"SUPERSIZE ME" – WORLDSCALE SRU / TGTU GOES OPERATIONAL IN KAZAKHSTAN

Robin Street (Technical Director – Sulphur Technology)
Ken Allan (Senior Process Engineer)
WorleyParsons Europe Limited
Parkview, Great West Road,
Brentford, Middlesex. TW8 9AZ, UK
www.worleyparsons.com

ABSTRACT

Over the last 15 years oil production at Tengizchevroil's facility in Tengiz, Kazakhstan has steadily increased and today it has the potential to produce nearly 600,000 bpd. Given the highly sour nature of the well fluids, sour gas processing, sulphur recovery and sulphur management have been key factors in the expansion of oil production at Tengiz. The most recent expansion at Tengiz boasts the world's largest single-train sour crude processing train, which includes a single-train 2350 t/d sulphur recovery and tail gas treatment unit. This paper describes the background to the project, discusses the design implications of a large single-train option and highlights some of the challenges faced whilst executing a worldscale project in Kazakhstan.

Contents

1. Tengizchevroil & Kazakhstan

Tengizchevroil (TCO) is a joint venture between Chevron, ExxonMobil Research and Engineering Company, Lukarco and KazMunayGas. The company is developing the Tengiz and Korolev oil fields located in the north-eastern reaches of the Caspian Sea in Kazakhstan. The joint venture was formed in 1993.

Tengiz is one of the world's largest oil fields and contains between 6 billion and 9 billion barrels (1 km^3 and 1.4 km^3) of recoverable oil. It is also the world's deepest operating super-giant oil field, with the top of the reservoir at about 3,660 m deep. The well fluids are characterised as highly sour (the associated gas is approximately 16% H_2S), therefore sulphur handling is a key component to oil production in Tengiz.

The Tengiz field is located in a remote region of Kazakhstan, approximately 350 km by road from the city of Atyrau. Transport options for major equipment include use of the Volga-Don canal system into the Caspian Sea and then rail from the port of Aktau into Tengiz. The canal system is impassable between November and March due to freezing. The rail system imposes size limits on the cargo which can be transported. The road conditions combined with the harsh winter climate makes road transport both slow and hazardous. The nearest international airport is Atyrau.

The climate in the region is markedly continental and arid. This is characterised by the marked contrast between day and night temperatures, winter and summer temperatures, and in the rapid transition from winter to summer with a short spring season. Typical features are limited rainfall (160mm per year), limited snowfall, severe snow blow, dryness of air and soil, intense evaporation processes, and an abundance of direct sunlight. Winters are cold (-36°C), but not prolonged. Summers are hot (+44°C) and fairly prolonged.

The combination of remote location and harsh climate drives the plant design towards proven, reliable and robust technology[Ref 2].

2. Project Description

The original facility at Tengiz consisted of five oil production trains feeding four sulphur recovery and tail gas units. In 1998 WorleyParsons was awarded a series of contracts to carry out the concept development, feasibility study, front-end engineering and execution phases for revamping the existing Sulphur Plants servicing the crude oil and gas processing facilities in Tengiz. The project included the upgrading of four Sulphur Recovery Units, both in terms of capacity (increased to 4000 tpd) and reliability, in order to handle the increase in acid gas resulting from the crude oil and gas units debottlenecking and expansion. The oil production increased from somewhere below 235,000 bpd to approximately 300,000 bpd.

Following concept development and feasibility study, WorleyParsons joined forces with Fluor to execute the front-end engineering and execution phases for Second Generation Project (SGP) and Sour Gas Injection (SGI). The combined objective of SGP/SGI was to expand oil and gas handling facilities by a further 280,000 bpd by constructing a new single train plant adjacent to the existing facilities. The technology challenges of SGI have been discussed in previous papers[Ref 4] and this paper focuses on the sulphur recovery component of SGP.

SGP scope included:

- Field Gathering Network and Meter Stations
- Processing (crude stabilization, gas treatment and sulphur recovery)
- Power Generation, Utilities and associated infrastructure
- New Sales Gas Export (120 km) and Crude Export Pipelines

An overall block flow diagram is presented in Figure 1.

SGP is the world's largest single train sour crude processing train, producing up to 280,000 bpd. The fact that it is a single train makes reliability and availability key drivers for the design of all process units, including the sulphur recovery unit.

The sulphur recovery technology was licensed from WorleyParsons (formerly Parsons E & C).

3. Sulphur Technology for 99.9wt% Removal

In common with the majority of oil and gas processing facilities throughout the world, discharges of sulphur compounds to atmosphere from TCO's plant at Tengiz are limited by environmental regulations. The associated gas released from the oil is treated in a DEA Amine unit to remove essentially all the H_2S and CO_2 (the treated gas contains < 3 ppm H_2S). The resultant acid gas produced contains 77.9% H_2S, 15.7% CO_2, 0.4% Hydrocarbons and is saturated with water at 50°C and 2.0 bar.

The acid gas is then further treated in a Sulphur Recovery Unit (SRU) and Tail Gas Treatment Unit (TGTU) prior to discharge. The SRU / TGTU does not make a profit for the operator but is an essential processing step to allow the overall facility to operate.

The SRU comprises a 3-stage Claus unit (refer to Figure 2).

A proportion of the H_2S in the feed gas is thermally converted to SO_2 in the reaction furnace.

$$H_2S + 1\tfrac{1}{2}O_2 \rightarrow SO_2 + H_2O \qquad (1)$$

The remaining H_2S then reacts with the resultant SO_2 to produce elemental sulphur according the Claus reaction.

$$2H_2S + SO_2 \leftrightarrow 3/xS_x + 2H_2O \qquad (2)$$

As the feed acid gas contains other compounds, which include CO_2 and mercaptans, the actual chemistry in the thermal stage is more complex than may appear from the above.

Since the combustion products exit the furnace >1000°C, waste heat can be recovered by generating steam at 38 barg. The gases are then further cooled in a condenser, by generating low pressure (5 barg) steam, to a temperature where the sulphur condenses and flows in liquid form to a collection pit.

The Claus reaction is then repeated across three subsequent catalyst beds in order to achieve approximately 96.5% recovery of the sulphur. The Claus reaction is exothermic and favoured by low temperature. Each successive reactor operates at a lower temperature with the temperature selected to ensure the sulphur produced stays in the vapour phase. Each reaction stage is followed by a condenser to remove the sulphur from the vapour phase. The gas leaving each sulphur condenser must be reheated prior to the entering the following reaction stage to avoid sulphur condensing on the catalyst bed.

In order to achieve sulphur recovery of 99.9% or more, a tail gas treatment unit was installed to process the gas from the final sulphur condenser in the SRU. In this instance the TGTU is a WorleyParsons licensed BSR/Amine process, as outlined in Figure 3 and Figure 4. The process has two sections, firstly the hydrogenation section where all sulphur compounds are converted back to H_2S and secondly an amine section where the H_2S is removed from the gas by absorption into amine solution.

In the hydrogenation section, fuel gas is burned substoichiometrically to produce reducing gases H_2 and CO which mix with the Claus tail gas and bring it to the correct temperature for the hydrogenation reactions which are catalysed in the hydrogenation reactor.

$$CO + H_2O \rightarrow H_2 + CO_2 \quad (3)$$

$$S + H_2 \rightarrow H_2S \quad (4)$$
$$SO_2 + 3H_2 \rightarrow H_2S + 2H_2O \quad (5)$$
$$CS_2 + 2H_2O \rightarrow 2H_2S + CO_2 \quad (6)$$
$$COS + H_2O \rightarrow H_2S + CO_2 \quad (7)$$

Again the reactions are exothermic and heat is recovered by producing low pressure steam. The gas is then further cooled, by direct contact with circulating water, to a suitable temperature for amine treatment. Water produced by the upstream reactions is condensed from the gas stream.

In the amine section the gas is contacted with lean amine solution in an absorber where the amine absorbs the H_2S and some CO_2. The treated gas is sent to the thermal oxidiser where residual H_2S is converted to SO_2 prior to discharge to atmosphere. The rich amine is thermally regenerated in the regenerator column and recirculated via a lean / rich heat exchanger, filters and storage tank. The acid gas, released from the rich amine by heating in the regenerator, is cooled and returned to the front of the Claus unit.

Since the tail gas entering the absorber contains significantly more CO_2 than H_2S a selective amine must be used in order to preferentially absorb H_2S and letting the CO_2 "slip" to the thermal oxidiser.

4. Worldscale Design Features

The H_2S concentration in the incoming well fluids is approximately 16%, which means that in order to produce 12 mmtpy of crude oil, approximately 88,300 Nm^3/h of acid gas is required to be processed and 2350 t/d of sulphur is produced. Table 1 highlights some of the key equipment sizes and shipping weights associated with a single train SRU/TGTU required to process this rate of acid gas.

Table 1: Key Equipment Sizes

Equipment Item	T-T Length (m)	Internal Diameter (m)	Dry Shipping Weight (te)
Waste Heat Boilers	10.2	4.2	202
1st Sulphur Condenser	16.1	5.2	202
Claus Reactor	29.0	7.5	341
Contact Condenser	38.0	7.6	328

Such equipment operating at pressure of 1 barg or less requires large diameter pipework and therefore large diameter valves. The main acid gas inlet pipe diameter is 48" and the main process lines in the SRU are 68" and up to 80" in the TGTU.

The combination of the equipment dimensions highlighted above and the remote location of Kazakhstan meant that the SRU/TGTU design was constrained by the logistics and transportation limits as well as pushing the boundary of what was physically practical to manufacture.

Transportation Limits

A stick-build construction approach was adopted for the project. Kazakhstan is land-locked and Tengiz has no direct access to the Caspain sea therefore all cargo arrives either by road or rail. Given the equipment dimensions illustrated above, direct road transport is impractical over long distances due to both width and weight of the cargo. Similar is true of direct rail transport from point of fabrication to Tengiz. Transportation options for large equipment are really limited to river barge through the canal system and into the Caspain Sea, followed by offloading at a port, transfer to railcar and completing the final few hundred kilometers by rail. In order to achieve this, the Process and Mechanical engineers had to ensure that the equipment dimensions fell within the canal shipping envelope. Even when this was achieved there were several cases where the resultant vessel still exceeded the rail transportation envelope. The rail line connecting the port and Tengiz had to be surveyed, upgraded in parts and numerous obstructions relocated or bypassed. A bespoke transportation frame was fabricated to accommodate the large "out of gauge" items. Special permits were obtained from the Kazakh rail authorities, which resulted a series of vessel movements including the heaviest single item ever moved by rail (11m x 10m and 506 tonnes).

Equipment Design & Fabrication Limits

Apart from the transportation limitations there are also manufacturing limitations for some of the equipment in the sulphur recovery unit.

Evaluations by WorleyParsons have shown that the critical parameter is the diameter limitation for Waste Heat Boiler (WHB) and Sulphur Condenser tube sheets. Discussions held prior to the project with heat exchanger vendors indicated a practical maximum diameter for tube sheets to be about 5.6 metres. This is due to tube sheet material currently being available at maximum widths of about 2.5 to 3.0 metres. Two such widths of tube sheet material welded together will then produce tube sheet stock at about the 5.6 metres width. Wider tube sheets would require more than two welds to join the tube sheet material, which was judged to be potentially a problem to produce a flat tubesheet.

Waste Heat Boilers are generally designed with lower tube velocities than Sulphur Condensers, hence this becomes the limiting factor in the size of the unit. The solution was to have two Reaction Furnace/Waste Heat boilers operating in parallel with common equipment downstream of this. (refer to Figure 5). This configuration allowed a 2350 t/d "single train" SRU/TGTU to be designed and fabricated.

Even with the WHB tubesheet limitations overcome, there were still considerable fabrication challenges due to the scale of the plant.

- High intensity acid gas burners of suitable capacity and proven track record were critical to the operation of the SRU.
- Even gas distribution over the very large catalyst beds required multiple inlet and outlet nozzles.
- Claus combustion air blowers were very large (7MW driver).
- Large diameter (up to 80") butterfly valves were required on the TGTU to allow the gas to bypass the unit directly to the thermal oxidiser. Leakage becomes more difficult to eliminate as the valve size increases.

Amine Selection

Given that an absorption type process had been selected during the conceptual design, the main consideration at commencement of front end engineering was the choice of solvent. The most widely used chemical absorbents are ethanolamines due to their high affinity to acid gasses. Non-selective primary and secondary amines (MEA and DEA) were not considered as they absorb too much CO_2. Alongside conventional amines (MEA, DEA, MDEA & DIPA) several proprietary formulated MDEA solutions and hindered amines are available. FLEXSORB® SE is a sterically hindered secondary amine which has been chemically tailored to increase its selectivity for H_2S pickup in the presence of high concentrations of CO_2. The structure of the amine promotes the fast reaction of H_2S and limits the reaction of CO_2. It was formulated by ExxonMobil Engineering and Research and is available through selected licensees including WorleyParsons. Table 2 gives a comparison of the amines which were considered during the initial stages of design. All performance figures are given relative to generic MDEA; absolute figures are not given. Cost data is based on 2Q2001 prices.

Table 2 – Comparison of Amines

Amine Type Name	Generic MDEA	Proprietary Formulated MDEA based	Hindered Secondary FLEXSORB SE
Able to meet 200ppmv H_2S spec?	**No** ~250ppmv	**Yes** 30ppmv	**Yes** <200ppmv
Amine concentration	50wt%	50wt%	25wt%
Amine Cost per unit mass	1	3.2	15.5
Required inventory vol.	1	0.64	0.50
Initial Amine inventory cost	1	2.2	3.5
Amine circulation rate	1	0.66	0.52
Solvent Contactor vessel volume	1	0.86	0.79
Solvent Regenerator vessel volume	1	0.66	0.45
Regenerator Reboiler duty	1	0.83	0.65
Regenerator Condenser duty	1	0.98	0.71
Lean/Rich Amine Exchanger Duty	1	0.68	0.51
Amine Air Cooler Duty	1	0.64	0.67

Generic (MDEA) did not achieve the required 200ppmv H_2S specification and the circulation rate was significantly higher than the formulated Amine and FLEXSORB SE solution.

The FLEXSORB SE solution can meet the requirements for H_2S removal and maximise CO_2 slippage. The proprietary formulation of MDEA was able to meet, and exceed, the 200ppmv H_2S specification however, due to the lower H_2S loading, the circulation rate is higher than the FLEXSORB SE solution. The lower circulation rates for the FLEXSORB SE solution leads to smaller equipment and lower capital cost (equipment capital cost for FLEXSORB SE was estimated as 70% of the equivalent equipment cost for formulated MDEA). Smaller equipment made fabrication and transportation a more realistic proposition, although still challenging. A lower circulation rate also has positive benefits in terms of future inventory management and storage.

Other factors which drove the decision towards FLEXSORB SE included:

- FLEXSORB SE is much more stable than generic MDEA[Ref 1]
- FLEXSORB SE has low foaming and corrosion tendencies[Ref 1]
- TCO already employ FLEXSORB SE in the original plant so using the same chemical in the new plant simplifies the inventory management

It is important to note that when licence fees and solvent costs are added to the equipment cost, the total direct capex cost differential between formulated MDEA and FLEXSORB SE is much smaller.

It is also worth noting that FLEXSORB SE **Plus** achieves higher H_2S removal at the expense of 20% higher circulation rate and a 70% higher inventory cost when compared to FLEXSORB SE. Given that the total installed cost for FLEXSORB SE Plus was estimated to be 20% higher than FLEXSORB SE, and there was no driver to go beyond the 200 ppmv H_2S spec, the decision was taken to proceed with FLEXSORB SE for this application.

5. Conclusions

Whilst results from performance tests are not yet available at this point in time, the Tengiz SRU and TGTU have been designed, fabricated, constructed, commissioned and operated close to the design rate of 2350 t/d sulphur. The combination of a parallel SRU reaction furnace/WHB to eliminate the tubesheet fabrication limit and the use of Flexsorb SE to limit the dimensions of the equipment in the TGTU amine section resulted in a supersized single train capable of processing the acid gas from the equally large upstream oil/gas separation unit. WorleyParsons' experience in the field of sulphur recovery has again shown that boundaries are there to be pushed and that plants of this scale are a reality even for remote locations such as Kazakhstan.

6. WorleyParsons

WorleyParsons was formed in 2004 when Worley acquired Parsons E&C, a global leader in downstream hydrocarbons with a widely recognised reputation for its high quality project services to the Power, Oil and Gas, Refining, Petrochemicals and Chemicals sectors globally. WorleyParsons has continued to grow and is now a major global provider of professional services to the resources and energy sectors and complex process industries – Hydrocarbons, Power, Minerals and Metals and Infrastructure – with over 32,000 employees.

Parsons and now WorleyParsons have a long history in the development and implementation of gas processing and sulphur removal technologies. WorleyParsons' experience of sulphur removal technology spans over 50 years from the invention of basic processing technologies (ammonia burning Claus, BSR Tail Gas Treating technology) to the present day when WorleyParsons' specialist Sulphur Technology Teams continue to provide state-of-the-art solutions and a Total Sulphur Management capability – treatment of sour oil and gas, smelter offgas cleaning, design of bulk sulphur handling facilities and re-injection technology[Ref3].

7. References

[1] Rameshni, M., WorleyParsons "*Selection Criteria for Claus Tail Gas Treating Processes*"

http://www.worleyparsons.com/CSG/Hydrocarbons/SpecialtyCapabilities/Documents/Selection_Criteria_for_Claus_Tail_Gas_Treating_Processes.pdf

[2] Roberts, P. and Armstrong, L., WorleyParsons "*Challenges for Processing Oil and Gas from Kazakhstan*", GPA Europe Conference, Warsaw 2005

[3] "*Sulphur Technology – Capability and Experience*" http://www.worleyparsons.com/CSG/Hydrocarbons/SpecialtyCapabilities/Documents/Sulphur_qualifications.pdf

[4] Block, M., Amott, N. and Lanterman, J., "*Sour Gas Injection Design Extends the Envelope in Kazakhstan*", GPA Europe Conference, Warsaw 2005

Figure 1: SGP Overall Block Flow Diagram

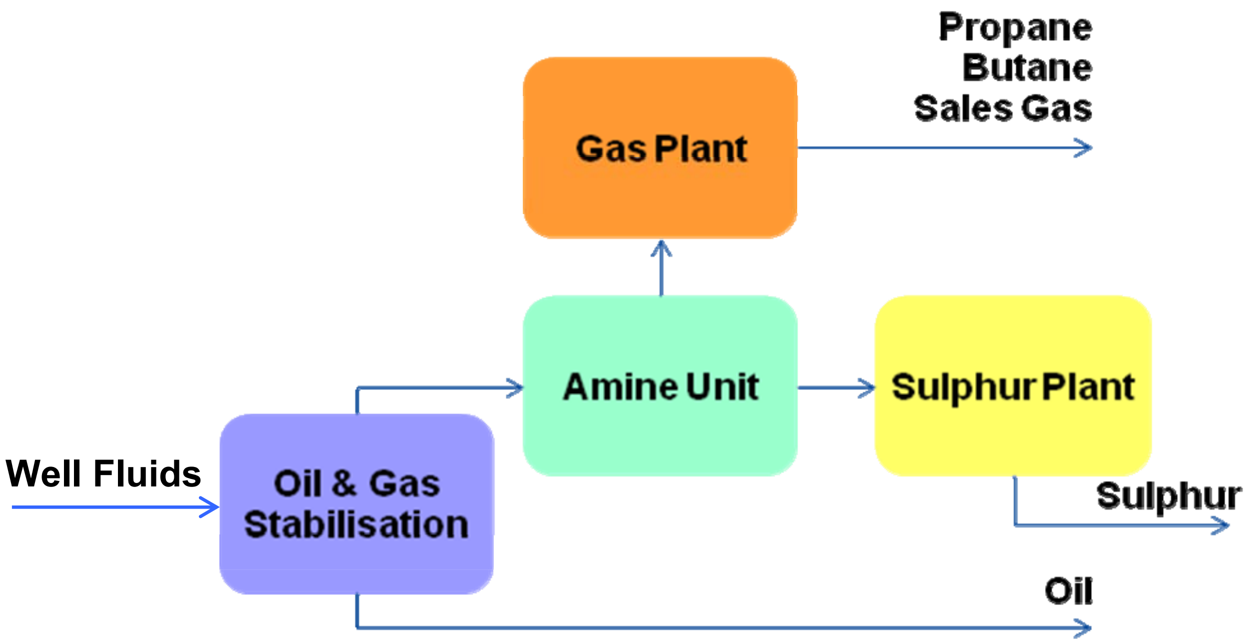

Figure 2: Simplified Process Flow Diagram of 3-stage Claus SRU

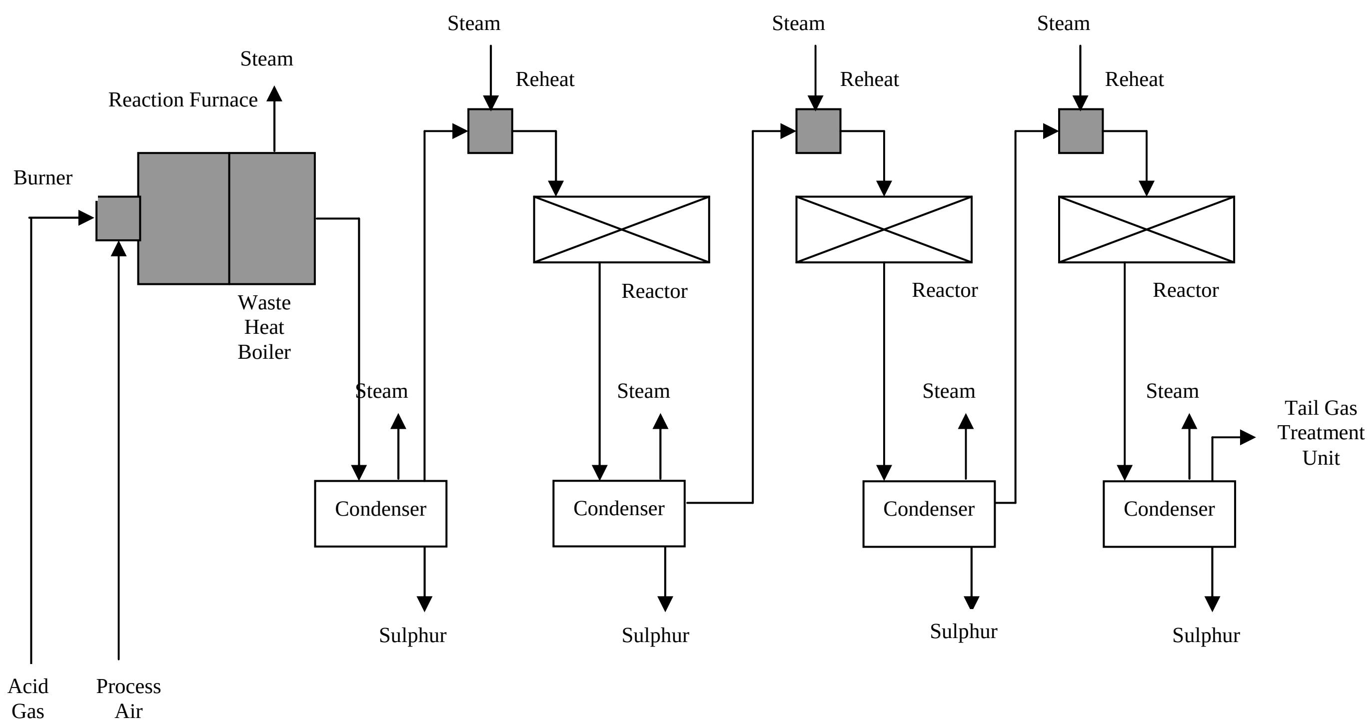

Figure 3: Simplified Process Flow Diagram of TGTU Hydrogenation Section

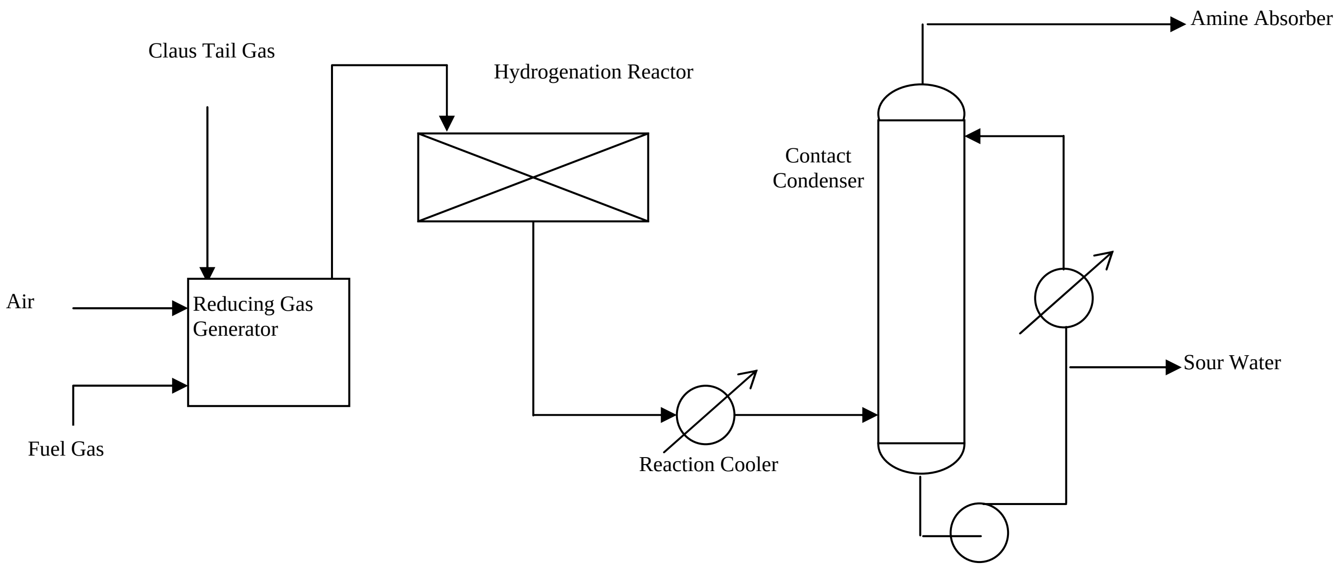

Figure 4: Simplified Process Flow Diagram of TGTU Amine Section

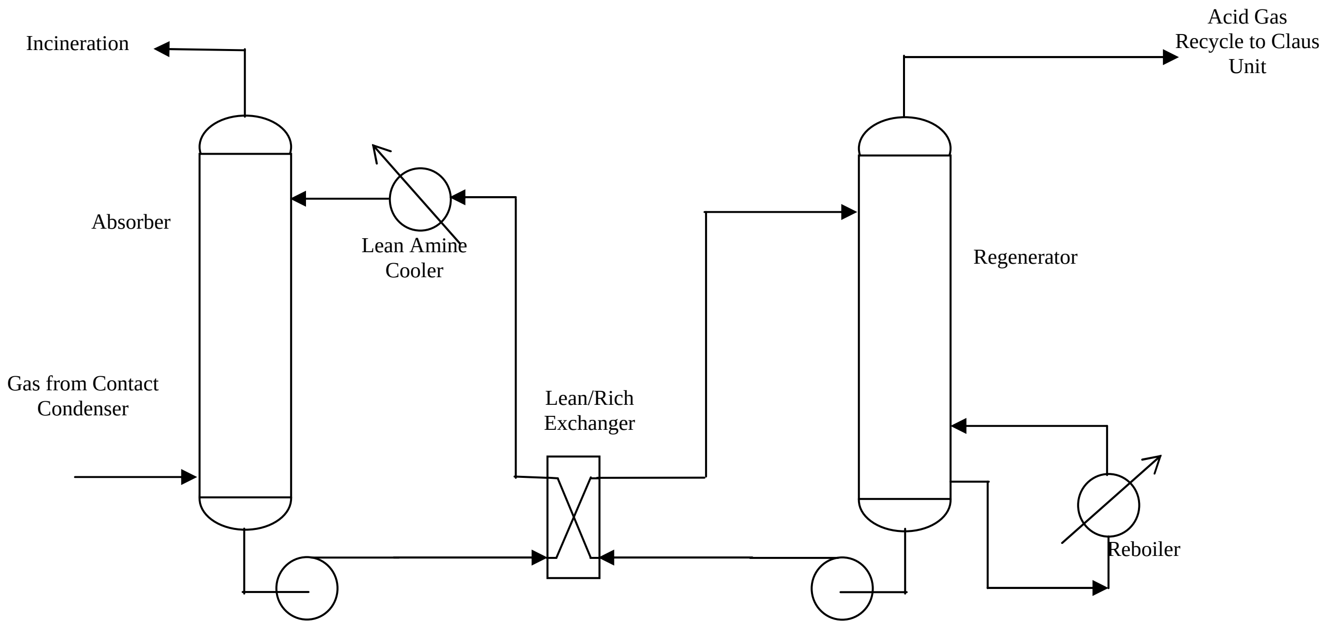

Figure 5: Simplified Process Flow Diagram of 3-stage Claus SRU with parallel Reaction Furnace/Waste Heat Boiler

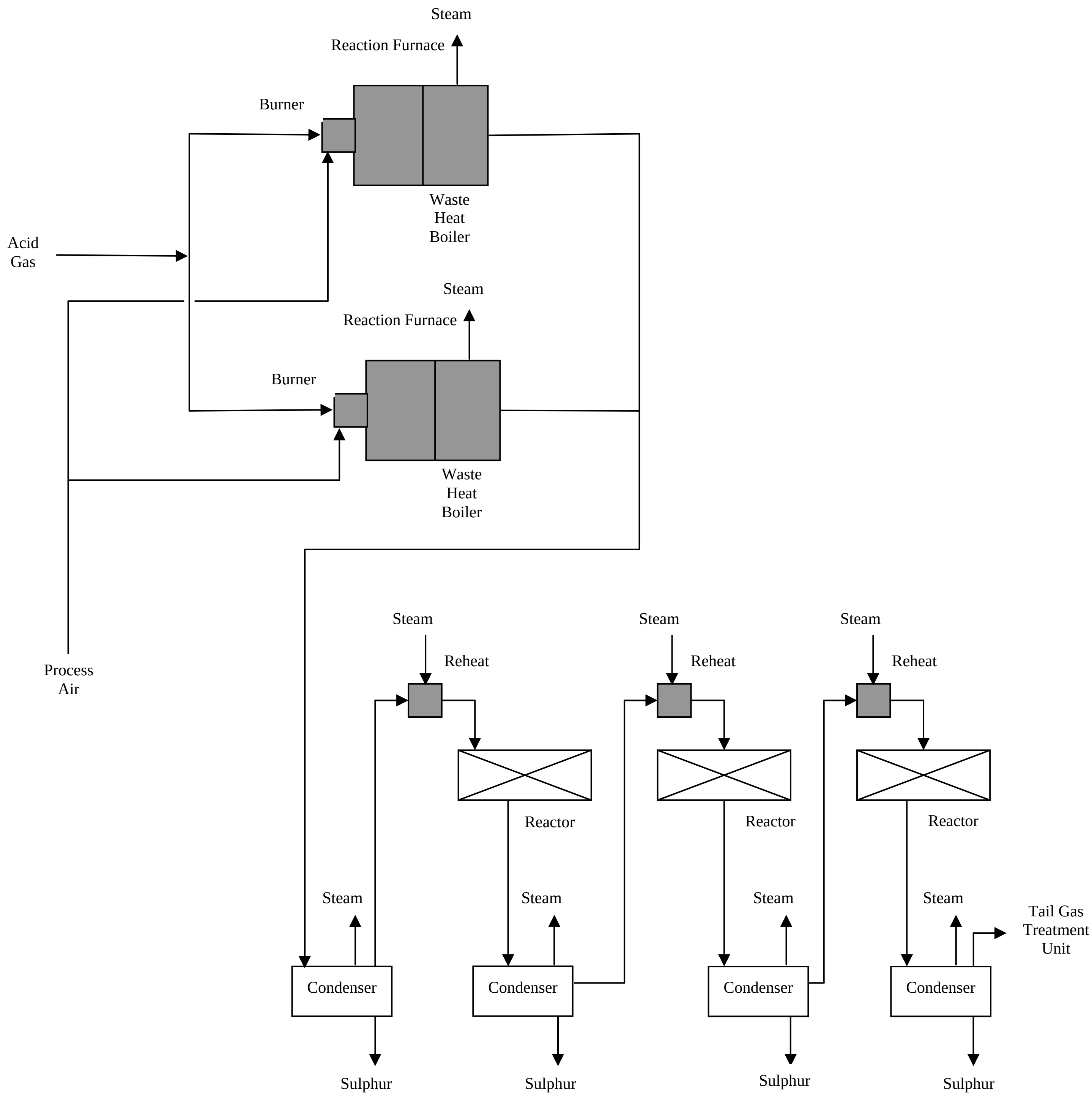

Photo 1: Overall SGP Plant with SRU and TGTU in Foreground

Photo 2: Transporting a 7.5m diameter x 29m t-t Claus Reactor (286 tonnes)

Photograph by kind permission of Tengizchevroil

Photograph by kind permission of Tengizchevroil

Photo 3: Large equipment on specially constructed transportation frame

Photograph by kind permission of Tengizchevroil

Photo 4: Reheaters and Condenser

Photograph by kind permission of Tengizchevroil

Photo 5: Hydrogenation Reactor

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