PLANT POWER FAILURES: CASE STUDY OF INDIRECT EFFECTS ON A WORLDSCALE OLEFINS PLANT

by

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Introduction

Operational upsets small and large often ripple through a hydrocarbon manufacturing facility. From a feed rate change to a thunderstorm these variations can have indirect impacts that may amplify the original disturbance. This discussion reviews a plant power failure upset and its resulting indirect effects.

Facility

The Olefins Manufacturing Facility under review here is a Worldscale integrated production plant. Figure 1 illustrates a simplified block flow diagram. Figure 2 depicts the plant's general physical layout. The facility's center is anchored by the control room. Cracking gas and liquids, the Pyrolysis furnace effluent is fractionated into hydrogen, ethylene, propylene, C4's, gasoline, fuel oil, and pitch. The gasoline is topped to recover useful C5's for additional processing. C6+ gasoline is hydrotreated to saturate Olefins. The resulting hydrotreated product is fractionated to produce a benzene stream for Sulfolane Unit feed.

The C4 byproduct is further processed in the Butadiene (BD) Unit. A mixed butane and butylene stream for Alkylation plant feed and a 99% purity 1,3 Butadiene (C4H6) stream are produced. Figure 3 illustrates a simplified BD Unit block flow diagram. This process employs Acetonitrile (ACN - CH3CN) as a solvent. ACN is added to the BD Unit fractionators where it alters the relative volatilities of the components being separated. C4 and C5 hydrocarbons are solublized by Acetonitrile. In particular ACN has a strong affinity for 1,3-Butadiene with progressively lower attractions for C4 mono-olefins and C4 paraffins.

The Olefins complex is supported by a number of ancillary but important utilities including steam boilers, flares, and oily water sewer oil/water separators.

Loss of Power

The sound of a hydrocarbon processing facility losing electrical power produces a sinking feeling in your stomach. It is a loss of resonance and vibration that is odd and unmistakable. You instantly know something is wrong. Compressors, motors, and process flows wind down after the electricity vanishes. There seems to be a brief pause before the resulting tumult of rumbling relief valves, alarm klaxons and loaded flares. In the control room you hope emergency power functions well enough to keep your instruments and a few lights online. Most of the alarms you have activate reporting process parameters out of the norm. Those that don't annunciate immediately soon will. Perhaps a total power failure alarm toggles on to confirm the obvious. There are procedures to follow, but a 'hard shutdown' or 'crash' accurately describes the event as an impact. Impacts must be absorbed before they are dealt with.

Pulling the plug is not an elegant way to halt an intricate, integrated facility such as an Olefins production plant. From the 1450 °F furnace outlet temperatures to the -250 °F refrigeration section, any sudden process swing can result in off-spec production or potential equipment damage. At the facility under review prudent steps had been taken to reduce the likelihood of plant-wide power failures. Two separate power grid feeds, each capable of supporting the complex, entered the location from independent geographic directions. This should prevent a stray truck or violent storm from knocking out a pole or sub-station and therefore the plant power supply. Steam-driven turbo generators on site specifically circuited to power the Olefins plant were online. Even if all power was lost, emergency systems should keep the main steam boilers operational to drive the turbo generators. If necessary a controlled Olefins plant shutdown could then be executed.

Despite the precautions, at 10:35 AM on a Wednesday morning the complex suffered a total power failure. Both electrical grid feeds were lost, and steam production fell off line tripping the turbo generators. It took 30 minutes for power to be restored. Table 1 details the time line of events precipitated by this incident.

There can be many direct effects from an Olefins plant electrical failure. To name a few: coked furnace tubes, pressure relief valves that lift and don't reseat, flashing liquid flow where none should be, potential compressor and pump damage, water where none should be, plugged cryogenic equipment, product loss, superfractionator contamination, distillation column internals damage, smoking flares, and environmental releases. If the facility is processing NOx bearing feed, an upset leading to cryogenic section warming could result in hazardous conditions from unstable gum or ammonium nitrate reactions.

Planned facility start-ups or shut-downs are times of higher operating risk as the process and the people are in flux. Unsteady-state rightly begins with 'unsteady'. Unanticipated power failures carry a higher degree of difficulty than planned outages. Uncontrolled shutdowns result in unstable process operations which lead to stream compositions that are not seen during typical operation. Failing pumps and heat exchange can result in liquid full drums and columns. Falling pressures can allow normally liquid components to vaporize. System overpressuring can send abnormal mixtures toward the lowest pressure equipment.

With all the risks and potential for problems associated with the power loss that Wednesday morning, quick - and correct - operator responses resulted in only unavoidable problems. Several of the Pyrolysis furnaces were coked when they came down. As the furnace feed pumps fail and the furnace dilution steam disappears, material left in the furnace tubes thermally degrades producing coke. Also, a substantial amount of coke was blown into or dislodged within the quench fractionator overwhelming the bottoms coke crushers leading to pitch pump failures. Given the magnitude of the upset, this minimal level of equipment damage was exemplary.

Start-Up

Of course after a power failure and accompanying hard shut-down, the most important thing to do is… *Start up!* At least that can be the overwhelming sentiment. However, after a facility has fallen down due to total electrical failure, an assessment of equipment and process status should be made to ensure operation can be resumed. If steam and instrument air headers depressure, they must be repressured or packed before use. That takes time. Getting steam, instrument air, cooling water, boiler feedwater, flare, hydrogen, sour gas and other utility systems blown down and checked is critical to a smooth restart. Confirming that the electrical outage cause is understood and unlikely to repeat is also prudent.

After the 30 minute power outage, 3 hours elapsed before the Olefins plant restart began. Was that enough time to prepare? The decision to start up was made with confidence.

In starting up an Olefins plant, the ancillary units are rarely of great concern. The large Process Gas Compressor and Pyrolysis furnaces get the most attention. Refrigeration and the superfractionators (C2 and C3 splitters) get nearly all the remaining focus. Byproduct purification units like the Butadiene extractive distillation plant receive less attention and are typically brought online after the main plant is running. Primarily that is because there is typically storage surge capacity in front of auxiliary units, but also because of their small size relative to the highly integrated ethylene/propylene production equipment. Operator and craftsman manpower peaks are also shaved by staging the unit startups in sequence.

Start up scenarios for the facility vary with the type of preceding shutdown. In this case the main Olefins plant start up began with steam boiler firing to power rolling of the process gas and refrigeration compressors. Ethane furnaces were then brought online. Since equipment had not been opened nor entered, purging and drying were not required.

Because the BD unit feed storage was nearly full, the BD unit start up coincided with the Olefins plant restart. If the Olefins plant has nowhere to store its C4 byproduct it must reduce rates. Pulling down the BD Unit feed tank levels by restarting the BD Unit with the main plant reduces the likelihood that Olefins plant production will be limited by high-gauged intermediate C4 storage.

Heavy Ends in the BD plant feed (1,2 Butadiene, heavy acetylenes, Butadiene dimer, C5's) are continuously removed by a drag stream pulled from the BD Unit solvent stripping section. After being stripped from the solvent laden drag stream, the Heavy Ends are water washed to remove ACN traces and then condensed. Figure 4 illustrates the Heavy Ends Absorber and Accumulator. The Heavy Ends Accumulator is the lowest pressure vessel in the BD plant. The Accumulator boot may collect a small amount of water over time which is sent to a degassing drum using a low capacity pump. Monitoring of the Heavy Ends Composition is important as ethyl and vinyl acetylene are rejected in this stream. Acetylene concentrations greater than 30 to 40 mole%, depending on the species, can become unstable.

Unidentified at the time of the restart, an unusual mixture of water, ACN, and C4's had made its way to the BD plant's Heavy Ends Accumulator during the power failure. A combination of equipment high liquid levels and columns at relieving pressure had forced the odd blend to the point of lowest pressure in the plant - the Heavy Ends Accumulator. To the level instruments and sight glasses of the Accumulator and its boot, the vessel appeared to be completely full of water. To the unit operators, the instruments appeared to be accurate.

Problems

While work began to bring all the steam boilers online on that Wednesday afternoon, a boiler feed water line up had been missed. One of the boiler feed water pumps was started to charge the equipment. However, valves at the boiler remained closed. The boiler feed water header reached the set-point of its pressure safety valve (PSV) and relieved to the oily water sewer. Unaware that the pump was not delivering its fluid to the desired location, operators did not stop the relieving flow for 30 minutes. This hot water flowed through the sewer to its separator where benzene bearing streams from other units also drained.

Figure 5 illustrates a typical corrugated plate interceptor sewer separator. Oily sewer water gravity flows into the covered, below ground compartments . As the inlet mixture passes through the corrugated plates hydrocarbons lighter than water coalesce and float to the surface of the first section where they are removed by a skimmer. Hydrocarbons heavier than water also coalesce across the corrugated plates and sink to accumulate in the outlet partition. The remaining clarified or recovered water is pumped from the outlet compartment to the bio-treaters. The bacteria at the bio-treaters, while amenable to consuming hydrocarbons, thrive on a consistent diet. Concentration swings in the bacteria's food, or the introduction of poisonous contaminants, can reduce the bio-treater's capacity through destruction of portions of the bacteria colony. A facility constipates quickly when it cannot process effluent water.

Due to the power outage, or in response to it, the recovered water pumps at the sewer separator were out of service as the relieving boiler feed water arrived. Sewer and separator fluid levels rose and, combined with the relatively high temperature of the water, generated an atmospheric odor spreading from the separator. This alerted operators to a problem. They quickly found and corrected the boiler feed water relief. They also gathered air samples for analysis. Benzene in air concentrations in excess of the 1ppm 8 hr time weighted average limit and exceeding the 5ppm 15 minute short term exposure limit were found. Portions of the C5 units near the boiler's sewer separator were cordoned off to prevent personnel exposure due to the atmospheric benzene content. Soon there would be another sewer incident.

About six hours after the startup began (or about 8 PM Wednesday evening), operators started to deal with the high levels in the BD Unit Heavy Ends equipment. The water boot level indicator and the boot high level alarm both suggested that the boot was full. The boot instrumentation is set so that it responds to the large density difference between water and hydrocarbon. A high level should mean that there is water present. The drum level indicator and its high level alarm suggested the vessel was also full. During normal operation only a small amount of water occasionally accumulated in the Heavy Ends Accumulator boot.

The startup of the BD Unit could not continue with a liquid full Heavy Ends Accumulator. Heavy hydrocarbons must be purged from the unit to produce an on-spec 1,3-Butadiene stream. The large volume of water apparently filling the accumulator would take over a day to move to the Degassing Drum using the available pump. This prospective length of time was at odds with the restart timing. A drain from accumulator boot outlet piping to the oily water sewer was available as an alternative to using the pump to transfer water to the Degassing Drum. This drain was commonly used during normal operation to drain the boot when the pump used for that purpose was out of service. Often the drain was also used due its convenience relative to the pump. When draining a vessel to the sewer in this manner an operator was always present visually checking the fluid to ensure hydrocarbon was not sent to the sewer. In order to facilitate the restart, draining of the Heavy Ends Accumulator from the boot directly to the oily water sewer began.

How could so much water have gotten into the Heavy Ends Accumulator? As operations drained the vessel they mulled the question. It sure seemed odd. There really was no water source in that part of the plant with a flow capacity large enough to have filled the vessel in a short period of time. The normal Absorber water flow would have taken hours to do so, but would first have had to fill up the Absorber and its feed piping. Yet, it is obvious when C4 olefins go to the atmosphere. They vaporize quickly, cooling or freezing the area from which they vent. Often the vaporization leaves behind a yellow film. Clearly the material draining from the Accumulator was not C4's as it was content to flow into the sewer hub. These were experienced operators. They had often seen unusual operation and had used their troubleshooting skills to understand many unit oddities. At shift change an hour and a half before Midnight, the BD Unit operator dutifully recorded the continuing draining in their log.

Accumulator draining continued until 12:30 AM Thursday morning when the vessel level appeared to stabilize. About 10 minutes later, an operator returning to the control room was startled by a 10 foot high spray of vapor and liquid shooting from an oily water sewer manhole cover. The sewer cover was in the road immediately adjacent to the control room. Sewer problems are more common than you would hope. Still, a small geyser spraying from a sewer manhole is a spectacular if unwelcome event.

The operator trained a fire water monitor deluge on the spray and notified the control room. The hydrocarbon release alarm sounded. Fire-fighting personnel and equipment were brought into the area. Roads leading to the area were cordoned off. For several minutes a small mist also exited the next closest manhole in the direction of the BD unit. After this smaller spray disappeared, the original jet continued. Operators described the odor as smelling of propylene.

Under examination, the spray was seen exiting the manhole cover lifting hole. A work glove was stuffed in the lifting hole slowing the vent. This manhole cover provided access to a junction box where sewer lines from several parts of the complex converged before entering the sewer separator. All the plant's operators scoured the facility searching for a hydrocarbon source.

At 1 AM an air sample near the spewing vapor was taken and analyzed by gas chromatograph. C4+ hydrocarbons were found including 300 ppm Benzene. Also at this time, hand held hydrocarbon sniffers were used to check vapors in sewer hubs leading away from the hydrocarbon release. The sewer line into the Butadiene Unit showed high hydrocarbon concentrations while all others were low. Water flushing of the BD sewer lines began in an attempt to sweep out any offending material.

What do you do while hydrocarbon is spraying from a manhole a few feet from the control room? You check instruments and search equipment for a source. A hydrocarbon vent is normally associated with the failure of some type of pressurized containment. Has a pipe, tank, or vessel ruptured? How is the material getting into the sewer? Why is it then choosing to exit the sewer? Is it going to get worse? Sewer fires and explosions are not unheard of.

The proximity of the manhole release to the control room became a larger issue at approximately 1:15 AM when the control room air-conditioners ingested some of the spray. An odor filled the control room. The air-conditioners were turned off and control room doors opened to cleanse the control room atmosphere. Control room air samples for analysis were not taken.

Two hours after it had begun, the manhole spray stopped. Shortly afterward, about 3 AM, the control room odor, and outdoor odors, had dissipated. The hydrocarbon release all-clear alarm sounded. Operations continued with the startup and tried to understand what had happened. At 4 AM another check of sewer hubs in the complex using hydrocarbon sniffers revealed high hydrocarbon concentrations where they previously had been low. Had the original checks been in error? Had something been missed?

By 9AM Thursday morning a substantial amount of 'help' had arrived at the facility. The early morning events were under discussion and scrutiny. Additional resources permitted enhanced analysis. A sewer separator water sample revealed significant Acetonitrile contamination where typically there was none. The BD Unit was the only source of that chemical.

As the day wore on, additional samples were gathered and analyzed. Operator logs and instrument system data were reviewed. Theories were developed and examined. In the early afternoon a picture of what probably happened became clear. Following the crash of the power outage, the BD Heavy Ends Accumulator had an unusual amount of water in it lifted from the Absorber bottoms. However, it also had a large amount of ACN and C4 hydrocarbons. The piping and vessels associated with the Heavy Ends system are such that high liquid levels in upstream distillation columns could allow stripped liquid solvent to be forced to the Heavy Ends Accumulator. If this solvent was unstripped, it might contain 20-30 %wt C4 hydrocarbons. High liquid levels of unstripped solvent in the distillation columns upstream of the Heavy Ends system were one consequence of the power failure. A higher than normal pressure differential between the columns and the Heavy Ends Accumulator also occurred during the power failure when tower overhead condensing systems failed.

As operations drained what they thought was water from the BD Heavy Ends Accumulator they also sent C4 hydrocarbon bearing Acetonitrile to the sewer. The C4's stayed in solution until the mixture combined with a stream which released the C4's by lowering their solubility. The sewer hub from which the spray emanated was a point of confluence for all the area's sewer lines as they fed the sewer separator. Warm water in the sewer box could have released the C4's when the solvent/hydrocarbon mixture arrived. The vaporizing

C4's lifted the gasoline boiling range oil normally present in the sewer causing the atmospheric benzene contamination.

In the light of day it was difficult to envision the descriptions by those who were there of a hydrocarbon jet exiting a manhole for two hours straight. It is interesting how often seemingly impossible things happen within the complexity of manufacturing facilities. However, 'interesting' was not a word commonly used by those who witnessed the event.

Afterward

With an understanding of what had happened, the dimensions of the remaining cleanup began to set in. A barrage of equipment problems also started to impact management of the remaining issues.

Thursday afternoon the pumps that transfer recovered water from the sewer separator to the bio-treaters began to suffer failures (If it can go wrong...). Separator levels became difficult to manage. Additionally, the Acetonitrile concentration in the recovered water being sent to the treaters was too high for biological degradation. Water flow to the treaters was stopped. The unit water flushing initiated to clean out the sewers was creating a large volume of ACN tainted water. This material now had to be collected and stored since the contaminant concentration was too high for the bio-treaters to process it directly. Pump mechanical problems lead to the use of vacuum (sucker) trucks to gather the water from the sewer separator recovered water basin and transfer it to tanks. Recovered water storage tanks near the sewer separator quickly filled. By Thursday evening, sewer separator levels were brought under control using sucker trucks and by halting the sewer water flushing in addition to repairing recovered water pumps.

Early Friday morning, separator water management again became difficult. Additional sucker truck support kept water levels at a stand still, but associated problems created new obstacles. A sucker truck rupture disk failed resulting in a spill of the contaminated water to the slab near the separator. Sucker trucks were found to be leaking their cargos into drainage culverts. Using vacuum trucks to lift water out of the separator necessitated removing the separator basin covers. Odors began to spread out from the sewer separator pushed toward the control room by an unfavorable wind. Vacuum truck workmen, who were wearing respiratory protection for their tasks, tracked oil and contaminated water into the control room.

Atmospheric monitoring around the sewer separator was extended to the control room. By 10:15 AM Friday morning over 1 ppm Benzene was found in the control room air. Operators donned respiratory protection while they ran the unit. Six and three-quarter hours later the control room air tested clean and respiratory protection measures ceased.

Sewer Separator water management continued into the next day before stabilizing with the repair of all the system's pumps. By noon Saturday the recovered water analyses suggested flow to the bio-treaters could be resumed allowing normal operation. However, the contaminated water gathered throughout the incident would take months to dribble to the bio-treaters at a rate which could be digested.

40 people were tested for urinary phenol content due to the events. This test is used to detect acute benzene exposure. Urinalysis testing of any kind is itself controversial as employees are concerned about their privacy. One individual's test results came back high.

Investigation

A team was formed to review the events and how they were handled. Specifically the team was to document the events and critique operational responses. The team was composed almost entirely of operations foreman with engineering, safety, and industrial hygiene members available as needed.

For months following the event the team labored over the various operating data, incident accounts, and operating procedures. One item of note was in the application of respiratory protection equipment. Despite the more than ample availability of respirators and supplied air breathing equipment, little use was made of them during the period during which hydrocarbon sprayed from the sewer hub. This was true even after air analyses revealed significant atmospheric benzene levels. Operators were well schooled in the hazards of the chemicals with which they worked. They were also well trained in the use of respiratory equipment. In general there was a good attitude at the facility concerning safety equipment and its appropriate use. Even so, personnel commented that the unexpected and odd nature of the event evidently diminished its risk in their minds. Later in the episode, when control room atmospheric contamination occurred, respiratory protection was properly worn in spite of its inconvenience.

Almost six months to the day of the event, the final report was issued. There were no grand revelations about a key factor or factors that led to the concatenated series of mishaps. The total power failure created a climate where a greater number than usual of flawless decisions was required to ensure proper operation. The largest single error made was improper draining of the BD Heavy Ends Accumulator. Enough information and analytical capability existed, along with established operating procedures and well trained operators, that draining of the accumulator at the least should not have gone on as long as it did. However, checking and blowing down lowpoints and water legs is an ordinary chore in a startup. The vessel was full and had to be emptied. Several operators and foremen had observed the draining and thought it sound - though odd. Surely you could not pour C4 hydrocarbons into the sewer like water. Nearly everyone on the investigation team had the feeling that under the same conditions they might have made the same error. Slowing down a little, under pressure to forge ahead, might have made the difference.

In general there was a feeling that a series of maladies had struck and been handled well. A host of recommendations were made. A few dealt with improved sewer system maintenance. New hydrocarbon analysis equipment for the units was recommended. But most of the recommendations centered on more thorough training on existing procedures.

Taking six months to review and comment on a few days of operation is partly a reflection of management style. But it is also an acknowledgment that even with books and books of procedures and regulations, even with decades and decades of operating experience on the job, hydrocarbon processing facilities are complicated places where new things happen every day. It can take a lot of effort to keep some of those things from happening again.

Table 1 - Event Time Line

Time	Event
	Day 1
1035 hrs	Total power failure
1105 hrs	Power restored
1400 hrs	Facility start-up begun
2000 hrs	BD Heavy Ends Accumulator draining begun
	Day 2
0040 hrs	Spray from sewer manhole begins
0100 hrs	Sewer checks identify BD as likely hydrocarbon source - water flushing of BD sewer begun
0115 hrs	Control room air-conditioning ingests spray causing control room odor
0230 hrs	Spray from manhole stops
0255 hrs	Control room and outdoor odor gone - All clear sounded
0900 hrs	Water flushing of all sewers begun - First realization that sewer water contains substantial amount of ACN
1230 hrs	First suggestion that BD draining of ACN/C4's could have caused event
1300 hrs	Sewer separator recovered water sump begins to back-up
1400 hrs	All sewer separator recovered water pumps malfunctioning, all sewer separator recovered oil pumps inoperative
1500 hrs	Sewer separator water flow to treaters stopped due to ACN content - sucker trucks begin to transfer fluid from local storage tanks to remote storage
1600 hrs	Local separator water storage tanks full - sewer water flushes stopped
2000 hrs	Sewer separator levels brought under control with sucker trucks and repaired pumps
	Day 3
0000 hrs	Sewer separator begins backing up again
0230 hrs	Sewer separator level very high even with additional sucker truck support
0400 hrs	Sucker truck rupture disk failure results in contaminated water spill
0630 hrs	Sewer separator back under control
0815 hrs	Sucker truck leaks found to be contaminating drainage culverts
1015 hrs	Control room atmosphere contains 1.3 ppm benzene - control room personnel in respirators/fresh air
1200 hrs	Control room atmosphere contains 2.2 ppm benzene - control room personnel still in respirators/fresh air
1330 hrs	All separator recovered water pumps malfunctioning
1500 hrs	Control room atmosphere clean, breathing equipment removed
	Day 4
0000 hrs	Sucker trucks continue to remove sewer separator water/oil.
0030 hrs	One of three sewer separator recovered water pumps back on line.
1000 hrs	Two of three sewer separator recovered water pumps on line
1200 hrs	All separator pumps repaired, local separator storage empty, operations smoothing

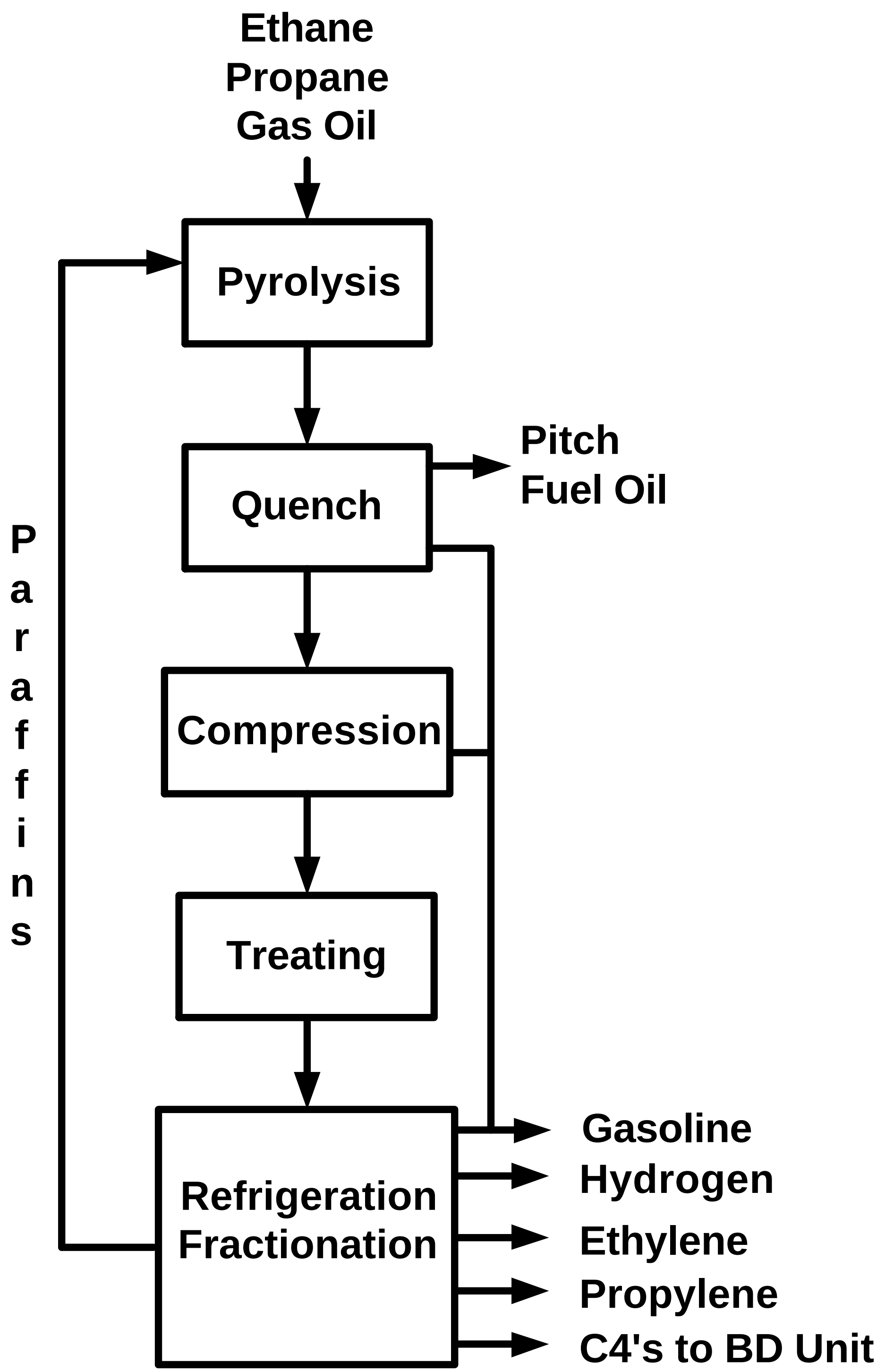

Figure 1 - Olefins Plant Simplified Block Flow

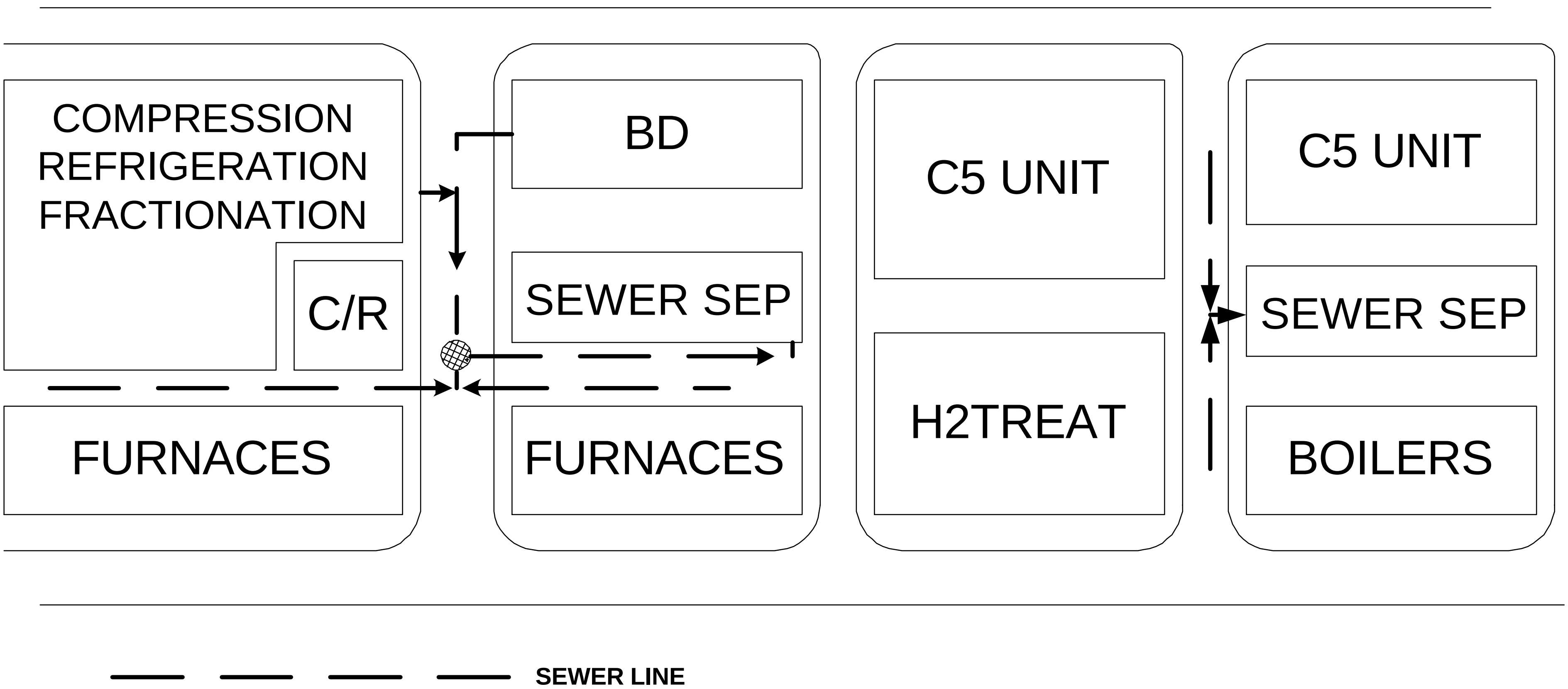

Figure 2 - Facility Simplified General Layout

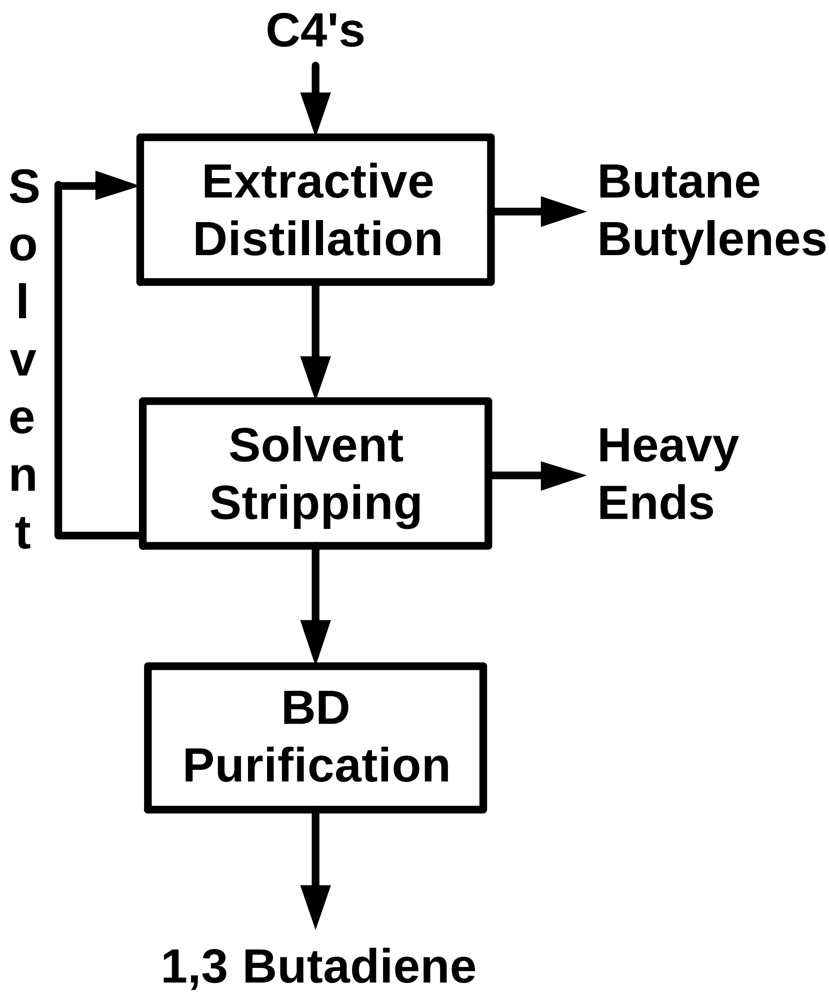

Figure 3 - Butadiene Plant Simplified Block Flow

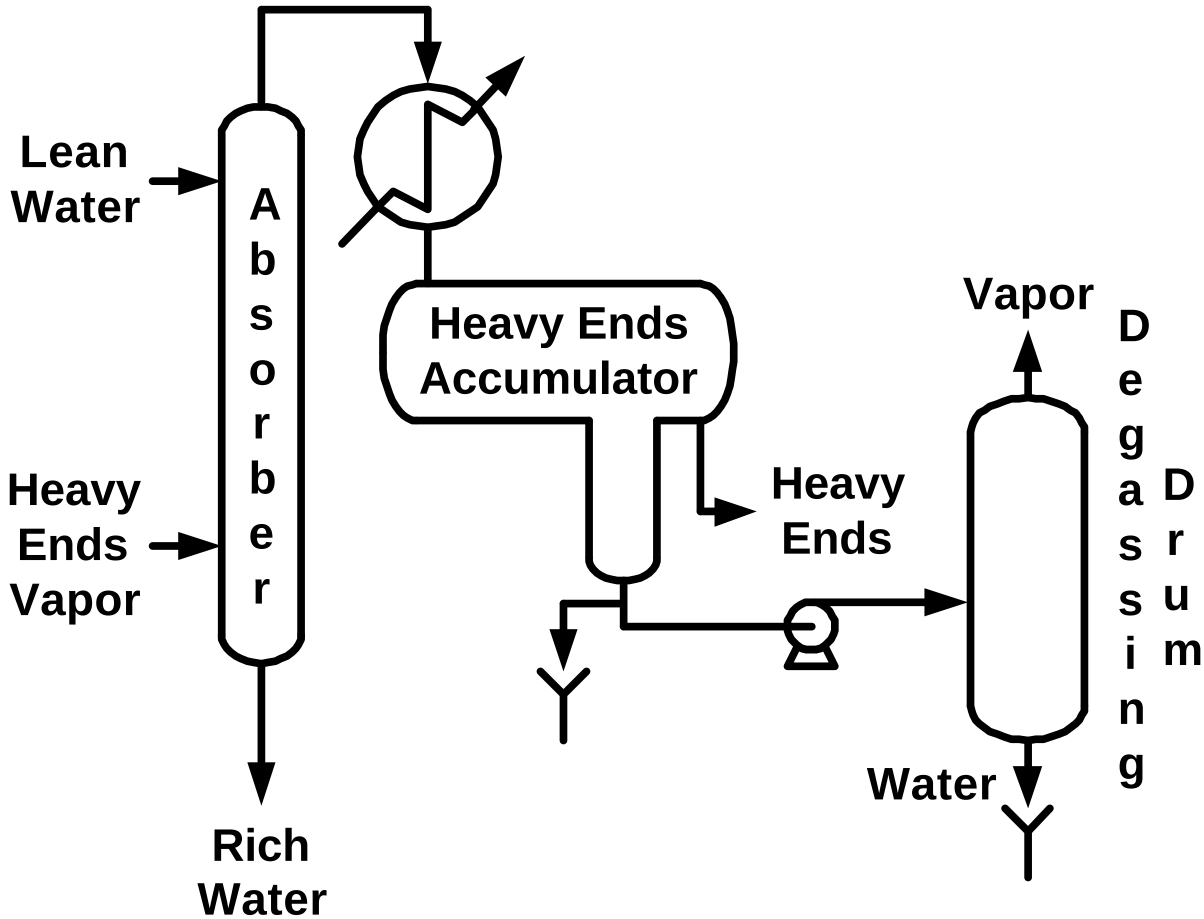

Figure 4 - Butadiene Plant Heavy Ends Recovery

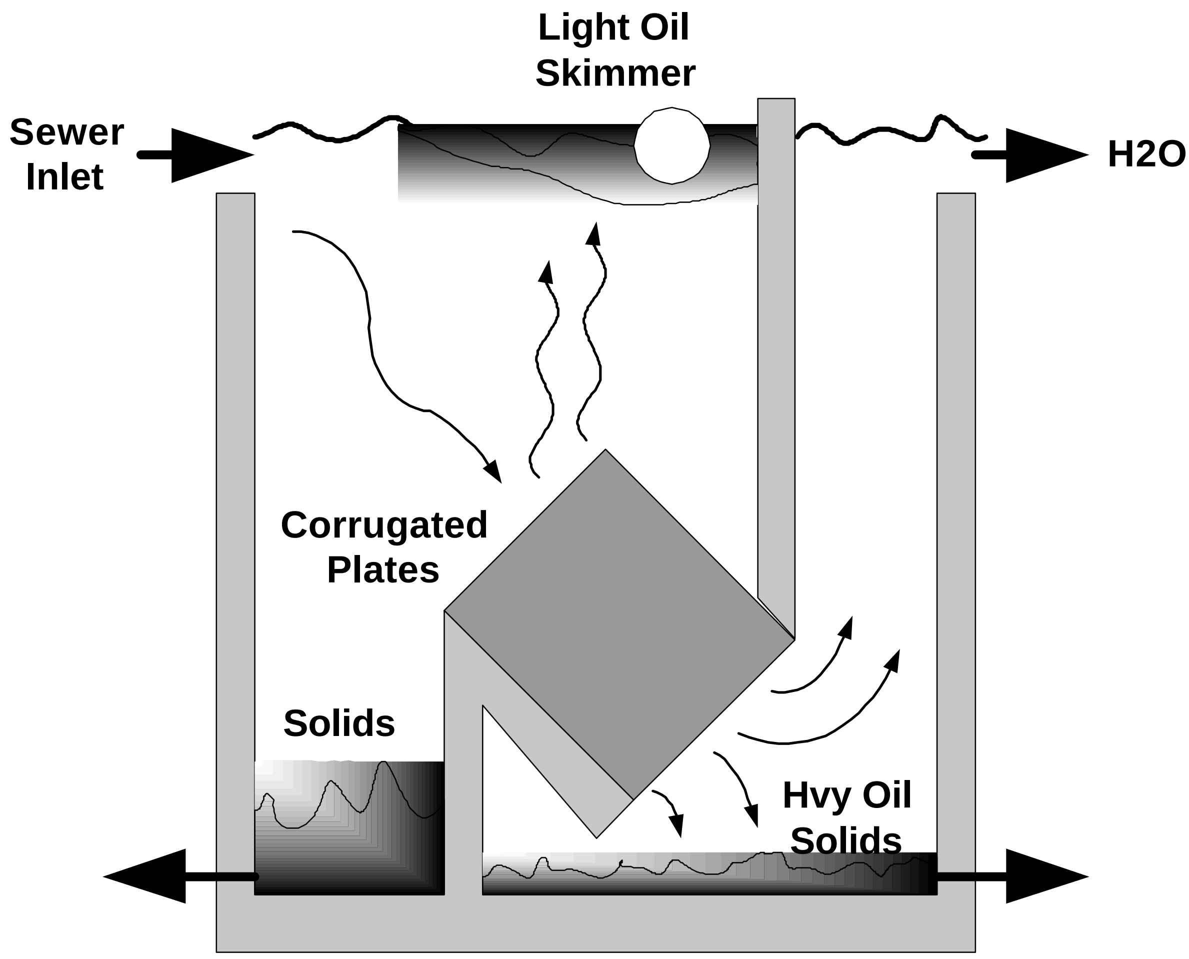

Figure 5 - Sewer Separator Simplified Layout

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