventional Claus SRU. The Selectox stage is usually followed by one or more Claus stages. Overall sulfur recoveries of 95-97% are possible with one Selectox stage and two Claus stages. A simple Selectox SRU flow diagram is shown in Figure 25.

Oxygen Enrichment

Lean acid gases can also be processed using a straight-through SRU processing scheme using pure oxygen or highly enriched air to replace a portion or all of the combustion air. By eliminating some or all of the nitrogen contained in the combustion air, the inert content of the combustion products is decreased which increases the flame temperature and stability. For lean acid gas stream with less than about 20 mol% H_2S , supplemental fuel firing will also be required even with 100% oxygen.

The required level of oxygen enrichment will depend on the acid gas composition. For acid gases that are 30-40 mol% H_2S , it may be possible to utilize low level oxygen enrichment in which pure oxygen is introduced into the combustion air stream. The maximum oxygen concentration using this low level enrichment scheme is 28% oxygen and 72% nitrogen on a dry basis. The maximum oxygen concentration is limited by piping and instrument component metallurgy and cleanliness of the combustion air system. Higher oxygen enrichment levels require the use of special oxygen piping and component cleaning and metallurgy and special burner technology.

Conventional high level oxygen enrichment applications require special flame temperature control systems to avoid overheating and damaging the Reaction Furnace and Burner refractory. These flame temperature limiting methods, such as a recycle

blower in the COPE® Process or multistage combustion in other processes, are not required for lean acid gas streams. The lean acid gas flame temperatures, even at 100% oxygen, are not high enough to damage high quality (90% alumina) refractory.

Oxygen enrichment also has other benefits. As the amount of nitrogen inert is removed, the hydraulic load on the SRU is reduced. When the hydraulic load is decreased, the SRU can process more acid gas feed. Capacity increases of 50-100% are achievable with richer acid gas feeds. SRU operators have used oxygen enrichment to avoid building additional capacity, to avoid using valuable plant plot space, and to provide SRU capacity redundancy. A slight increase in overall sulfur recovery (0.5-0.7%) is also realized at higher levels of oxygen enrichment.

TAIL GAS CLEAN-UP

Most SRU's built today require some form of tail gas clean-up unit following the SRU. The primary TGPU process that has been implemented is the amine-type unit. All sulfur compounds in the SRU tail gas are converted to H_2S . The H_2S is then recovered from the stream and recycled to the SRU by an amine unit using a selective solvent. This type unit is normally referred to as a SCOT (Shell Claus Offgas Treating) type unit. SCOT type TGPU's typically achieve 99.8+ % overall sulfur recovery.

SUPERCLAUS Process

SCOT type overall sulfur recoveries are not always required. The SUPERCLAUS Process was developed by Stork Comprimo to improve the overall SRU recovery in a simple process at a much lower cost than a SCOT unit. Claus SRU's processing rich acid gas feeds and utilizing the SUPERCLAUS Process can achieve overall sulfur recoveries of 98-99%. The process uses special SUPERCLAUS catalyst in the last conversion stage to selectively oxidize H_2S contained in the process gas directly to elemental sulfur. Unlike the conventional Claus reaction, the oxidation reaction is not equilibrium limited. The SUPERCLAUS Process is applicable to U.S. SRU's up to 20-

30 LTPD, most Canadian SRU's, and can be used to unload an existing downstream TGCU. A simplified flow diagram of a SUPERCLAUS unit is shown in Figure 27.

MAJOR DESIGN CONSIDERATIONS

Many design considerations for Claus plants are discussed in the literature.^{1,3,4,7,8}
The major design criteria to be considered are:

1. Composition of acid gas feed (design and expected variations in H_2S and impurity content)
2. Acid gas feed temperature and pressure
3. Knockout drum vapor-liquid separation efficiency
4. Reaction Furnace residence time
5. Catalytic Converter bed temperatures
6. Catalytic Converter bed space velocity
7. Optimum reheat schemes(s)
8. Sulfur Condenser outlet temperatures
9. Sulfur Condenser mass velocity
10. Sulfur Condenser outlet channel/Coalescer design for maximum separation of entrained sulfur from condenser effluent gases
11. SRU turndown requirements

MAJOR OPERATING AND CONTROL VARIABLES

The major operating and control variables for a Claus plant are:^{2,5,7}

1. Control of the H_2S/SO_2 ratio at the optimum value of 2/1 (control of combustion air feed). A high quality, well maintained tail gas analyzer with feed back control to a trim air loop is required for optimum control.

2. Catalytic Converter feed gas temperatures (reheater outlet). The inlet temperature must be kept high enough to prevent sulfur condensation in the catalyst bed. Catalyst maintenance is discussed in the literature.⁹
3. Final Sulfur Condenser outlet temperature.
4. Proper control instrument maintenance and reliability checks.
5. Proper operation of upstream amine and SWS processing units to eliminate hydrocarbons and other impurities in the acid gas feed.⁶
6. Proper operation during turndown, start-up, and shut down

CONCLUSION

The Claus process has been used extensively in industry and is recognized as a very reliable and very "forgiving" process. In the past, industry was able to operate Claus plants with relatively little attention with resulting large fluctuations in SRU sulfur recovery and tail gas composition. The Incinerator handled large swings in tail gas flows and composition. However, with the advent of TGCUs that are not quite so "forgiving" as the parent Claus plant and tightened emission controls, much closer process control and greater operator attention is required.

Tight control of upstream processing units to provide steady acid gas feed flow and composition is as important as good SRU and TGCU control. The SRU must have good quality equipment and control instrumentation if the unit is to operate efficiently and reliably over the life of the plant. Optimum performance from a Claus SRU depends on the designer, the equipment fabricator, construction contractor, and operator.

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LEGEND FOR FIGURES

SYMBOL	DESCRIPTION
B	Combustion Air Blower
RF	Reaction Furnace with Burner
WHB	Waste Heat Boiler
C ₁ , C ₂ , C ₃ , C ₄	Sulfur Condenser
R ₁ , R ₂ , R ₃	Catalytic Converters
RH ₁ , RH ₂ , RH ₃	Steam Reheaters
RB ₁ , RB ₂	Reheat Burners (In-line Type)
G-G Exch.	Gas-Gas Exchanger (Reheater)
ERH ₁ , ERH ₂	Electric Reheaters
C _L	Coalescer
STK	Incinerator/Stack
FG	Fuel Gas
AG	Acid Gas
HPS	High Pressure Steam
LPS	Low Pressure Steam
HTM	Heat Transfer Medium (Hot Oil or Glycol/Water)
BFW	Boiler Feed Water
S _L	Sulfur Liquid

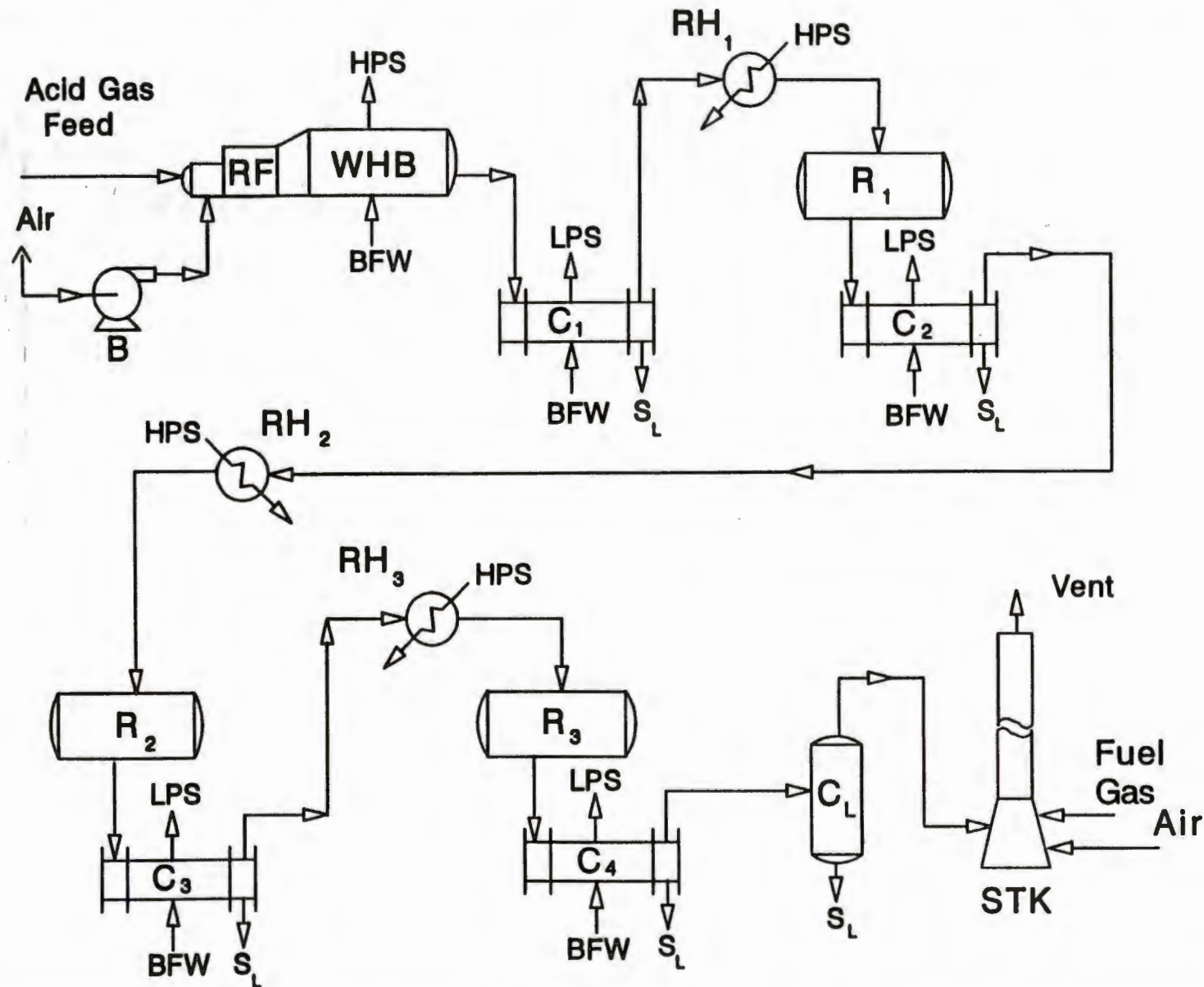


FIGURE 1

TYPICAL ONCE-THROUGH CLAU S SULFUR RECOVERY UNIT
(Three Converters, Four Condensers & Steam Reheaters)

Figure 2
Theoretical Conversion of H_2S to Sulfur
by the Claus Reaction¹

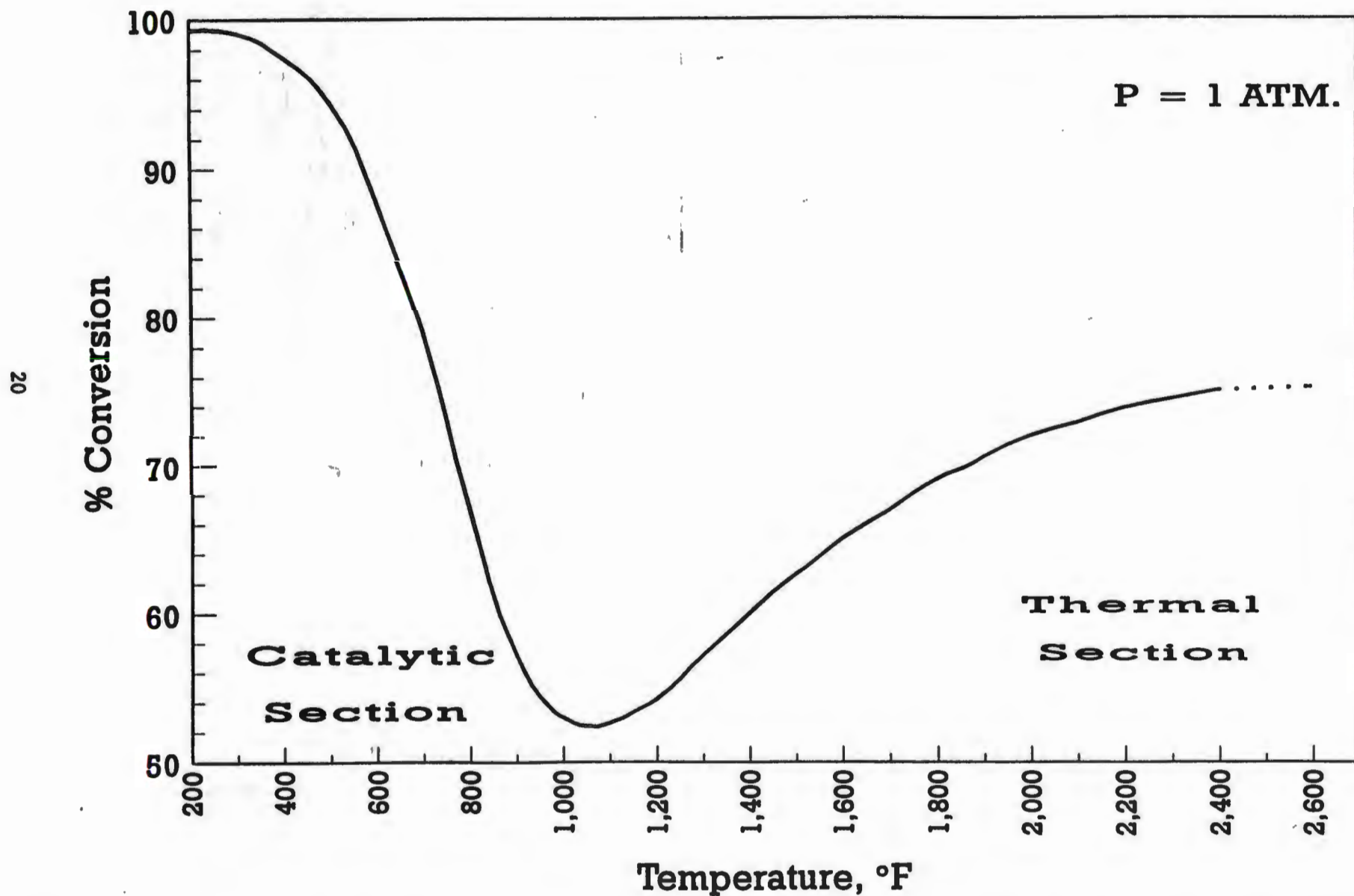


FIGURE 3

CLAUS PROCESS

POSSIBLE REACTION FURNACE SIDE REACTIONS

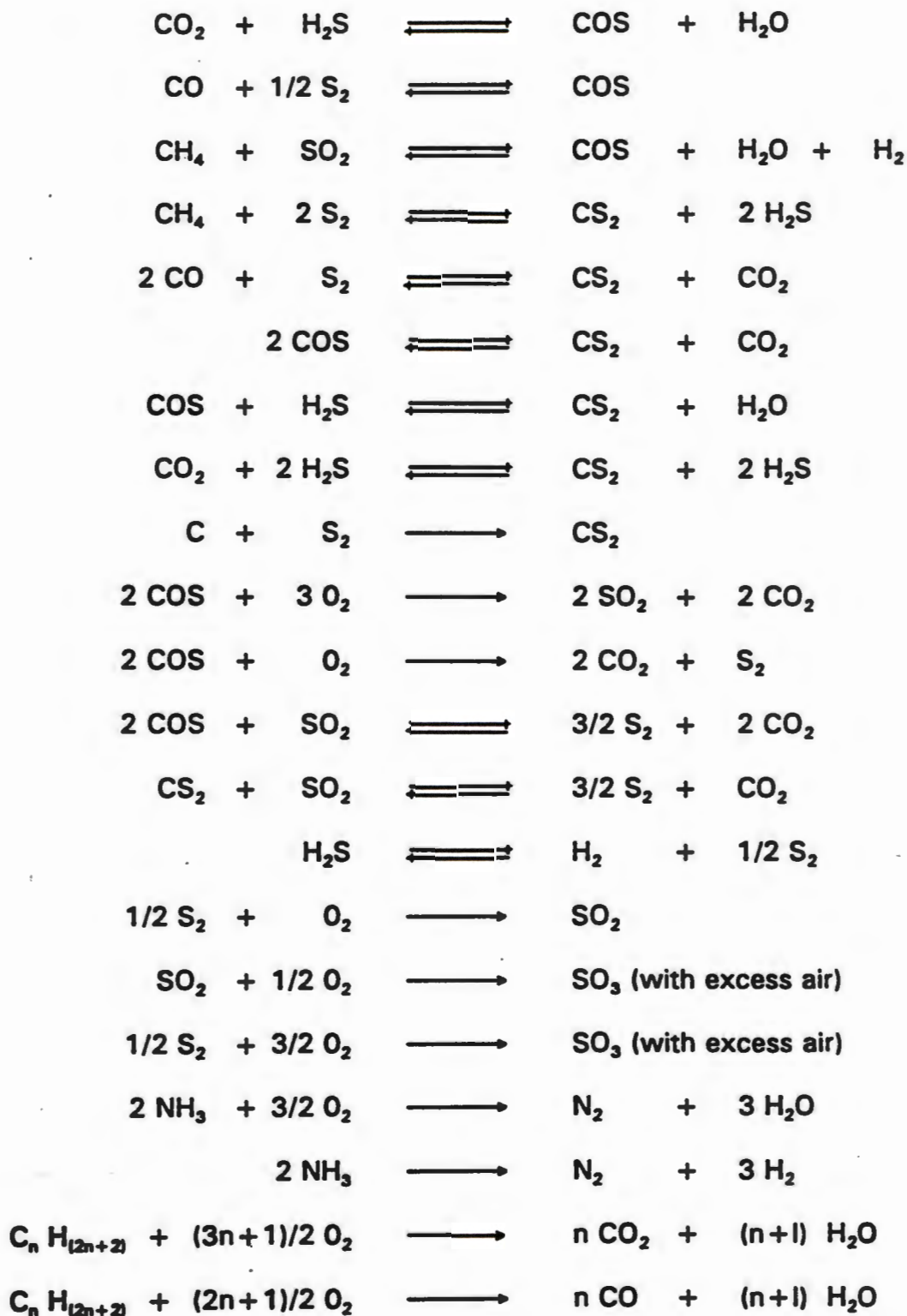
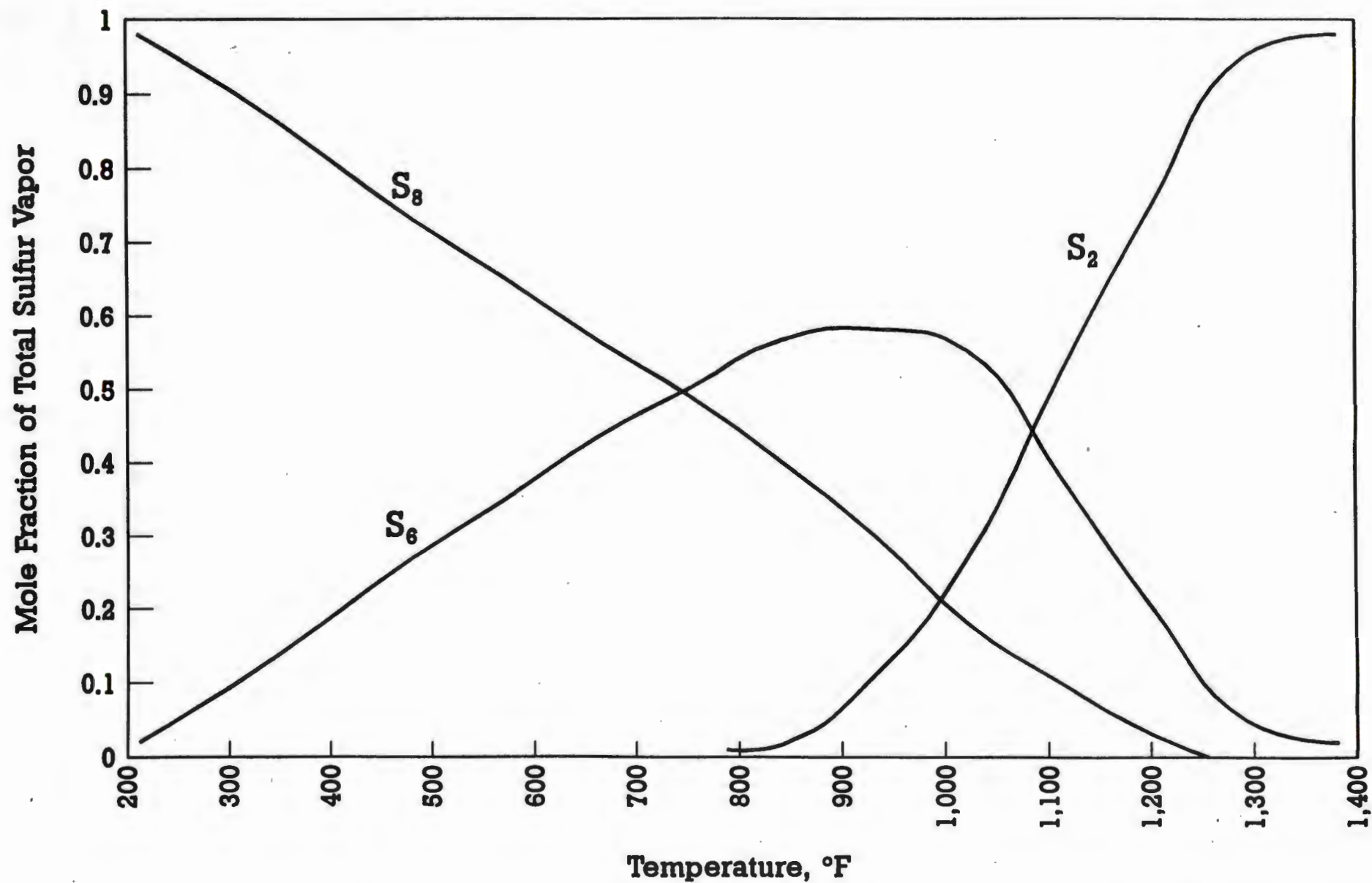


Figure 4
Equilibrium Between Major Vapor Phase
Molecular Sulfur Species¹



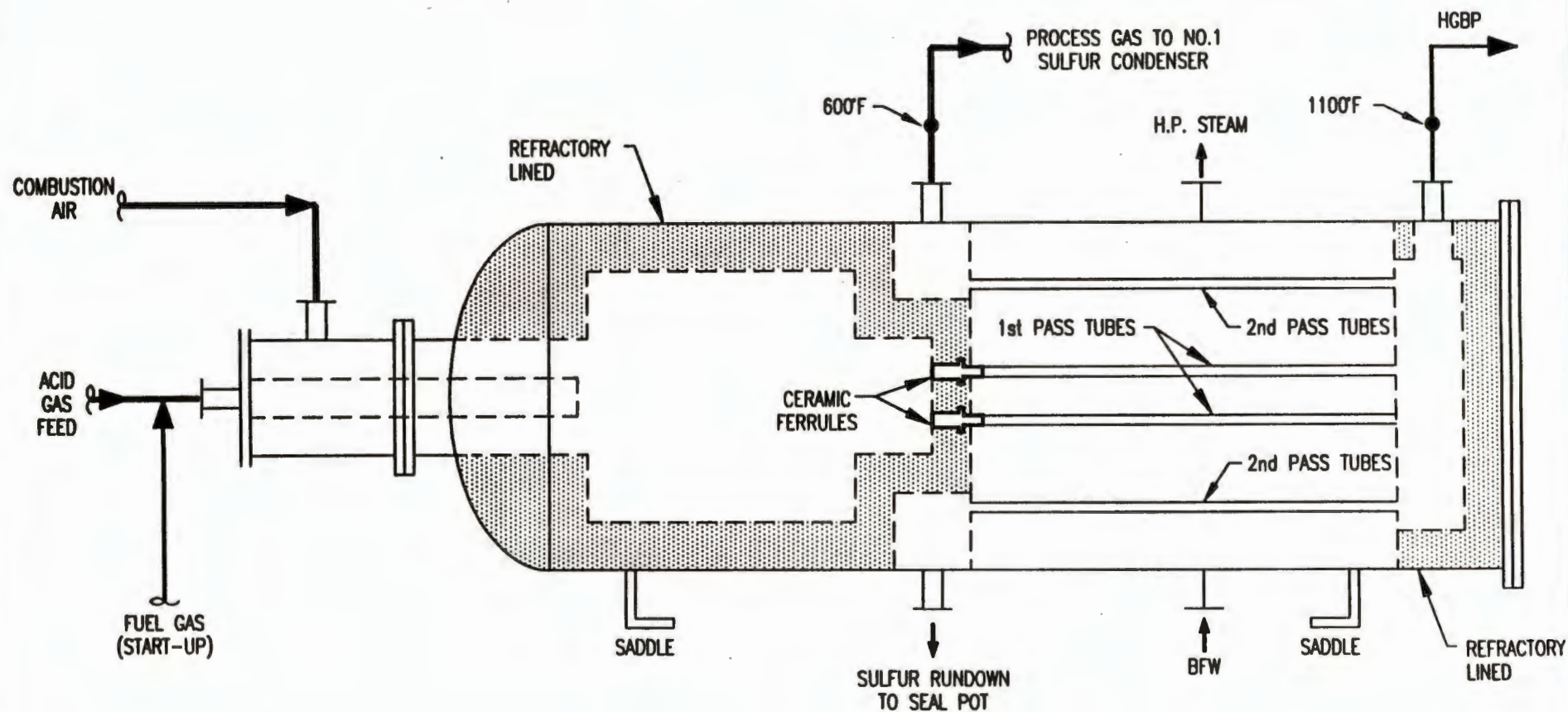


FIGURE 5

TYPICAL BURNER, REACTION FURNACE AND TWO PASS WASTE HEAT BOILER
FOR A CLAUSS PROCESS SULFUR RECOVERY UNIT

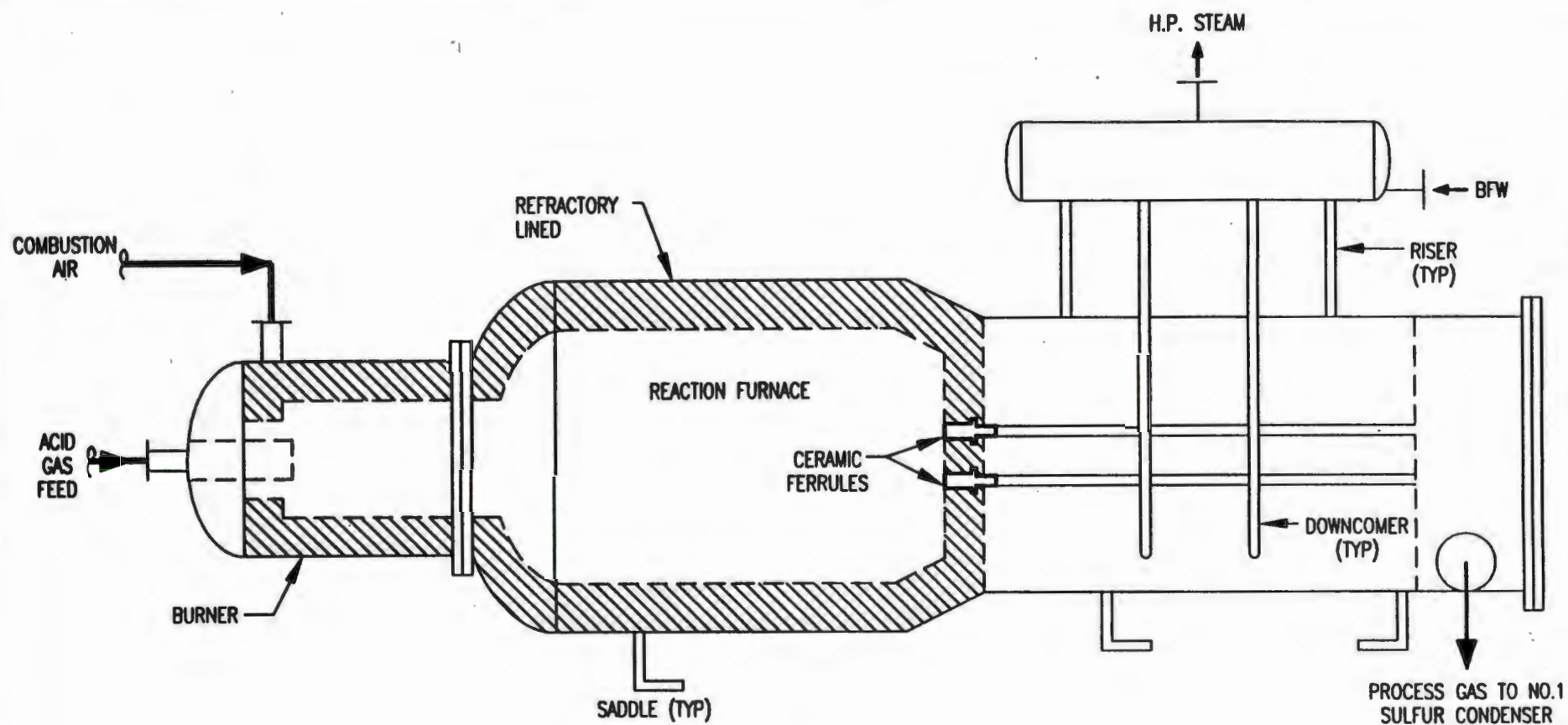


FIGURE 6

TYPICAL BURNER, REACTION FURNACE, AND ONE PASS WASTE HEAT BOILER w/STEAM DRUM
FOR A CLAUSS PROCESS SULFUR RECOVERY UNIT

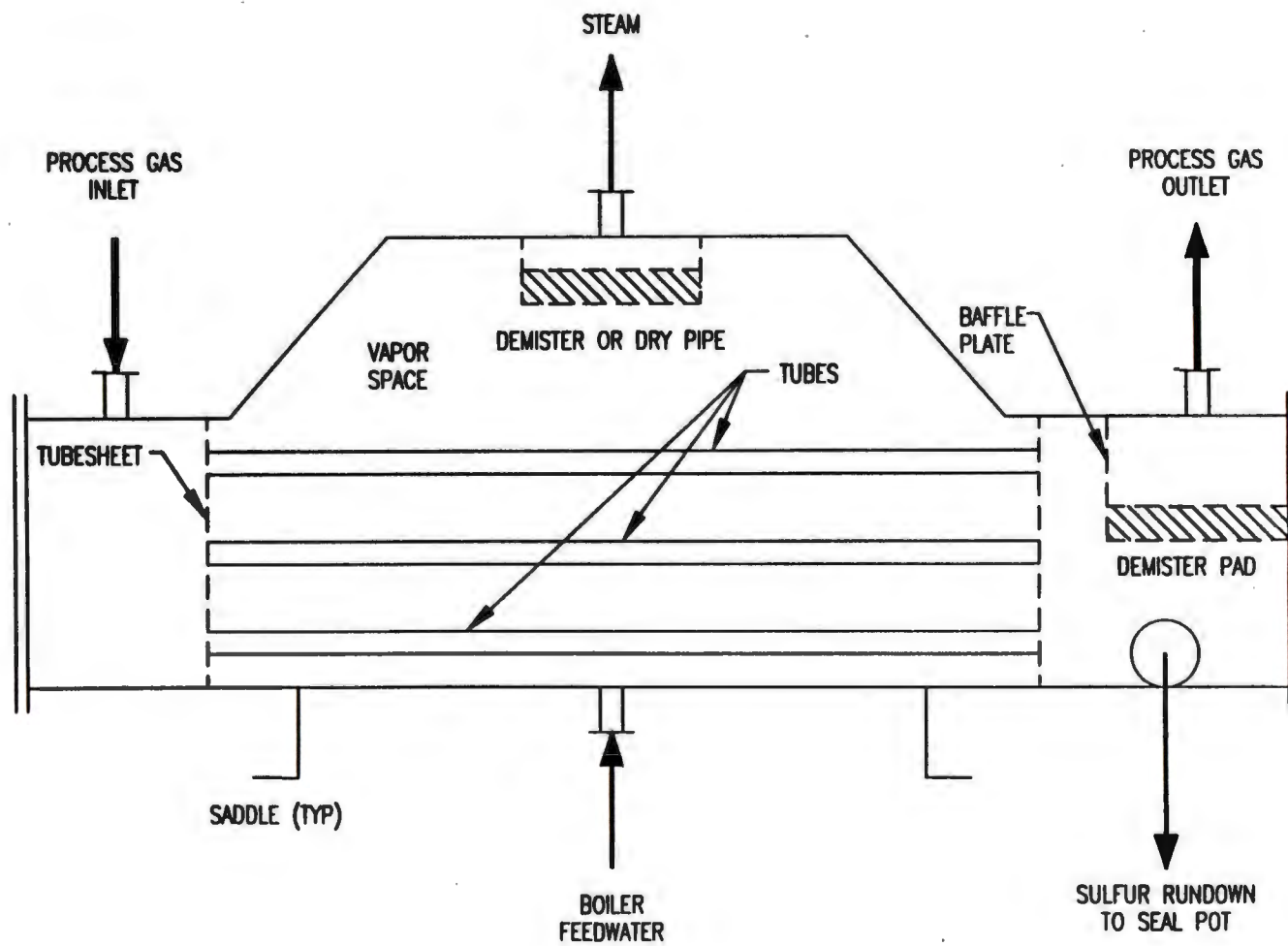


FIGURE 7
TYPICAL KETTLE TYPE CLAU PROCESS SULFUR CONDENSER

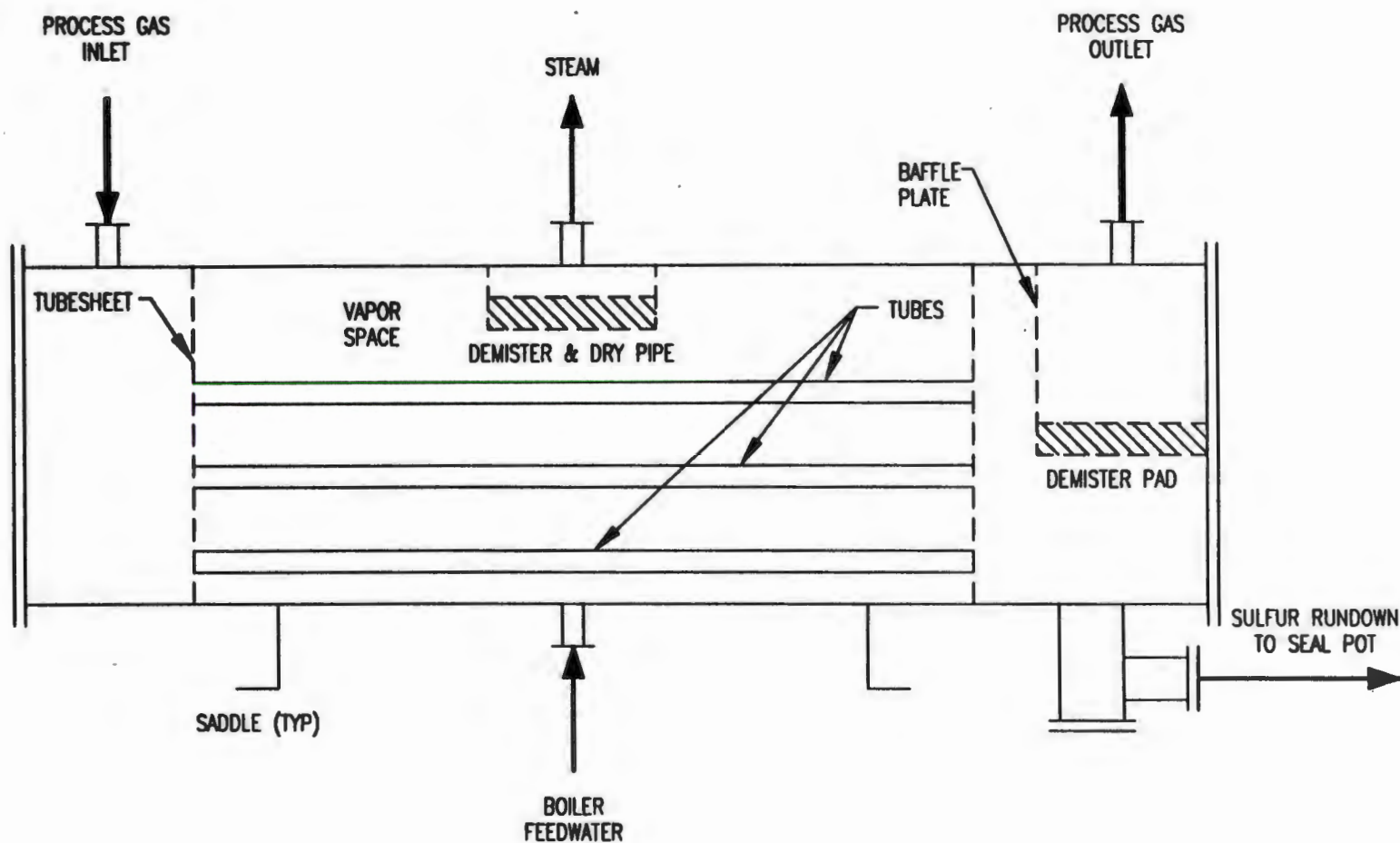


FIGURE 8
TYPICAL STRAIGHT SHELL CLAU PROCESS SULFUR CONDENSER

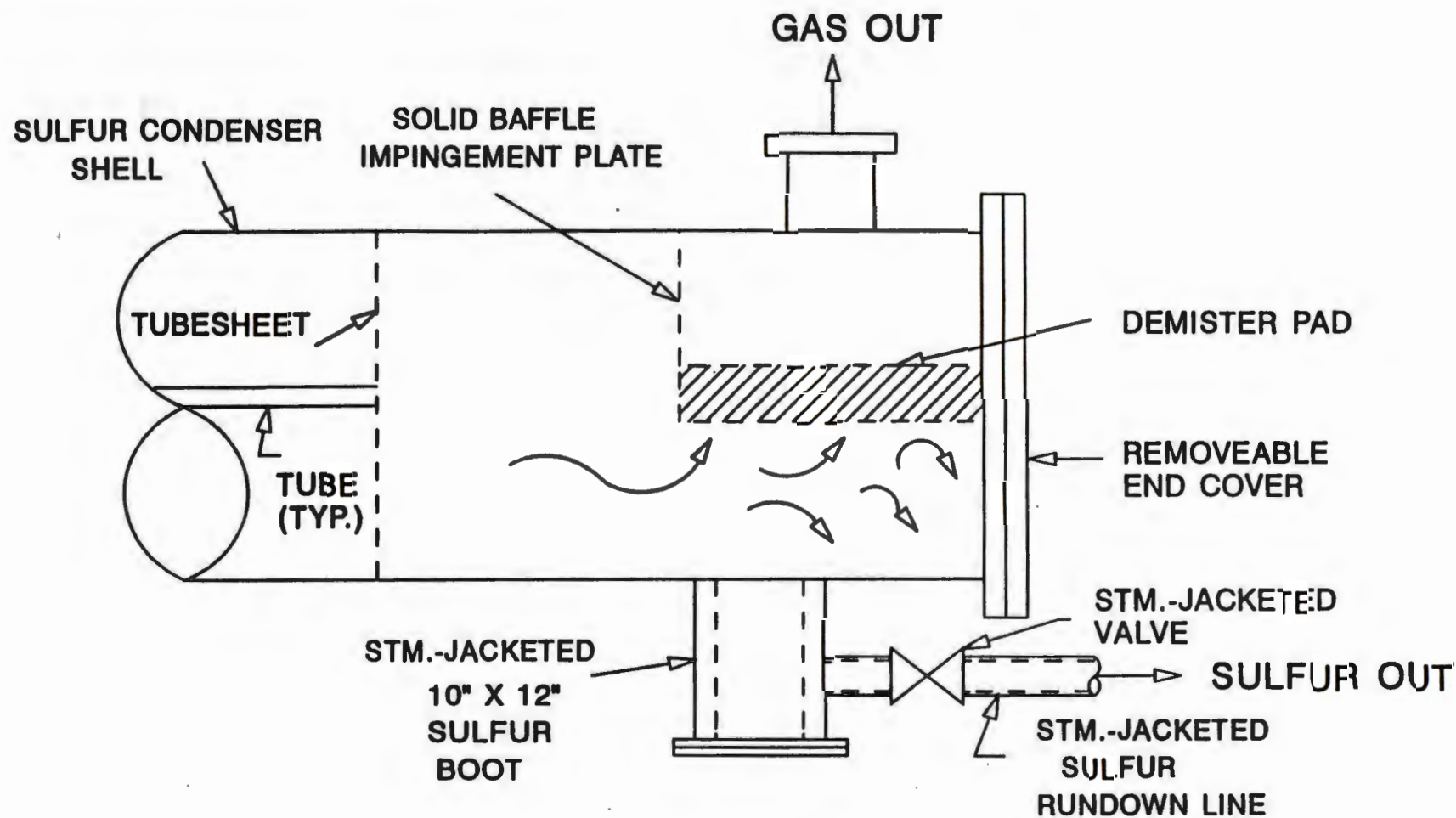


FIGURE 9

PREFERRED SULFUR CONDENSER OUTLET CHANNEL DESIGN

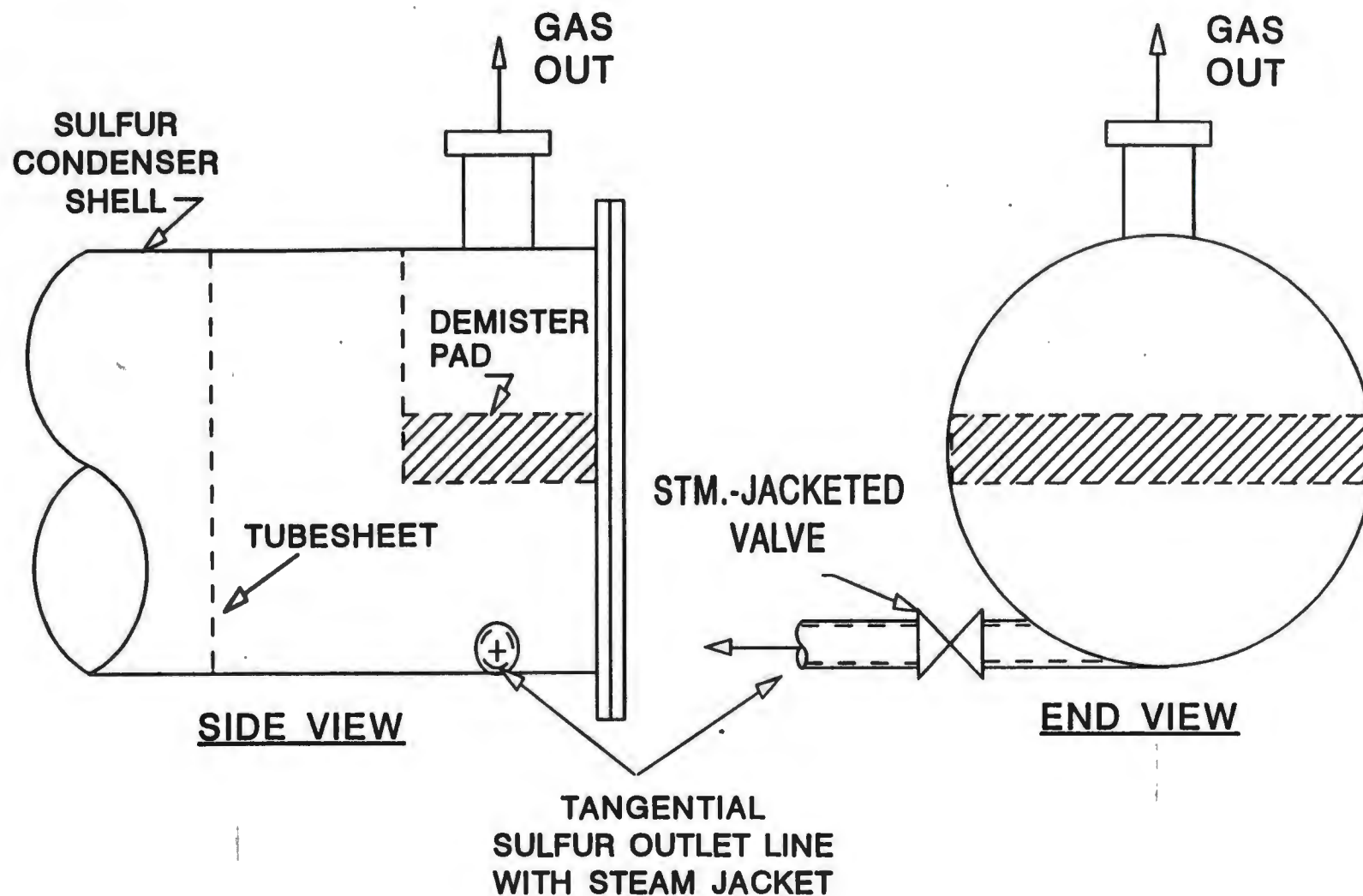


FIGURE 10

**ALTERNATE SULFUR CONDENSER
OUTLET CHANNEL DESIGN**

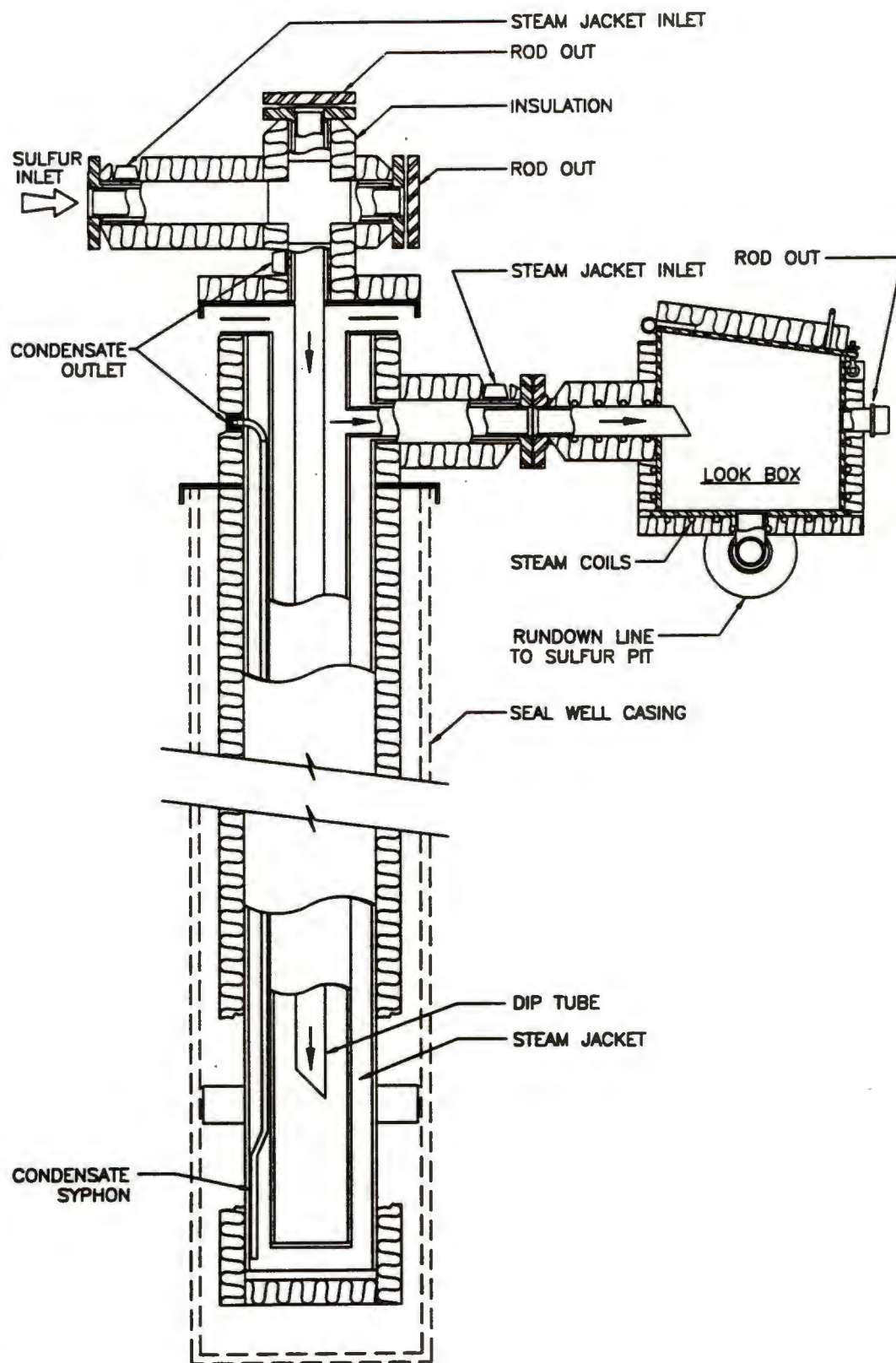


FIGURE 11
TYPICAL SULFUR SEAL AND LOOK BOX

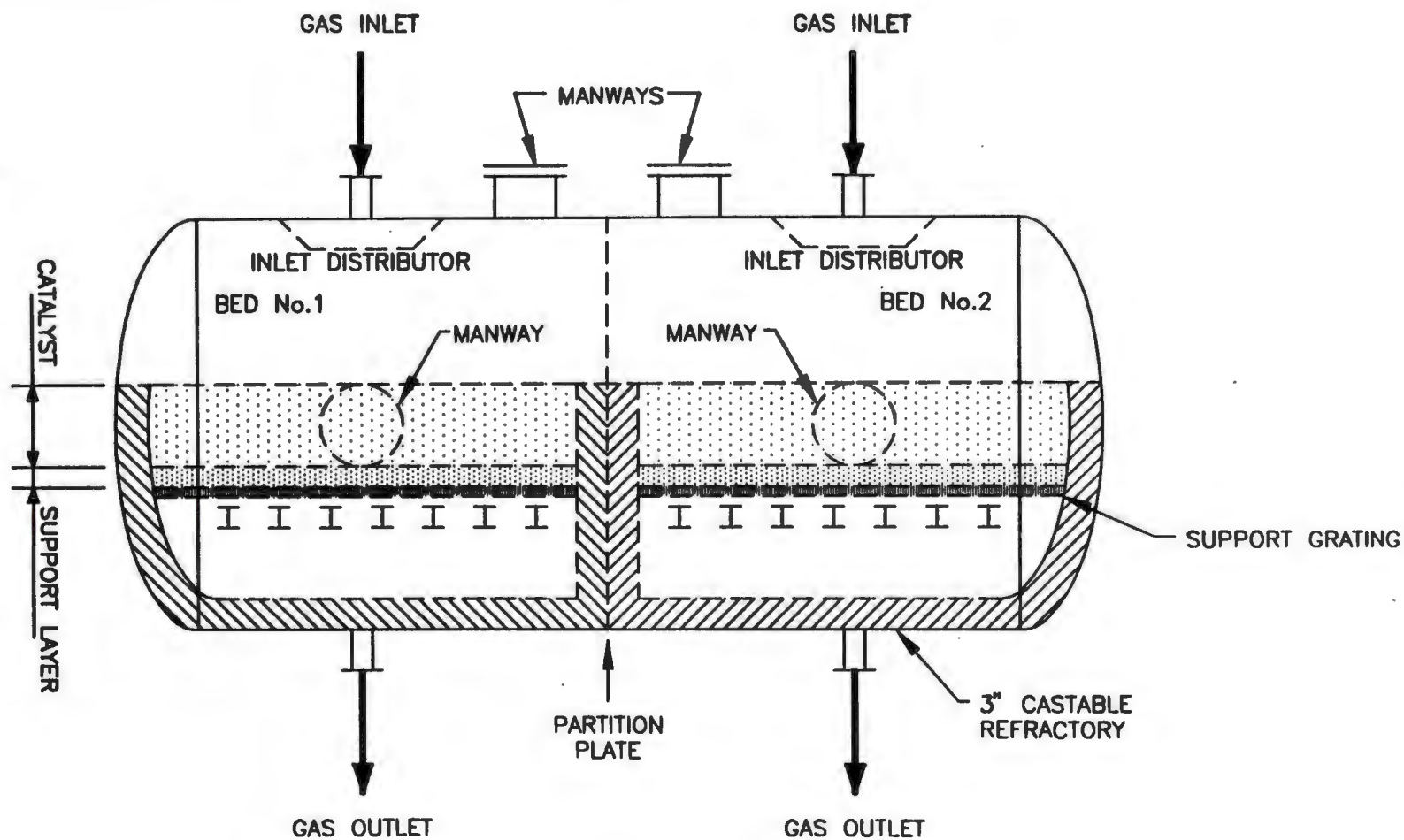


FIGURE 12

TYPICAL TWO BED CLAUSS PROCESS CATALYTIC CONVERTER VESSEL

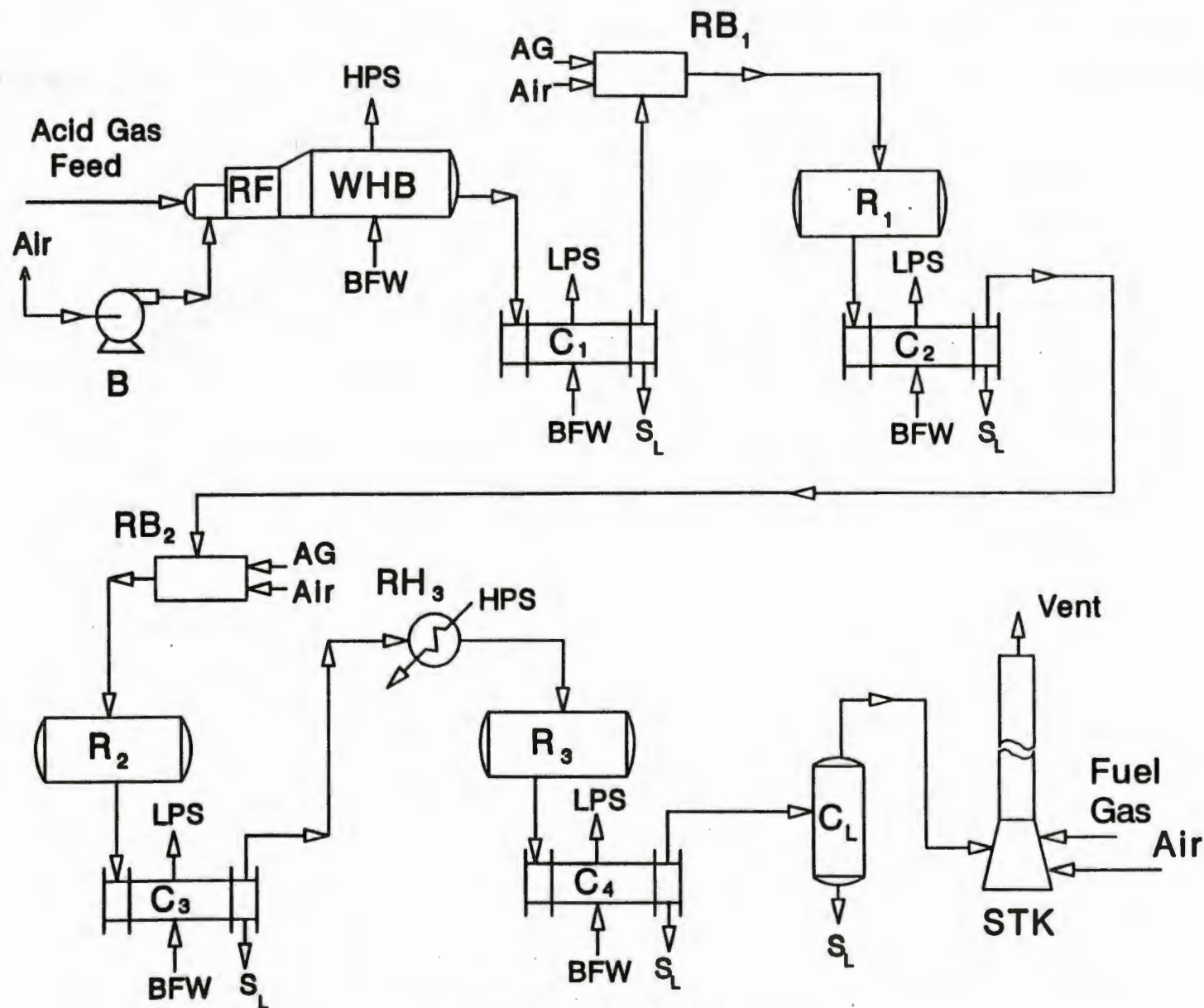


FIGURE 13

ONCE-THROUGH CLAUS SULFUR RECOVERY UNIT
(Using Acid Gas In-line Reheat Burners & a Steam Reheater)

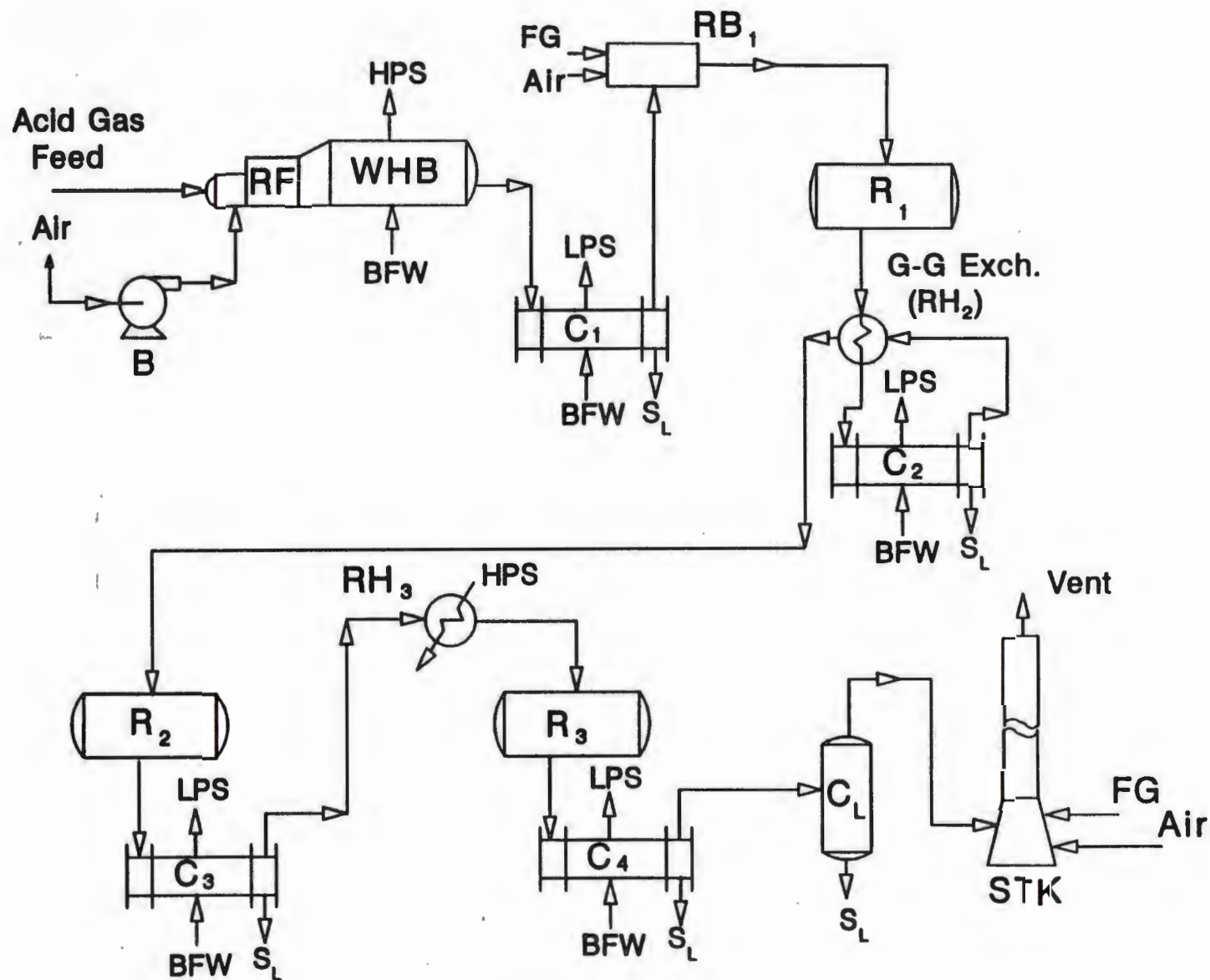


FIGURE 14

ONCE-THROUGH CLAUSS SULFUR RECOVERY UNIT

(Using a Fuel Gas In-line Reheat Burner, a Gas-Gas Exchanger & a Steam Reheater)

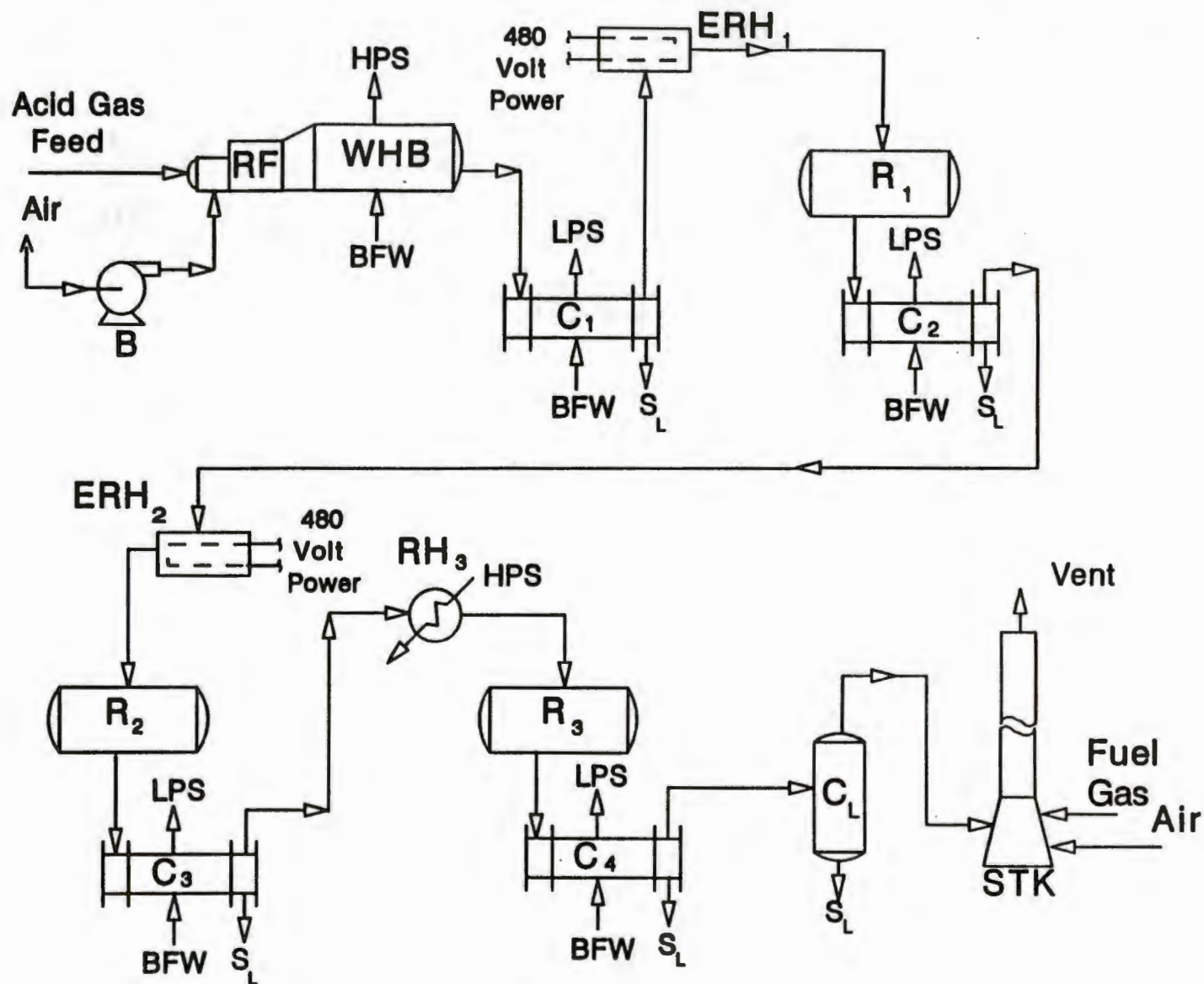


FIGURE 15
ONCE-THROUGH CLAUS SULFUR RECOVERY UNIT
(Using Two Electric Reheaters & A Steam Reheater)
(For Smaller Units)

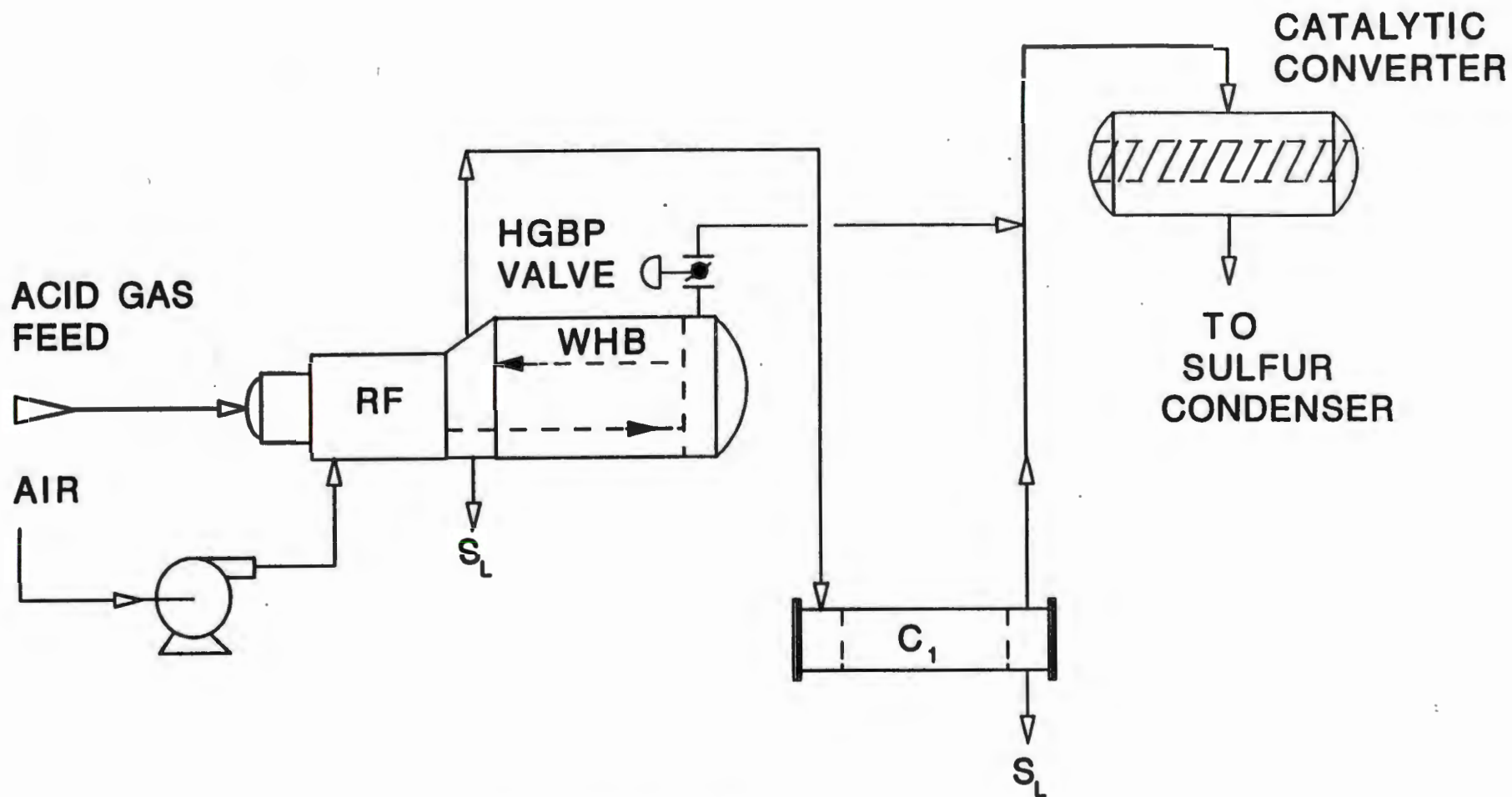


FIGURE 16

**TYPICAL HOT GAS BYPASS (HGBP) REHEAT
WITH TWO-PASS WASTE HEAT BOILER**

96FIG16

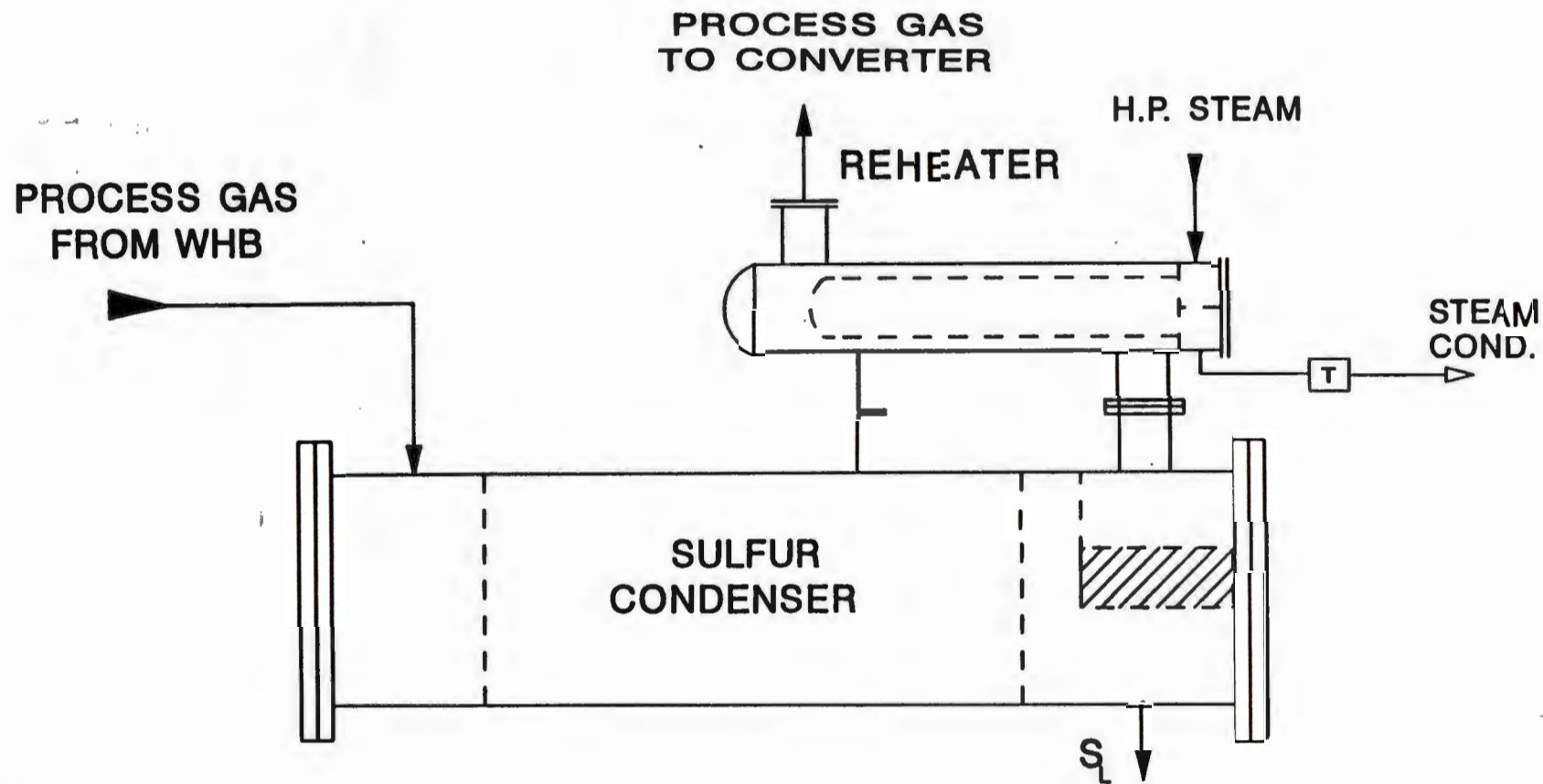


FIGURE 17
TYPICAL HORIZONTAL STEAM REHEATER

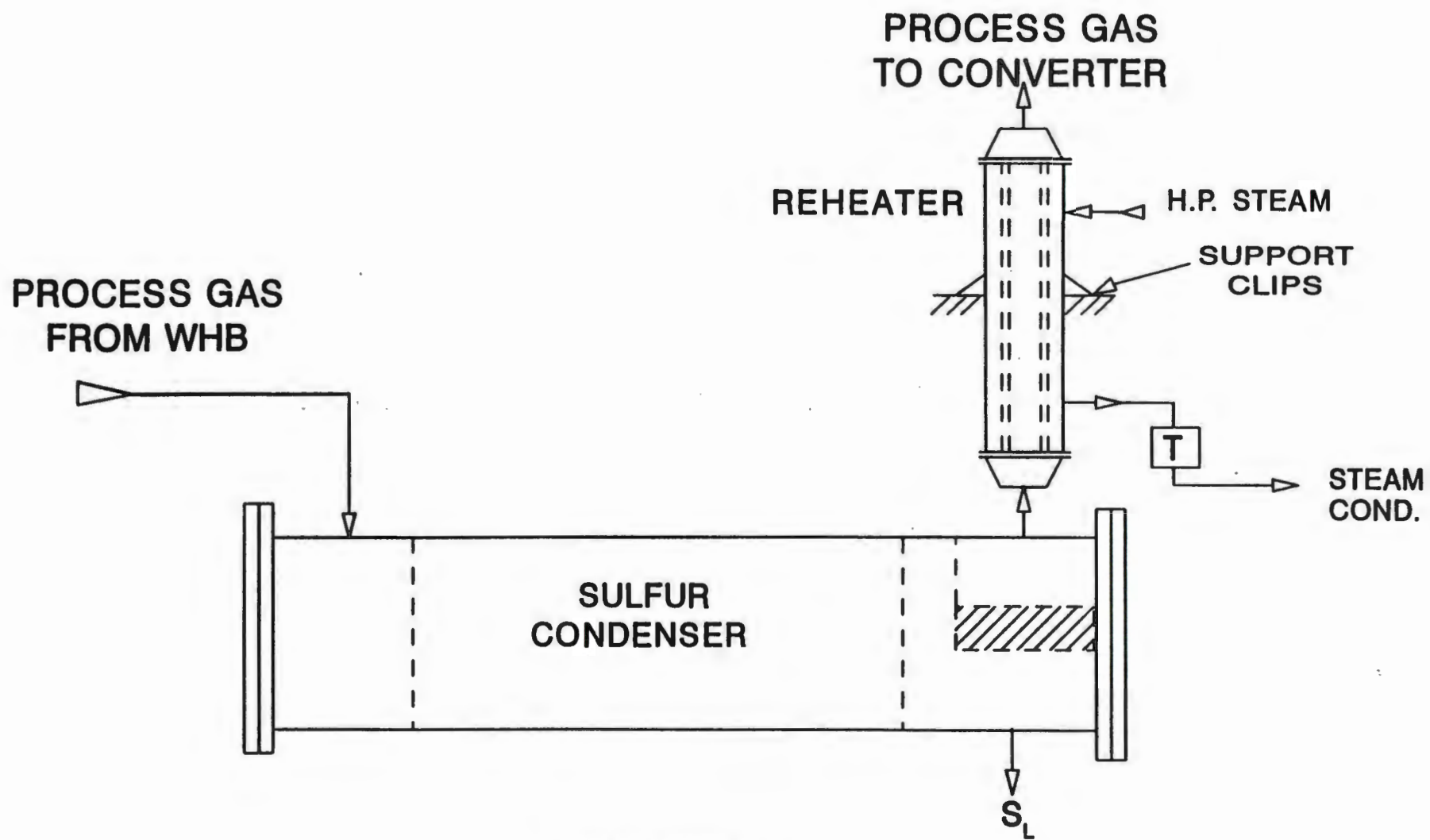


FIGURE 18
TYPICAL VERTICAL STEAM REHEATER

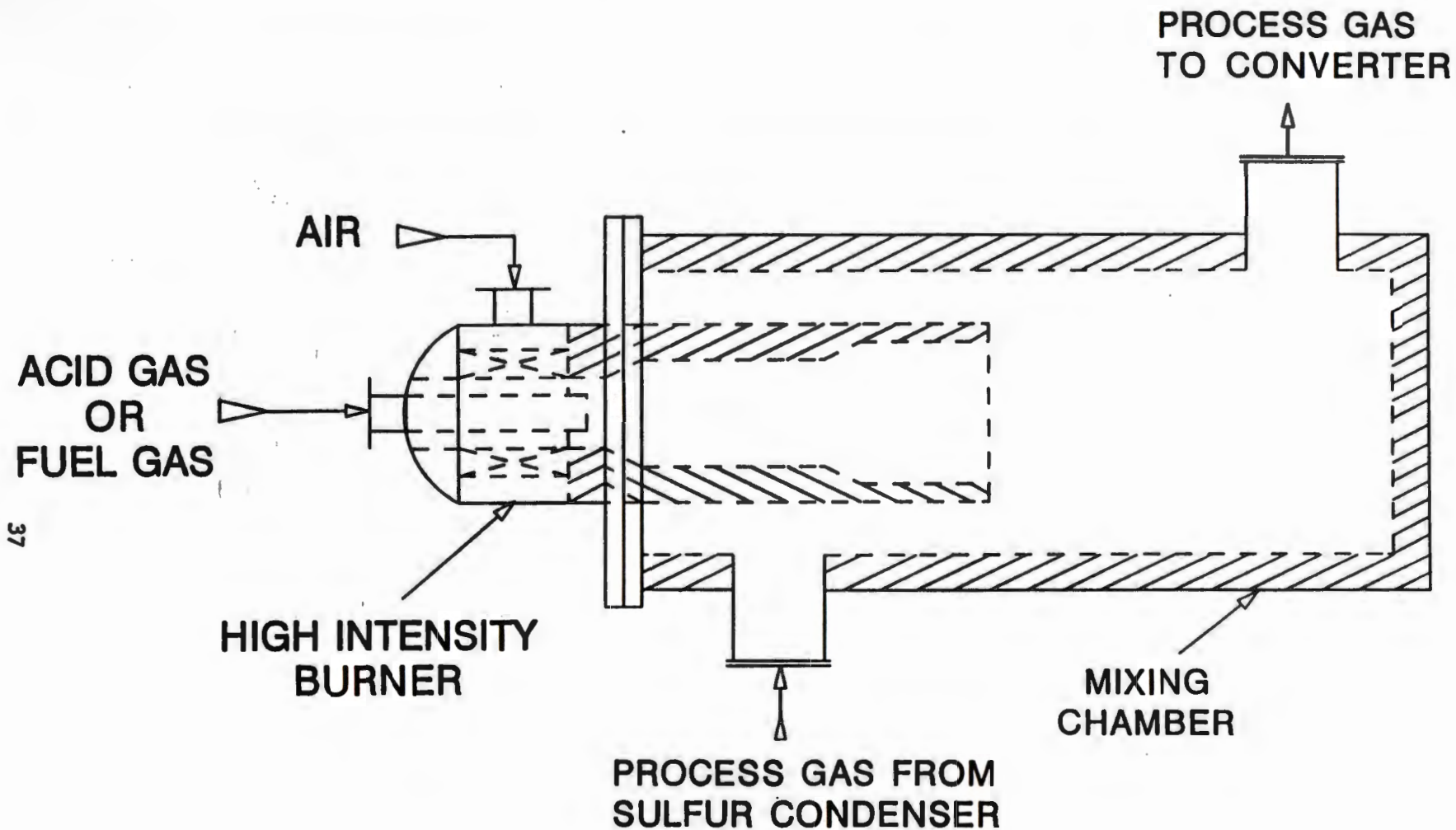


FIGURE 19

TYPICAL IN-LINE REHEATER (AUXILIARY BURNER)

PROCESS GAS FROM
CONVERTER NO. 1

PROCESS GAS TO
CONVERTER NO. 2

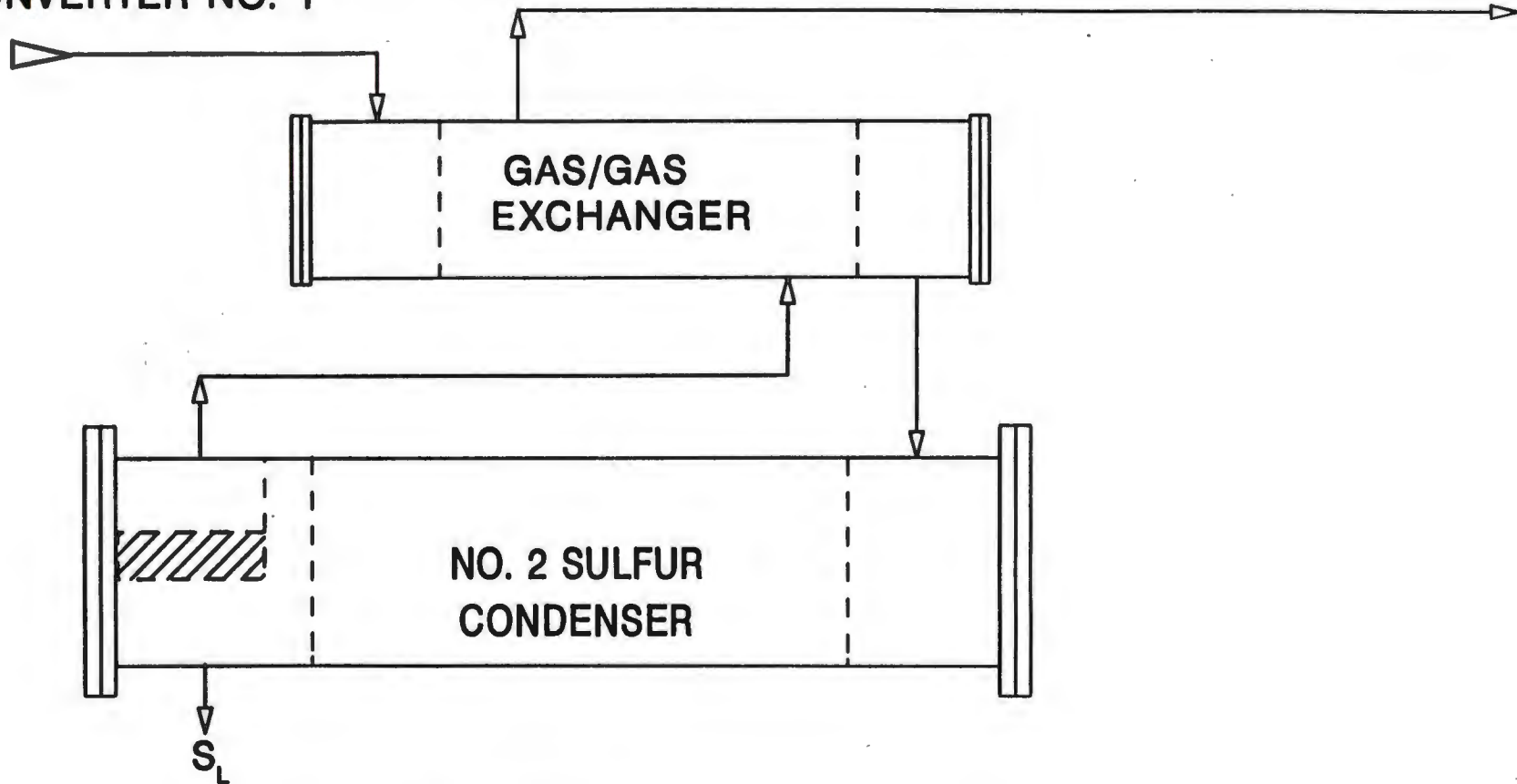


FIGURE 20

TYPICAL GAS/GAS EXCHANGER REHEATER

96FIG20

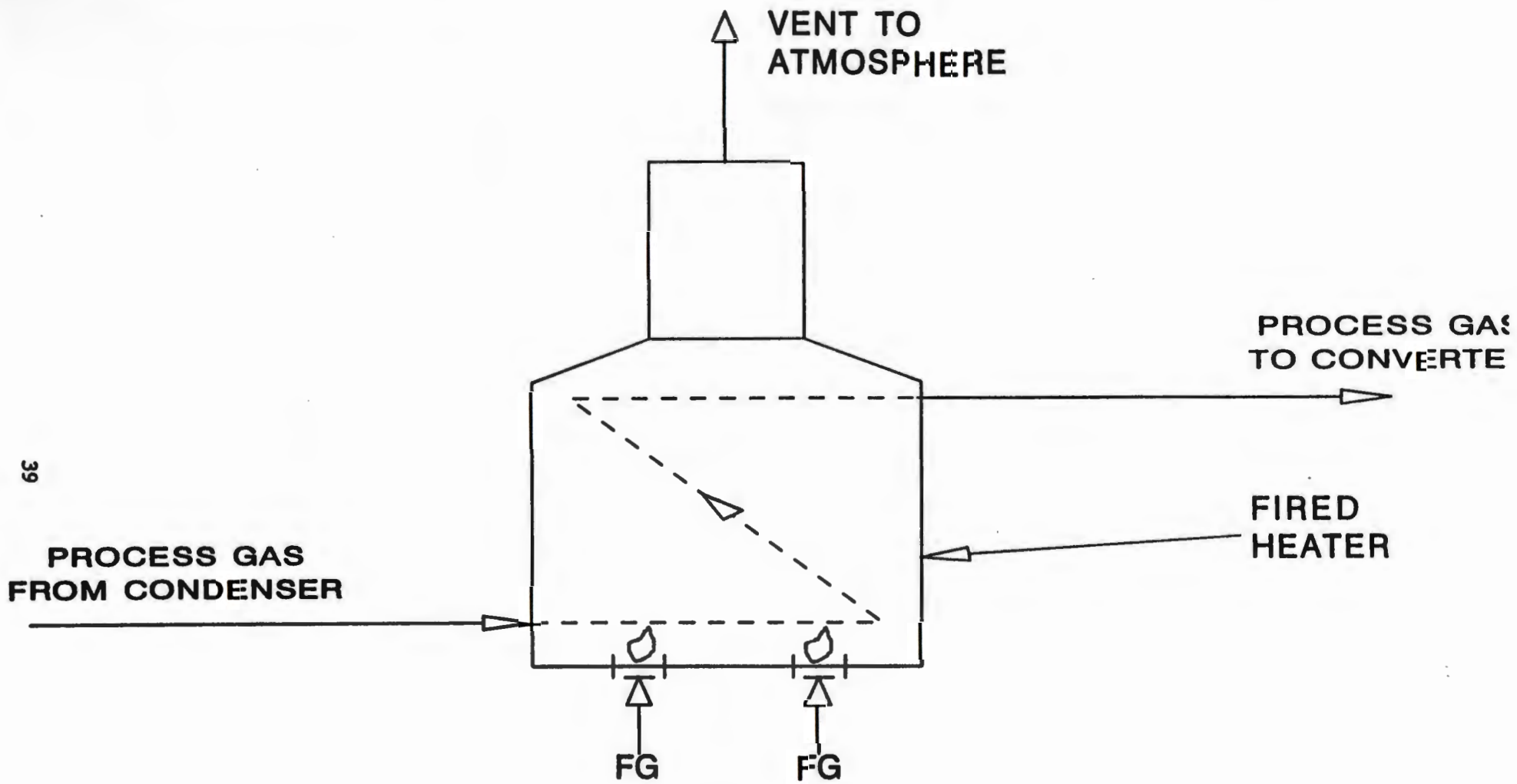


FIGURE 21

TYPICAL INDIRECT FUEL GAS FIRED REHEATER

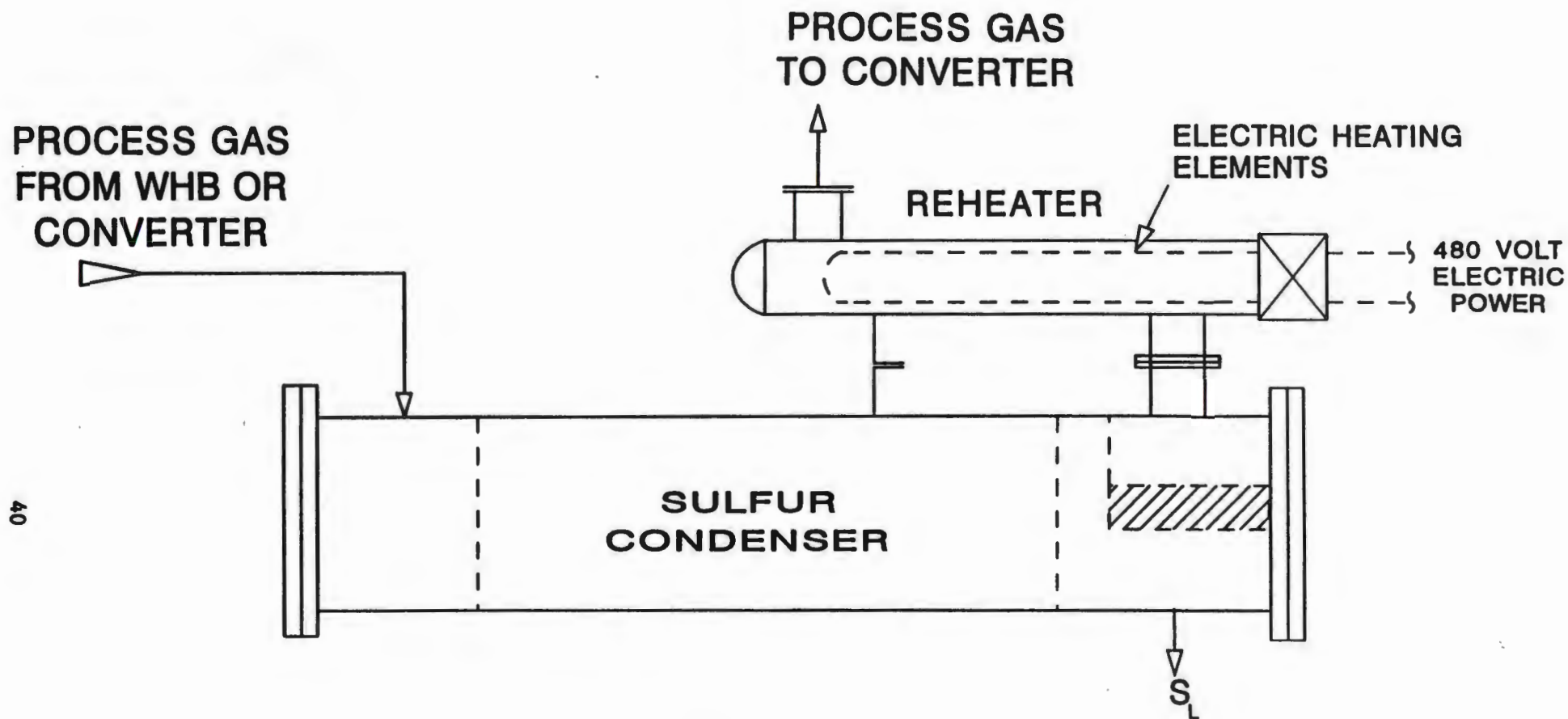


FIGURE 22
TYPICAL ELECTRIC REHEATER
FOR SMALL SULFUR PLANTS

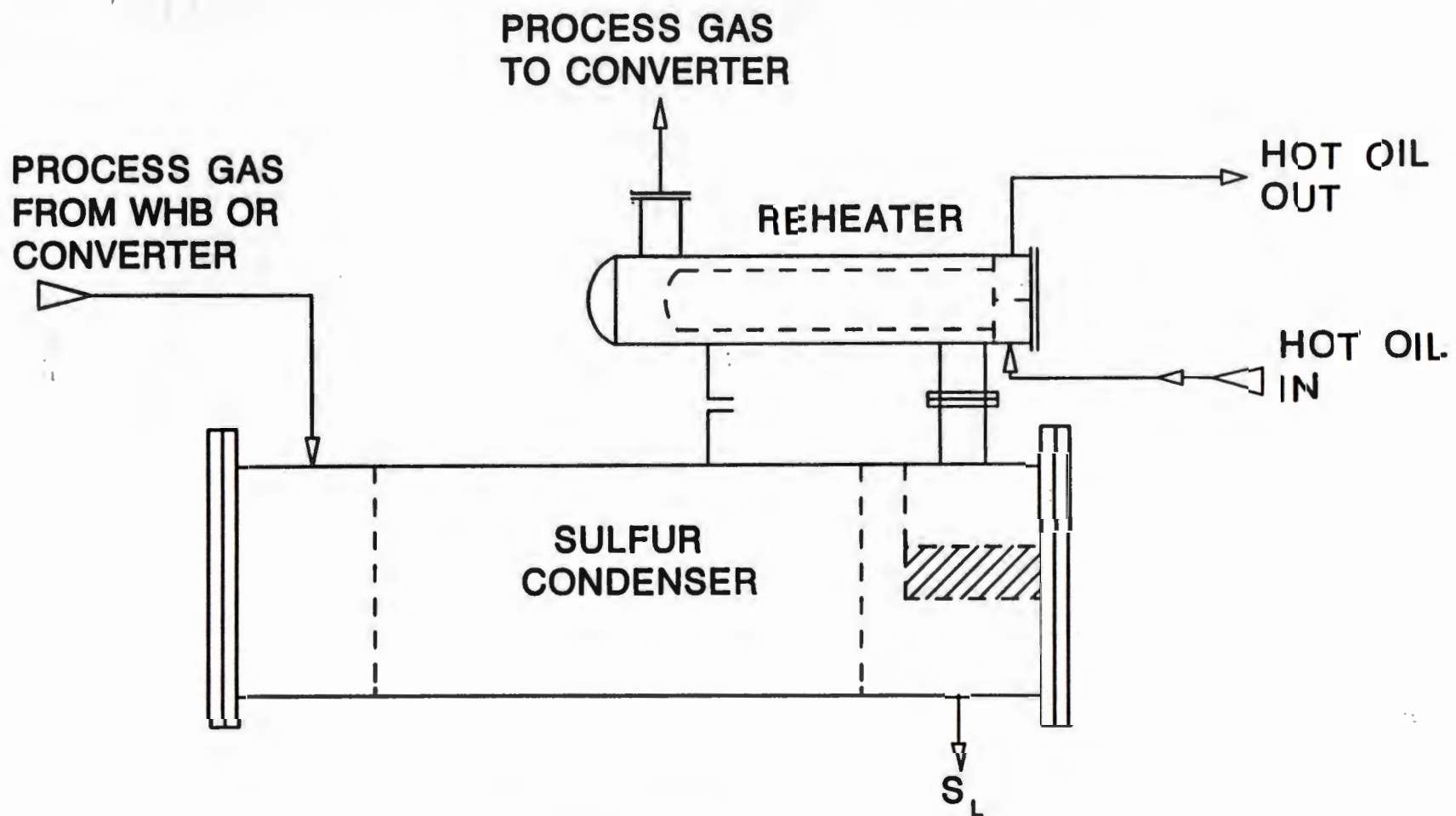


FIGURE 23

TYPICAL HOT OIL REHEATER

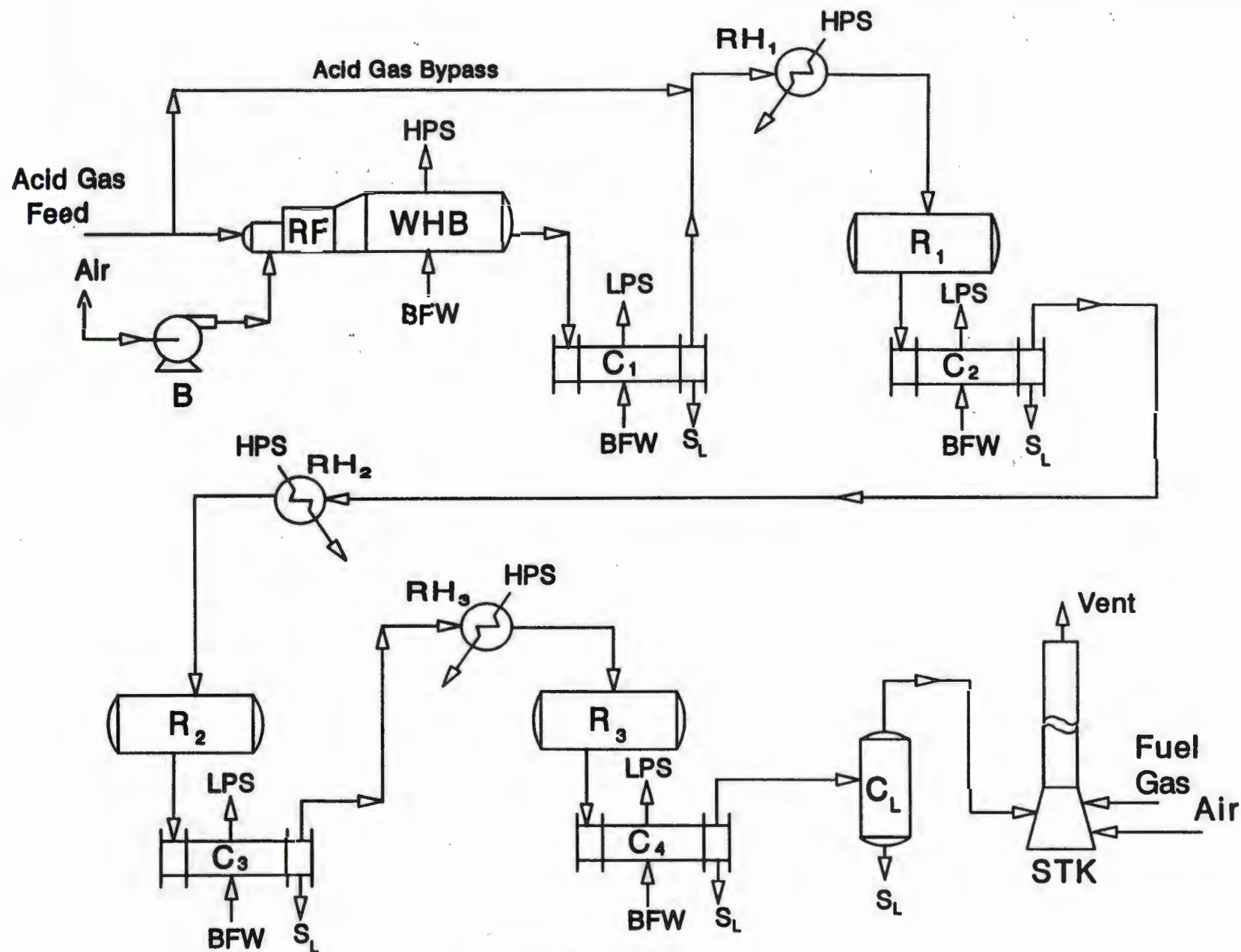


FIGURE 24

SPLIT-FLOW CLAUS SULFUR RECOVERY UNIT
(Using Steam Reheaters)

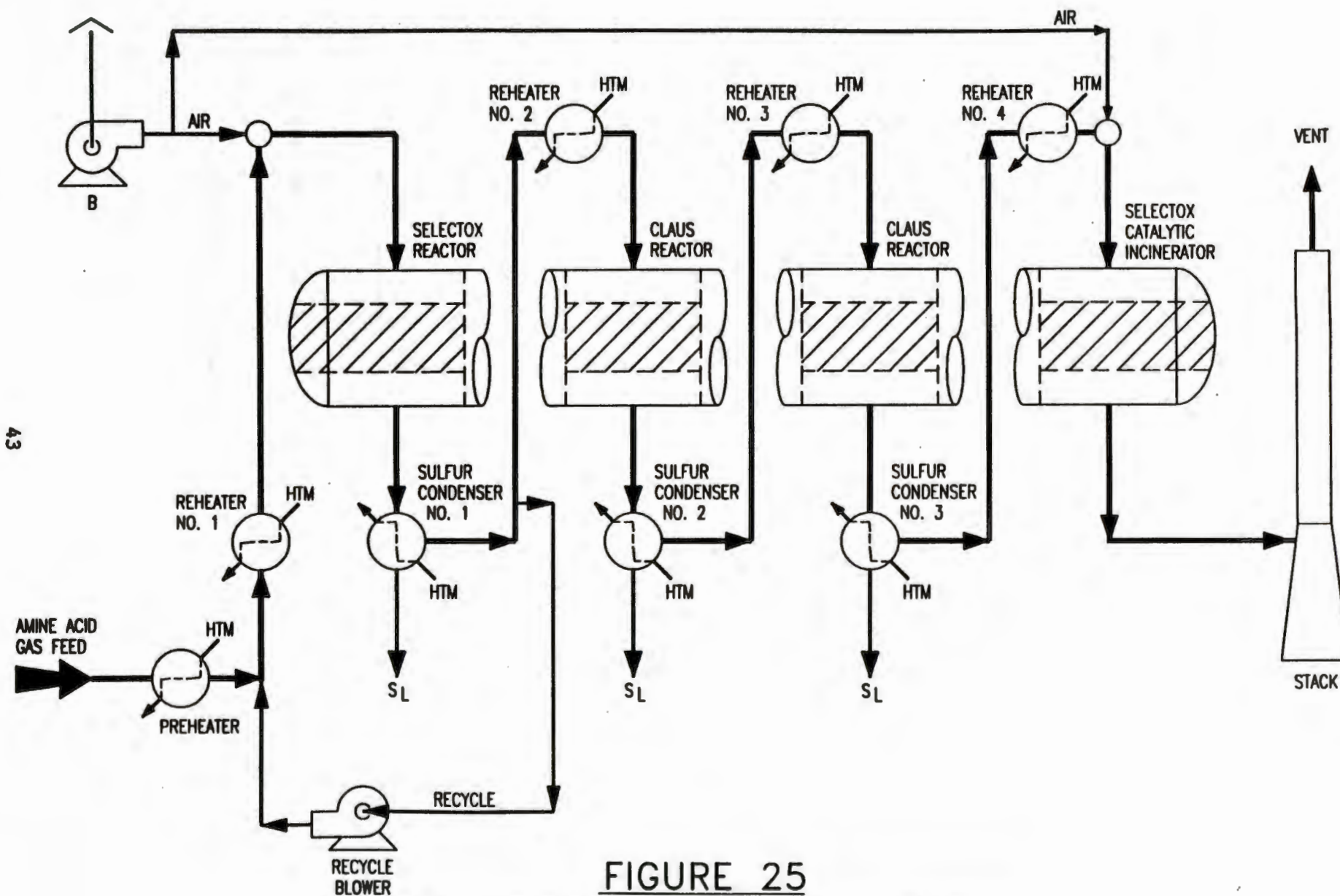
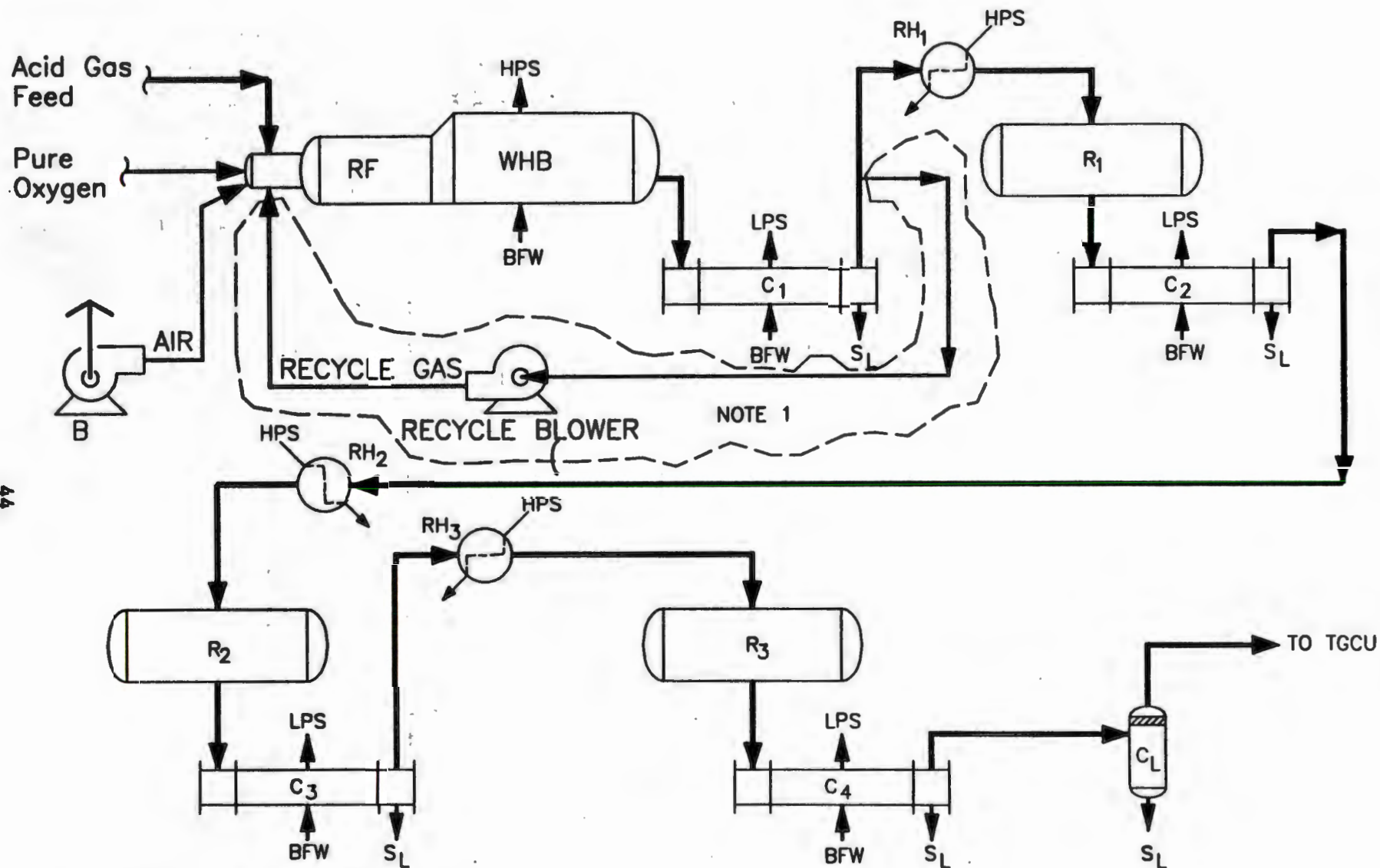


FIGURE 25
SIMPLIFIED SELECTOX PROCESS FLOW DIAGRAM



NOTE 1: RECYCLE BLOWER REQUIRED ONLY FOR
COPE™ PHASE II PROCESS.

FIGURE 26
SIMPLIFIED COPE™ PROCESS FLOW DIAGRAM

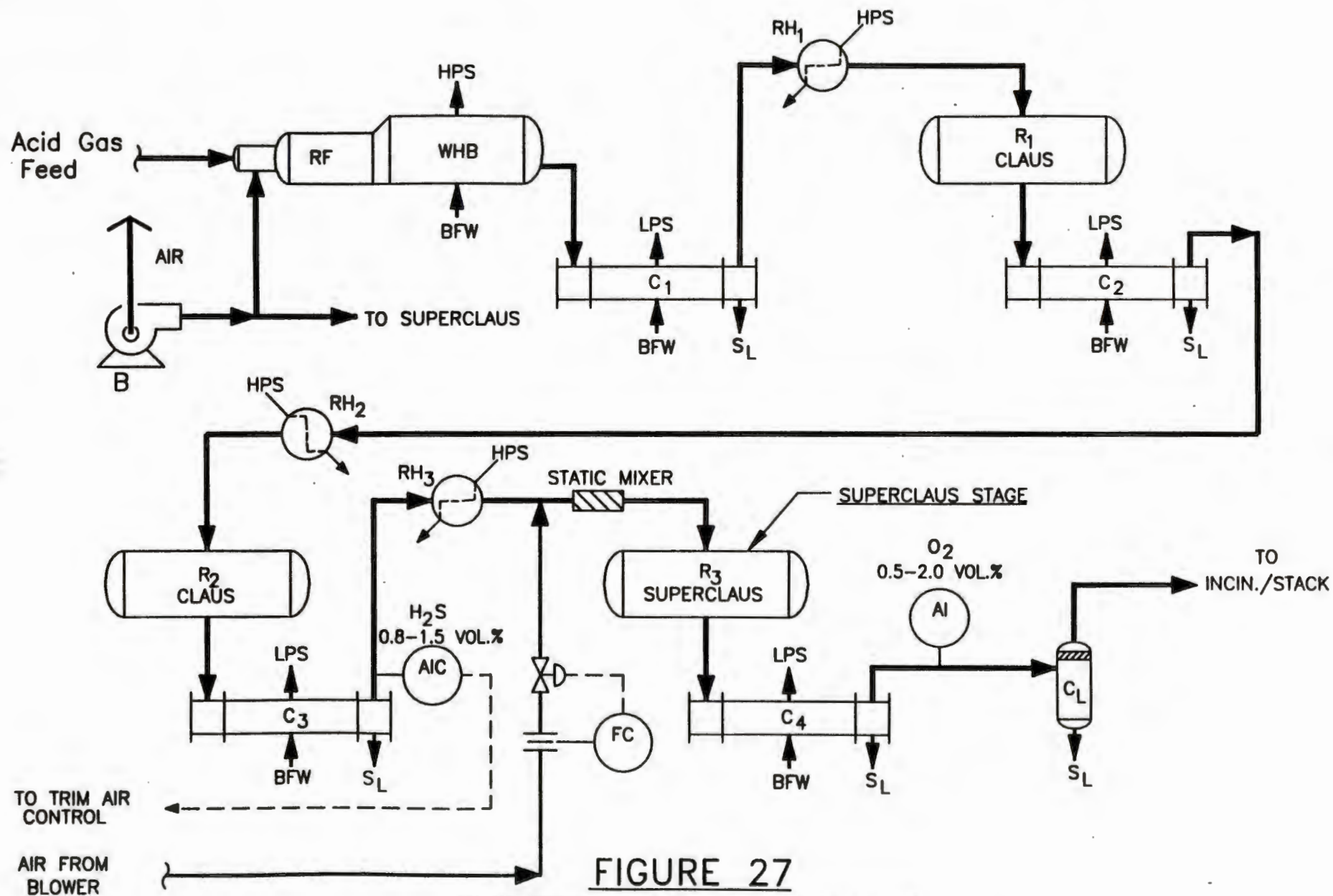


FIGURE 27
SIMPLIFIED PROCESS FLOW DIAGRAM
SUPERCLAUS-99 PROCESS

