Dynamic Behaviour of Coke Drums PSVs During Blocked Outlet Condition

By

Hessam Vakilalroayaei

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

The maximum yield taken in an oil refinery can not exceed 70% without including Delayed Coker Unit (DCU) as part of unit operations in the refinery. This implies naturally a big attraction on investing of such a unit for refiners. However, during the past decades, there were few refiners included Coker unit in the refinery, due to the fact of its large capital investment with a high marginal profitability. On the other hand the technologies developed to operate a coker unit, involve a series of process steps that require highly trained and well experienced operators with a state of art of design to overcome all the challenges with this unit operation. Safety, as a prime factor of design and operation requires much attention in the design of this unit.

Among different safety consideration in the design and operation of Coker Unit, this project thesis focuses on the dynamic behaviour of Coke Drums PSV (Process Safety Valve) relief and its interaction with Blowdown section of the unit that leads also to the PSV relief of Blowdown section with change of temperature versus time during the first 15 minutes that is considered as the time required for operators intervention.

The main findings in this thesis are about the complications in the design aspects of delayed coker unit as well as the importance and role of safety of operation of this unit. It also gave me an insight of cascade relief during the upset condition in an online coke drum and the importance of a reliable piping system to handle the hydraulics as well high temperature conditions.

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Chapter 1:

1.1. Introduction

Delayed Coker Unit (DCU) as one the most complicated unit operations in each refinery plant, needs plenty of design expertise and operation experience to get together and make such a state of art work smoothly. Due to its semi-batch operation nature at the Coker Island section and Closed Blowdown section that operate at high temperature with hydrocarbons at auto ignition condition as well as possibility of coking in the piping/equipment due to misoperation and/or poor design, therefore safety in this unit is the prime factor. There are different layers of protections required to be identified in different parts of this unit (through various safety analysis that includes multiple disciplines in design and operation as well as maintenance). The main goal of advocating these different layers of protections is to ensure a safe operation of this unit in the refinery.

This thesis is intended to provide a clear understanding about the features of safe design and operation in the Delayed Coker Unit. It starts with this chapter to explain the importance of DCU in a refinery plant as well as its history of design and operation. Chapter two will continue with detailed process description/operation accompanying with some sample Block Flow Diagram/Process Flow Diagram and P&IDs. Chapter three will emphasize on troubleshooting rules as well as focus on one of the most interesting safety concerns to elaborate all the possible and credible scenarios of upset conditions in the coke drums operations (i.e. all possible ways of blocking the open path flow of hydrocarbon vapors from online coke drum into the main Fractionator that lead to overpressure the online coke drum and hence Process Safety Valves (PSVs) will open to prevent any uncontrolled disaster)and explains all the possible ways of controlling these upset conditions. Chapter four will be continued as to develop the simulations and calculations of PSV relief mainly for governing cases. It also discusses about the safety aspects in design and operation of delayed coker unit with a focus on the coke drum design and operation. Chapter five will provide a summary of the findings of this thesis and offer appropriate conclusions.

1.2 Literature Review

Generally speaking, Delayed Coker Unit operation is one of the very interesting topics for many researchers to study different features of this unit. Although the process itself is not that much complex unit like FCCU or ISOMAX that involve catalytic reaction and regeneration processes, due to its semi batch process feature at high temperature conditions, it is considered as a very challenging operational/maintenance units and much effort are made in design for ease of safe operation and maintenance of such a unit. Some licensors in the past, tried to change the semi batch process into continuous process with continual removal of coke materials from the coke drums to eliminate the offline mode of operation coke drums and there are still some Coker Processes in some refineries that operate in the fluidized conditions (similar concepts done in FCCU) but the challenges shown in this type of process never made it attractive to bring the attention of researchers into this point of view and main focus still remained on the improvement of the processes in design, operation and maintenance to for ease of safe operations in Delayed Coker Unit.

The main topics of interest to many researchers (in the brackets below) in this unit can be categorized:

- **Dynamic Model of DCU [1,2,3]**

  These papers are mainly discussing about different feature of dynamic behaviour of coke drum operations and methods of predicting the behaviour of different parameters that has impact on the yield and throughput as well as quality of the products in this unit. This thesis is looking into a new window which discusses the dynamic behaviour of online coke drum during an upset condition that the normal path flow of exit vapor from online Coke Drum is blocked and hence the online coke drum will get over pressured and finally it will relieve to closed Blowdown section.

- **Safety [4,5,6,7,8]**

These papers are all discussing about different safety features of operation of delayed coker unit and the ways of improving the safety of operation. There are many steps of operation that needs direct involvement of operators in an environment that potentially any mistake can lead to the exposure of hot and auto ignited hydrocarbons to the environment and this easily would result in explosion and fire. The Current thesis discusses the importance of safe release of hot hydrocarbons during upset conditions.

- **Process Control Strategies [9,10,11,12]**

These papers are mainly focusing on process control strategies that help to maintain a stable operation during each cycle as the coke drums switching has immediate impacts on product flow patterns as well as liquid levels. Therefore control valves should have a reasonable range of operability to deal with these circumstances at each cycle. Since the subject of thesis is about the PSV relief during the blocked outlet conditions of online Coke Drum, therefore, this thesis will not take any credit of control system to moderate or retard the relief conditions. However, the control system will rapidly show the changes of operating conditions to the operators for their prompt interventions.

- **Process performance and yield [13,14,15,16]**

These papers are discussing on the process performance from two different views. In one view it relates to the design of DCU with the nature of VTB (Vacuum Tower Bottom) feed whether to maximize the HCGO (Heavy Coker Gas Oil) or type of Coke residue in the coke drum after each cycle. The other view is discussing about the impact of coke drums switching on the quality and yield of products as well as equipment operations.

- **Optimization [17,18,19,20,21,22,23,24]**

These papers are discussing on different optimization goals that can be defined for the operation of a delayed coker unit. Decision on one kind of product maximization (for example type of coke residue) would have an impact on operating pressure of coke drums and hence design pressure that will lead to higher total capital investment (TIC). Therefore, there are many ways to design DCU for one or the other optimization objective that consequently define the constraint functions and almost none of them are linear.

1.3 IMPORTANCE OF DCU IN A REFINERY

Nowadays many oil companies are planning to expand or upgrade their existing refineries in the North America and Europe with addition of a fairly complex unit called Delayed Coker Unit (DCU). Figure 1.1 shows a simplified process scheme of this unit.
This unit operates in two sections; one section is semi-batch which has a cyclic nature that includes of at least two coke drums, one online mode and the other offline mode. The online drum receives the hot oil vapor feed (mainly VTB-Vacuum Tower Residue) at almost 940ºF and fairly moderate pressure (varies 15 to 65 psig on different design

objectives) at the bottom of coke drum to start thermal cracking and produce coke and hydrocarbon vapors. The produced hydrocarbon vapors that include from very light gases up to heavy Coker gas oil range will be directed to the main Fractionator for further fractionation.

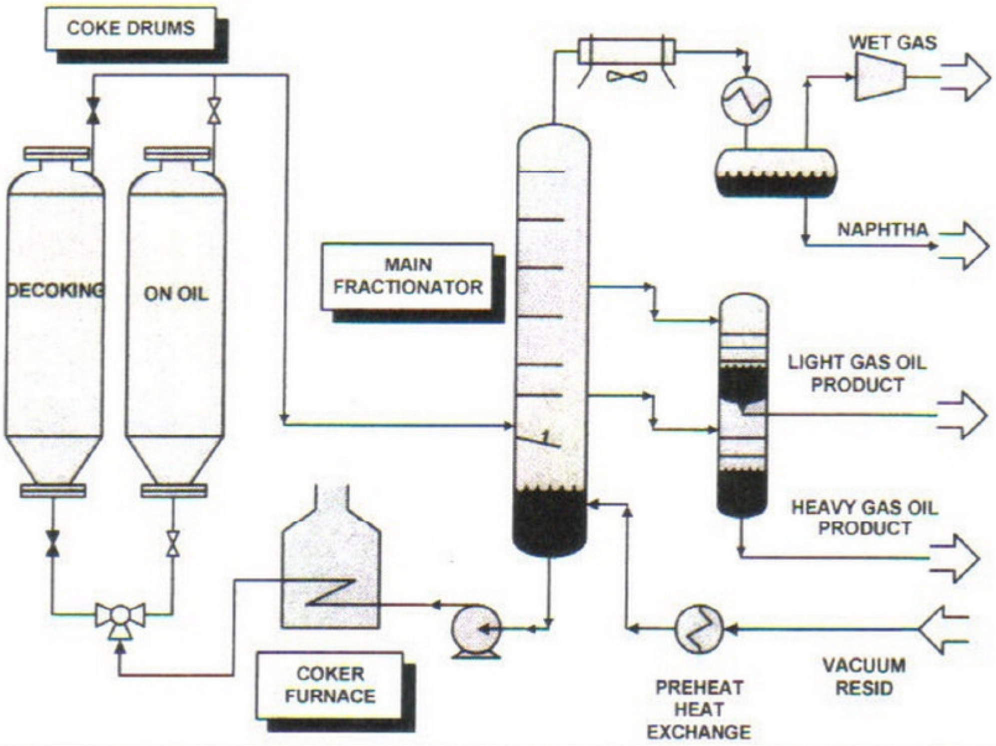


Figure 1.1- Simplified Delayed Coker Process Scheme

Since the online coke drum (Coking Mode) has a certain capacity, once the produced cokes level reaches to a certain limit, it should be switched to offline (De-Coking Mode) and the previously offline drum would also be ready by that time to get into online mode immediately. Normally the cycle time designed for each Coke drum operation is between 15 to 18 hours to provide sufficient time for the De-Coking operations of the offline drum. The new offline drum will also get ready again for the next cycle during this cycle time that the other coke drum is in online mode and consists of 13 steps. During this period the offline coke drum is interacting with a closed blow down section to get cooled and depressurized before opening its heads from top and bottom and cleaning the drum from residual coke with a coke cutting drill that utilizes a very high pressure of 4000 psig of water to cut the porous stone-like coke. Then again it should be warmed up (to almost 650ºF for the next online cycle.

The second section is almost a continuous operation that includes a main Fractionator with its side strippers (depends on the number of cut products) as well as overhead reflux and bottoms recirculation facilities.

A constant stream is coming as VTB feed at almost 600ºF and almost 12 psig pressure while another constant stream leaves the main Fractionator through a charge pump to be forwarded into a very highly unique fired heater with specialized design. The fired heater increases the process hydrocarbon temperature up to 940ºF at thermal cracking conditions of heavy hydrocarbons. This has to be sent to the online coke drum through transfer lines as soon as possible without any coking reaction taken place in the heater tubes and transfer lines.

This is one of the most critical design proprietary to the licensors and their vendors to design and operate the heater and all piping assemblies to ensure that thermal cracking is taking place in the coke drum and nowhere else (i.e., within the transfer lines or switching valve) as this can cause severe and unscheduled shut down in the unit. That's the reason of calling this unit as Delayed Coker unit.

Although the history of DCU units is long enough in the refineries (even older than the current conversion units), but due to its requirement of a very high TIC (Total Investment Costs) thus far, it had some very limited licensors interested to develop this process or try to improve it.

However, these days due to rising prices in the oil market **(which currently suffers from some downward turbulence for a short while in the believing of author of this thesis)**, now it can pass easily its marginal profitability and is one of the most attractive refinery process units for upgrading the existing refineries. It is also worth noting that regardless of such a trend in the oil market, it was always an attractive investment in Canada, especially in Alberta, due to the nature of available oil sands reservoirs in that area. Therefore, any refinery in that area would start naturally with DCU and not crude distillation section.

Addition of such a huge super structure process not only requires highly well-trained operators to understand all modes of operations (as it is a semi batch operation at high temperature mainly with above auto ignition temperatures by nature), but also it has big impacts on all other existing refineries because almost none of its products are final and need to be routed to other existing units for further conversions/physical treatments to become marketable products.

Understanding the different modes of operations and their related safety concerns and providing the different layers of protections through analyzing with LOPA (Layers of Protection Analysis) is a major of concern during the design and development of this unit.

One of the areas of LOPA which this thesis discusses on is about the development of calculations for PSVs sizes for online coke drum. This is mainly interesting during the blocked outlet incident in the pathway of the online drum, and then the existing alternatives for relieved vapors to a sink to cool down the hot vapors at almost 870ºF before forwarding them to the flare stack in the refinery.

One of the natural alternatives for this sink is the abovementioned closed Blowdown section that should be designed properly to handle this incident while it is working in its normal mode of operations (i.e., interaction with other offline drum)

Due to importance of this part of design, this thesis is intended to present the relevant PSV calculations and its related simulations to specify the following objectives:

1. Maximum probable relief temperature
2. PSV set pressure of Blow Down tower and receiver
3. Relief loads from blow down tower and receiver at the following scenarios:

   - Coke Drum blocked outlet when Blowdown system is in quench mode
   - Coke Drum blocked outlet when blow down system is in idle or heat up mode.

This project thesis will be backed up with HYSYS simulation results to demonstrate the objectives discussed above.

1.4 HISTORY OF THE DELAYED COKING PROCESS [7]

“Petroleum coke was first made by the pioneer oil refineries in Northwestern Pennsylvania in the 1860's. These primitive refineries boiled oil in small, iron stills to recover kerosene, a valuable and much needed luminescent. The stills were heated by wood or coal fires built underneath which over-heated and coked the oil near the bottom. After the distillation was completed, the still was allowed to cool so the workmen could dig out the coke and tar before the next run.” The use of single horizontal shell stills for distillation of the crude was used until the 1880's, with the process sometimes stopped before bottoms coked to produce heavy lubricating oil. Multiple stills were used to process more fractions by running the stills in series with the first still producing the coke. In the 1920's the tube furnace with distillation columns (bubble cap distillation trays patented by Koch ushered in the modern distillation column) were being built with the bottoms from the distillation column going to wrought iron stills in which the total outside of the horizontal still was in direct contact with the flue gases.

This produced the maximum amount of heavy gas oil. Some of these units were still in operation after World War II. Operators assigned as decokers used picks, shovels, and wheelbarrows and had rags wrapped around their heads to protect against the heat.

The coke that was produced in the horizontal stills had a high density, low volatile matter (VM) content of around 8 wt%, and less than 1 wt% moisture. One problem was that ash content was high, around 1 wt% compared to under 0.2 wt% in most modern delayed cokers. Conners thought that this was due to the lack of desalting and washing of the crude oils processed at that time.

The origin of the vertical coke drum was probably from thermal cracking of gas oil for the production of gasoline and diesel fuel. From 1912 to 1935 the Burton process developed by Standard Oil at Whiting, Indiana converted gas oil to gasoline with the production of petroleum coke. Dubbs and other thermal cracking processes also produced petroleum coke. Lack of an adequate supply of crude oil and the lack of a heavy oil market caused land-locked Middle American refineries to process the heavy fuel oil (atmospheric distillation bottoms and vacuum distillation bottoms) in a delayed coker to produce more gasoline and diesel fuel. Decoking the drums was difficult. “Manual decoking was a hot and dirty job. Various mechanical devices were tried. One of the common systems employed was to wind several thousand feet of steel cable on holding devices in the drum. The cable was pulled by a winch, to loosen the coke. Coke was also removed by drilling a small hole, then a large hole, after which beater balls on a rotating stem knocked out the remaining coke.”

The first delayed coker was built by Standard Oil of Indiana at Whiting, Indiana in 1929. The development of hydraulic decoking came in the late 1930's. Shell Oil at Wood River, Illinois presented a paper on hydraulic decoking 4.0 m (13 ft) diameter Dubbs units and stated that they had patents along with Worthington Pump Company on hydraulic decoking bits and nozzles. Standard Oil of Indiana had patents on the original cutting nozzles used by Pacific Pump. A very similar nozzle is currently used in the new compact combination coke cutting unit. A pilot hole is drilled down through the coke in the drum using high pressure water, and then the coke is cut out with a drilling bit with horizontal water nozzles. Roy Diwoky while at Standard Oil Whiting was one of the key people in developing the hydraulic decoking in the 1930's. Diwoky in May 1952, while Executive Vice President of Pan Am Southern Corp. (Owned by Standard Oil of Indiana), worked with Great Lakes Carbon Corporation to produce the first needle coke in a delayed coker. Bernard Gamson, the Director of Research and Development for Great Lakes Carbon at the time, stated in a report that Diwoky was “the father of delayed coking.

Delayed coking combined a number of the features and improvements from the development of the thermal cracking process. The use of pressure as well as heat for cracking and separating the heater from the coker and the use of two drums enabled the delayed coker to operate on a continuous basis. The number of cokers built before 1955 was small, with a surge in delayed coker construction between 1955 to 1975 at 6% per year and an 11% growth rate during the 1965 to 1970 period. The growth of delayed cokers was in step with the growth of fluid catalytic cracking and rapid decline in thermal cracking. A fluid coker, similar to a fluid catalytic cracker except that fluid coke is circulated instead of catalyst, was first built in 1954 at Billings, Montana. Five more fluid cokers were built in the late fifties, and one in 1970. In 1958, the head of petroleum refining engineering at Colorado School of Mines, J.O. Ball, stated that there would not be any more delayed cokers built. Ball thought all new cokers would be fluid cokers, and that a delayed coker was just a garbage can in the refinery. Today there are 49 operating delayed cokers in the U.S. and only six fluidcokers/flexicokers.

1.5 Thesis Organization

This thesis is elaborating the path forward of understanding of DCU as one the highly complicated refinery unit operations to enhance the subject of safety and its importance in design and operation as well as upset conditions to prevent any damage to operators, assets and minimize the environmental impacts. It also focuses on the simulation and calculations of Coke PSV relief into closed blow down section.

In order to achieve this goal, different chapters are outlined to provide a comprehensive understanding of process operation in chapter 2, and then it continues to troubleshooting rules in the design of DCU in chapter3 with an emphasize on coke drum relief at upset conditions. Chapters 4 is discussing on the subject of this thesis and focusing on the upset scenarios of online coke drum as well as simulation/calculations on the PSV size, relief load and temperature increase during the relief in the time frame of first 15 minutes that operators' interventions can be happened to mitigate and finally stop the relief and its impact on the unit operation. Chapter 5 is a brief conclusion that summarizes all chapters.

Chapter 2: Process Operation

2.1 Introduction

This chapter discusses mainly on the process description as well as operational issues of running Delayed Coker Unit in the refinery. One of the main objectives of good engineering design and common practices in the operation of Delayed Coker Unit is to have a turn around cycle between 5 to 7 years of continuous operation. This mainly applies to a well designed main Fractionator to minimize the coke accumulation at the bottom section of it accompanied with continuous bottoms recirculation and filtration. On the other hand, the feed charge heater, which is the other main equipment in the unit should undergo of different online cleaning processes (on a cyclic base and planned schedule) to remove the coke residue in the heater. The cleaning process also applies to fouled materials in the VTB feed preheat exchangers while the process doesn't shut down. These requirements will specify the sparing philosophy (redundancy) as well as isolation philosophy to ensure ease of maintenance and operation in the unit [6]. Therefore, this type of design requires many safety considerations to save the operators and investments.

In the following, the process operation not only tries to elaborate the process flow but also discusses about all common operational maintenance issues to give a very good insight about the challenges in the design of such a unit. At the end, a sample Block Flow Diagram as well as many sample PFDs and a few P&IDs out of normally 200 P&IDs are attached to identify the main equipment/piping and valving system in this process for the upcoming discussions in the next chapters.

2.2 Process Description [7]:

Delayed coking is a thermal cracking process used in petroleum refineries to upgrade and convert petroleum residuum (bottoms from atmospheric and vacuum distillation of crude oil) into liquid and gas product streams leaving behind a solid concentrated carbon material, petroleum coke. A fired heater with horizontal tubes is used in the process to reach thermal cracking temperatures of 485 to 505°C (905 to 941°F). With short residence time in the furnace tubes, coking of the feed material is thereby “delayed” until it reaches large coking drums downstream of the heater. Three physical structures of petroleum coke: shot, sponge, or needle coke can be produced by delayed coking. These physical structures and chemical properties of the petroleum coke determine the end use of the material which can be burned as fuel, calcined for use in the aluminum, chemical, or steel industries, or gasified to produce steam, electricity, or gas feedstocks for the petrochemicals industry.

To understand the delayed coking process, one must understand how the delayed coker is integrated with the rest of the refinery. Delayed coker feed originates from the crude oil supplied to the refinery. Therefore, brief descriptions of each of the processing steps preceding the delayed coking unit are provided below. A basic refinery flow diagram is shown on the following page in Figure 2.1.

Crude Oil Desalting

Crude oil contains around 0.2% water in which is mixed soluble salts such as sodium chloride and other metals which are on the edge of the sphere of water. In desalting, crude oil is washed with around 5% water to remove the salts and dirt from the crude oil. The water, being heavier than the oil, drops out of the bottom, and the cleaned oil flows overhead with around 0.1% water.

Atmospheric Distillation

The desalted crude oil is heated in a tube furnace to over 385°C (725°F), just below the temperature that cracking of the oil can occur, and then flashed into a distillation column. The primary products are straight run gasoline, kerosene, jet fuel, diesel, atmospheric gas oil (AGO) and atmospheric reduced crude.

Vacuum Distillation

The atmospheric reduced crude (ARC) is then heated to around 395°C (743°F) and flashed into a vacuum distillation column that is operated at low pressures, 10 mm Hg absolute desired but more common 25 to 100 mm Hg absolute. The desired aim is to lift the maximum amount of oil boiling below 565°C into heavy vacuum gas oil (HVGO) reducing the production of vacuum reduced crude (VRC), the main feedstock to the delayed coker. The HVGO and the AGO are the principal feedstocks to a fluid catalytic cracking unit (FCCU) for the production of gasoline and diesel. Improving vacuum distillation is one of the best methods for increasing gas oil yield in a refinery while at the same time reducing the amount of vacuum reduced crude (coker feed). This enables higher refinery throughput rates to be achieved.

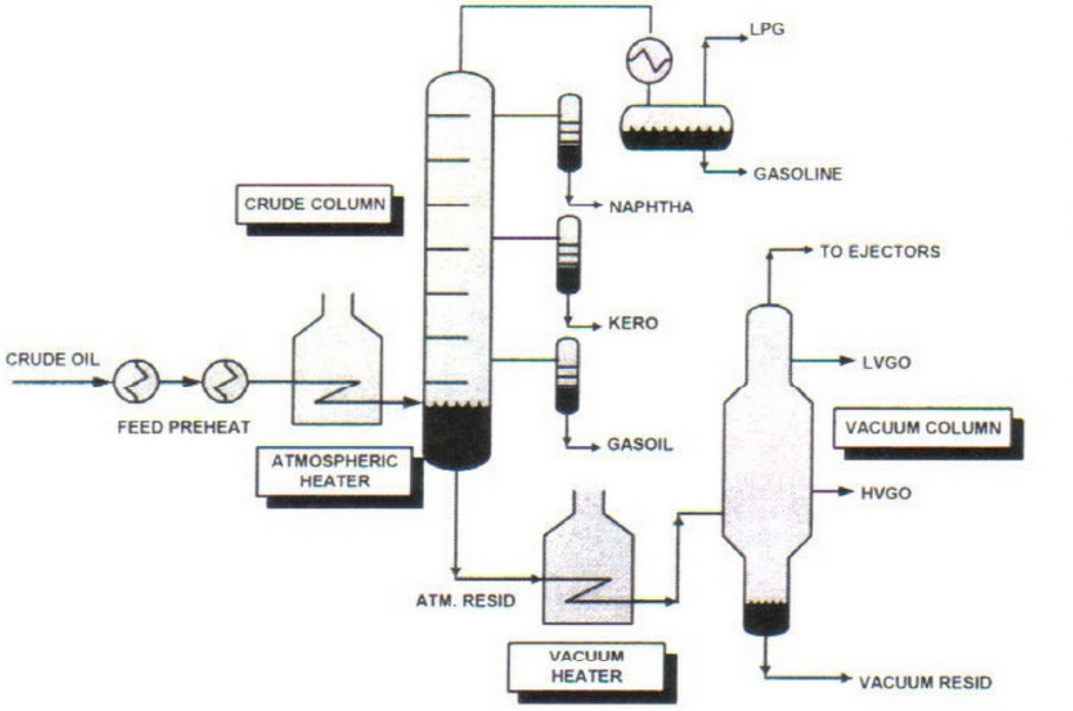


Figure 2.1- Basic Refinery

2.2.1. Vacuum Reduced Crude Processing Options or End Uses

Delayed Coking

Visbreaking - Primary function is to reduce viscosity of the oil with some production of heavy gas oil. **Resid FCC -** Residuum Fluid Catalytic cracking, metals deactivate catalyst, must use passivating chemicals to reduce unwanted reactions

Resid Hydrocracking - Feed is contacted with a catalyst and hydrogen at high temperature and pressure to remove sulfur, nitrogen, and some aromatic compounds with some conversion to lighter liquid products. **ROSE -** Residual Oil Supercritical Extraction for production of metal free gas oil, asphaltenes and resins **Propane Deasphalting / Bright Stock -** Solvent extraction of heavy lubrication oils

Road Asphalt

Roofing Asphalt - May require air blowing to increase hardness

Fuel Oil - Burner and slow RPM marine diesel

MODERN DELAYED COKING PROCESS

The delayed coker is the only main process in a modern petroleum refinery that is a batch-continuous process. The flow through the tube furnace is continuous. The feed stream is switched between two drums. One drum is on-line filling with coke while the other drum is being steam-stripped, cooled, decoked, pressure checked, and warmed up. The overhead vapors from the coke drums flow to a Fractionator, usually called a combination tower. This Fractionator tower has a reservoir in the bottom where the fresh feed is combined with condensed product vapors (recycle) to make up the feed to the coker heater.

Delayed Coking Drum Cycle

Since the feed stream is regularly switched between drums, a cycle of events will occur on a regular interval depending on the delayed coking unit feed rate, drum size, and throughput capacity. Most typical delayed cokers currently run drum cycle times of about 16 hours with one drum filling on-line while its counterpart is off-line for stripping, cooling, and decoking. Drum cycle event approximate time requirements for such a cycle are shown below in Table 1. Shortening the cycle time is one method of increasing throughput on delayed coking units. One refinery regularly runs 12 hour drum cycles and has attempted 10 and 11 hour cycles, but cycles this short are extremely difficult due to minimum time requirements for each of the steps of the drum cycle. Some of the more important drum cycle steps are described in detail in the following sections.

Table 2.1: Typical Short Cycle Coking Operations

Drum Cycle	Hours
Steam to Fractionator	0.5
Steam to Blowdown (Figure 2.3)	0.5
De-pressure, Water Quench and	4.5
Drain	2.0
Un-head Top and Bottom	0.5
Cutting Coke	3.0
Re-head / Steam Test / Purge	1.0
Drum Warm-Up (Vapor Heat)	4.0
Total Time	**16**

Drum Warm-Up (Vapor Heat): To prepare the cold empty coke drum to be put back on-line to receive the hot feed, hot vapors from the on-line drum are circulated into the cold empty drum. The hot 415°C (780°F) vapors condense in the cold drum, heating the drum to a target temperature of around 340°C (650°F). While the drum is heating, the condensed vapors are continuously drained out of the drum.

On-line Filling: After the cold drum has been vapor heated for a few hours, hot oil from the tube furnace at about 485°C (905°F) is switched into the drum. Most of the hot vapors condense on the colder walls of the drum, and a large amount of liquid runs down the sides of the drum into a boiling turbulent pool at the bottom of the drum. The drum walls are heated up by the condensing vapors, so less and less vapors are condensing and the liquid at the bottom of the drum starts to heat up to coking temperatures. A main channel is formed similar to the trunk of a tree. As time goes on the liquid pool above the coke decreases and the liquid turns to a more viscous type tar. This tar keeps trying to run back down the main channel which can coke at the top causing the channel to branch. So the limbs of the "tree in the drum" appear. This progresses up though the coke drum. Sponge coke is formed from this liquid which remains in a quiescent zone between the main branches or channels up through the coker. The liquid pools in the quiescent zones slowly turn to solid coke. Shot coke has a different type of coke structure indicating that it is produced while suspended in the vapor phase in the drum. This will be discussed in detail later in the paper.

On top of the liquid layer is foam or froth. Paraffinic type feedstocks with some sodium present foam readily compared to aromatic feedstocks which tend to have smaller foam heights. Higher temperatures greatly decrease the height of the foam. At high temperature, needle coke has very small or no foam present. After the coke drum is filled, the hot oil is switched to the new drum.

Steam-Stripping / "Hot Spots:" Steam must be flowing before the switch and immediately after the switch; otherwise, the yet unconverted liquid feed on top of the coke bed will run down the channels which will coke or solidify and plug the channels. The plugging of the channels causes problems in cooling the coke since sections of the coke bed will be isolated from the steam and cooling water by the plugged channels. This is the cause for "hot spots" and "steam eruptions" when cutting the coke. Cold water from the cutting nozzle hits the exposed hot coke which results in a steam explosion. This is particularly hazardous when the pilot hole is being cut, since the drum is filled with a large quantity of hot water. A steam explosion during pilot hole cutting can cause the hot water to erupt out of the top of the drum and has caused fatalities in the past.

Steam stripping also serves to transfer heat from the hot bottom section of the coke bed to the unconverted liquid present at the top of the coke drum. Adequate steam stripping increases the amount of recovered gas oil yield while at the same time reduces the amount of volatile matter and pitch left in the top section of the coke drum. After the steam has been flowing up through the coke bed for about thirty minutes with the vapors going to the Fractionator, the vapor line is vented to Blowdown system. Steam is increased for a short time or in some cases water is immediately introduced at the bottom of the drum which instantly flashes to steam. The steam is backed out and the flow of cooling water is gradually increased. The top vapor temperature in the drum may increase slightly at first before cooling due to the increased flow of steam up through the coker.

Water Cooling / "Drum Bulging:" The rate of cooling water injection is critical. Increasing the flow of water too rapidly can "case harden" the main channels up through the coker without cooling all of the coke radially across the coke bed. The coke has low porosity (the porosity comes from the thermal cracking) which then allows the water to flow away from the main channels in the coke drum. Porosity of delayed coke has been measured experimentally in the past by measuring water flow through cores about the size of hockey pucks cut from large chunks of needle coke from different areas of a commercial coke drum. Most of the coke cores were found to have no porosity except the coke right at the wall which had some porosity. This explains problems that have been found to occur with drums bulging during cool down. If the rate of water is too high, the high pressure causes the water to flow up the outside of the coke bed cooling the wall of the coke drum. Coke has a higher coefficient of thermal expansion than steel ($154 \times 10^{-7}$for coke versus 120×10^{-7} for steel, cm/cm/°C). This was measured in the transverse direction from a chunk of needle coke. The coefficient of thermal expansion for raw sponge coke is probably even greater than that of the needle coke tested.

DELAYED COKING UNIT HARDWARE

A basic coker operation flow diagram is shown below in Figure 2.2 to illustrate some of the delayed coking unit hardware.

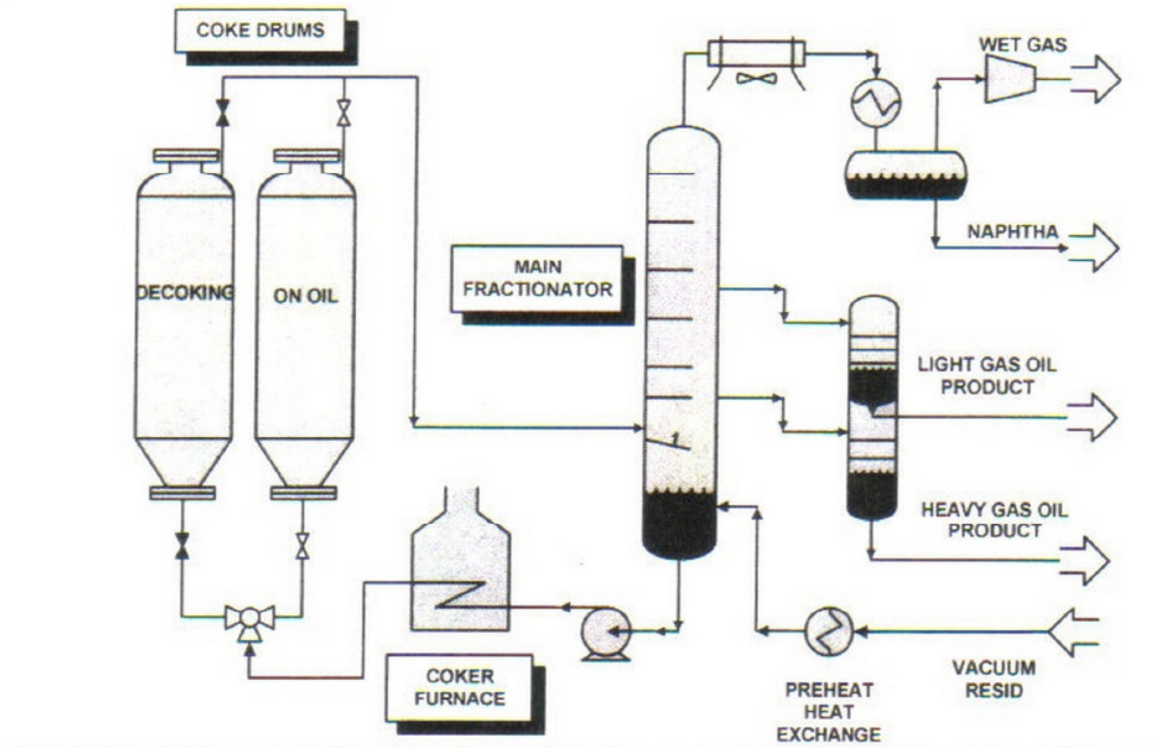


Figure 2.2- Basic Coker Operation

Figure 2.3 also shows the basic hardware for closed Blowdown section that requires relatively high reliability equipment with sufficient capacity to be able to be operated under normal conditions for cooling and warming up the offline drum as well as upset conditions to handle the hot vapor relief from online drum.

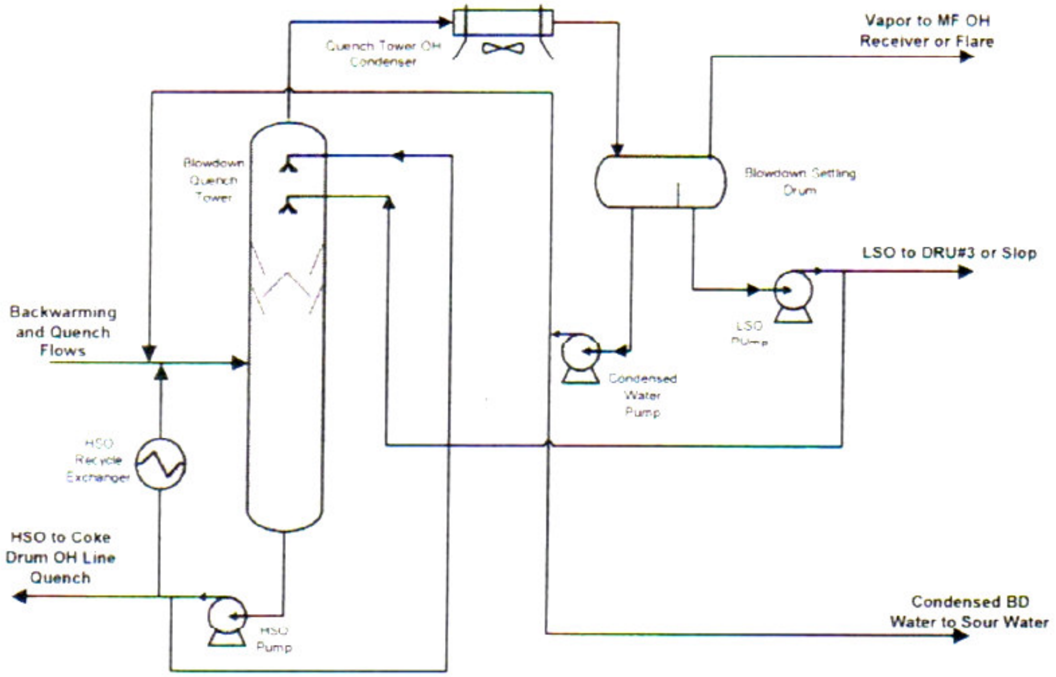


Figure 2.3- Closed Blowdown Section

Feed Preheat

In some refineries, delayed coker feed which is usually vacuum reduced crude (VRC) arrives at the coker hot, straight from the vacuum distillation unit, but in most cases, delayed coker feed is relatively cold coming from tankage. The feed is preheated by heat exchangers with gas oil products or in some rare cases by a fired coker preheater (tube furnace). In some refineries, the convection section of the main coker furnace is used to preheat the cold feed. The hot coker feed, ranging from 360 to 400°C (680 to 750°F), then enters the bottom of the Fractionator / combination tower where the fresh feed is combined with some condensed product vapors (recycle) to make up the feed to the coker heater. The Fractionator bottom provides some surge storage capacity for the incoming fresh feed, and in some units, heat is transferred to the fresh feed by flowing a split of the fresh feed above the drum overhead vapor entrance to the Fractionator. This practice usually results in increased amounts of heavy coker gas oil recycle in the furnace charge.

Coker Charge Pumps

The coker charge pumps located between the Fractionator bottom and the coker heater are normally driven by an electric motor with a steam-driven turbine pump as a backup. The pressure is in excess of 35 bars (500 psig) with a mechanical seal operating up to 382°C (720°F). See P&ID **Coker Heater Charge Pumps. Figure 2.21: 710-062d2041.**

Coker Tube Furnace

The coker tube furnace is the heart of the delayed coking process. The heater furnishes all of the heat in the process. The outlet temperature of a coker furnace is typically around 500°C (930°F) with a pressure of 4 bars (60 psig). See P&ID **Coker Charge Heater-Cell A &B. Figures 2.22 and 2.23: 710-062d2061 & 2062.**

Coker Furnace Design:

Delayed coker furnace design objectives are:

- High in-tube velocities resulting in maximum inside heat transfer coefficient
- Minimum residence time in the furnace, especially above the cracking temperature threshold
- A constantly rising temperature gradient
- Optimum flux rate with minimum practicable misdistribution based on peripheral tube surface
- Symmetrical piping and coil arrangement within the furnace enclosure
- Multiple steam injection points for each heater pass

Normally the modern-day furnace has two to four passes per furnace. The tubes are mounted horizontally on the side and held in place with alloy hangers. The furnace tubes are around 100 mm ID with 6 to 12 mm wall thickness and are at least a 9% chrome alloy. Higher alloy tubes are being used with the more rapid steam spalling and steam-air decoking methods. Aluminized tubes have been tried, but offer no advantage. Multiple burners are along the bottom of the radiant wall opposite from the tubes and are fired vertically upward. The burners for each firebox are controlled by the temperatures of tubes in that firebox only. The control thermocouple for the firebox should be three or more tubes back from the outlet to prevent coke forming on the thermocouple. The outlet thermocouple is initially read and an off-set from the control thermocouple is then used to control the furnace. Tall furnaces are advantageous since the roof tubes are less likely to have flame impingement and overheating by both radiation and convection. Normally just the radiant section of the heater is used to heat the oil for a delayed coker. The upper convection section of the coker heater is used in some refineries to preheat the oil going to the Fractionator or for other uses such as steam generation.

The typical gas burners in a delayed coker furnace are 3 MM BTU size. The burners will produce flame height of around 0.33 meter per 1 MM BTU. The average radiant flux rate should be below 9000 BTU/HR/FT^2 with cold oil velocity of 2 meters/sec (6 ft/sec) or mass velocity of 1800 kg/sec/meter^2 (400 lb/sec/ft^2) or greater. Velocity steam is added at around 1 wt% of the feed. This helps increase the velocity in the tube furnace, and reduces the partial pressure in the drum so that more gas oil product is carried out of the drum. The specific heat of the steam is less than the oil, so steam is not a good source of heat in the drum. The main use for the steam is that it keeps the velocity flowing in the tube furnace if the oil flow is momentarily is lost or decreased which reduces the chance of coking up the furnace tubes.

Heater Tube Decoking: When coke forms in the heater tubes, it insulates the inside of the tube which results in elevated temperatures on the outside of the tube. With good operational practices, coker furnace run lengths of 18 months are possible before decoking of the tubes is needed. When temperatures approach 677°C (1250°F) on the exterior skin thermocouple, the furnace must be steam spalled and/or steam-air decoked or cooled down and cleaned by hydraulic pigging.

Steam Spalling: Steam spalling was probably first practiced by Exxon but was perfected by Lloyd Langseth while operating the cokers at Arco in Houston, Texas in the 1970’s. He was able to operate a coker furnace over four years without shutting down by practicing on-line steam spalling. The only reason he had to shut down was that Texas had a law that required steam boilers to be inspected every five years. On-line steam spalling requires replacing the oil with steam in the pass and then heating and cooling the tubes to snap or spall off the coke inside the tube. The steam and coke go into the drum. The main problem is in controlling the velocity and speed of spalling off the coke. Too rapid spalling can plug the tube outlet, and too high steam velocity can erode the metal in the elbows. In one refinery, return bends failed after the second steam spalling. Steam spalling requires that the delayed coker be supplied with four passes or more. Attempts to steam spall a two-pass furnace has been tried, but the large amount of steam being handled caused problems in the Fractionator.

Steam-Air Decoking and Pigging: The usual method of decoking the tubes in a coker furnace is to take the furnace off-line, steam spall, then burn the coke out of the tubes by steam-air decoking. After steam-air decoking, the tubes need to be water washed since the salts still remain in the tubes and will cause rapid coking of the tubes. A new method of decoking the tubes is to steam spall, and then use water pressure to push Styrofoam pigs with studs and grit on the exterior through the tubes and around u-bends (even u-bends with clean-out plugs). The pigs scrape out the coke without scratching the tube walls. Early methods of pigging coker heaters left scratches on the tube walls, but with the grit-coated pigs, pigging just polish the inside of the tube wall. Pigging is faster than steam-air decoking, and refiners generally have longer campaigns on the heater compared to steam-air decoking.

Heater Tube Deposits: Iron sulfide is probably not totally removed in steam-air decoking. Coke deposits have very high content of iron, silica and sodium. Deposits recovered from return bend clean-out plugs are sometimes long cylindrical shapes and in another case looked like a thick scallop shell. These deposits were mostly sodium and calcium.

2.2.2. Transfer Line and Switch Valve

Transfer Line: The line from the furnace to the switch valve and on to the drum is referred to as the transfer line. The transfer line must be very well insulated to prevent coking and plugging. The shorter the line will result better operation with less possibility of coking in the transfer lines. Long transfer lines with many crosses and tee's used for clean outs will rapidly coke and increase the pressure on the furnace which usually results in increased fouling of the tubes in the furnace. Flanges near the drums are difficult to insulate without causing the joints to leak. Some transfer lines have a pressure relief valve in the line, but most furnaces and transfer lines are designed to withstand the maximum pressure the charge pump can produce in case of an accidental switch into a blinded valve.

Switch Valve. The switch valve is a three-way valve with ports to the two drums and a port (recirculation line) back to the Fractionator which is used in startup and shutdown. Older cokers used a manually operated Wilson-Snyder valve which was a tapered plug valve that required unseating before rotation.

See P&ID **Switch Valve. Figure 2.15.**

The newer units and retrofits are using ball valves which are usually motorized. One problem with the ball valves is that many separate steam purge lines are required to keep coke from forming on the seal bellows. If the steam purges are not monitored, they can decrease the temperature of the oil going to the coke drum resulting in high volatile matter coke being produced.

2.2.3. Coke Drums

The coke drum diameters range from 4 to 9 meters (13 to 30 ft) with the straight side being around 25 meters (82 ft) with a 1.5 meter diameter top blind flange closure and a two meter diameter bottom blind flange in which the 15 to 30 cm diameter inlet nozzle is attached see P&ID **Coke Drum A &B. Figures 2.17 and 2.18.**

Both the top blind flange and the bottom must be removed when decoking the drum. Usually the drum is constructed from 25 mm of carbon steel and is clad internally with 2.8 mm of stainless steel for protection against sulfur corrosion. The pressure ranges from

1 to 5.9 bars, typically around 2 to 3 bars. The vapor outlet nozzles, 30 to 60 cm diameter, are located at the top of the drum. Pressure relief valves are also located on the top of the drum on modern cokers. The outside of the drum is insulated with around 10 cm (4 in.) of fiberglass insulation with an aluminum or stainless steel covering. The coke level in the drum is usually determined with three nuclear backscatter devices mounted on the outside of the drum.

Overhead Vapor Lines

The vapor overhead line runs from the top of the coke drum to the Fractionator. The temperature in the line is around 443 ℃ (830 ℉) see P&ID **Coke Drum Overhead Lines, Figure 2.16.**

The temperature is decreased by about 28 ℃ (50 ℉) by injecting hot heavy coker gas oil into the line as quench oil. This prevents coking in the line. The heavy coker gas oil is a wash oil coating the inside of the pipe. If the liquid layer dries out, coke starts to form. Some refineries leave the insulation off the overhead lines to help drop the temperature and keep the inside wetted. Prevention of coke in the line is important since this will increase the pressure in the coke drum thus increasing reflux of gas oil in the drum. Decreasing coke drum pressure increases liquid yield (decreases coke yield). Also, high pressure drops in overhead lines can cause foaming in the coke drum during the drum switch. Vapor line sizes are very large in order to obtain the minimum amount of pressure drop. One refinery used two 760 mm (30 inch) vapor lines in parallel.

Antifoam Injection System

Injection of silicon antifoam should always be furthest away from the vapor overhead line outlet at the top of the drum to prevent silicon from being carried overhead into the vapor lines to the Fractionator see P&ID **Coke Drum A & B. Figures 2.17 & 2.18.**

The heaviest possible antifoam that can be handled in the refinery should be used. Lower viscosity antifoams appear to break down at lower temperatures and are not as effective. Usually a carrier stream is used to carry the antifoam into the drum;

heavier carrier material would not be as easily flashed off in the drum. Several refineries are using less antifoam and having fewer problems with foam since starting continuous injection of antifoam. A Dow Chemical Company representative stated in 1981 that it is easier to prevent foam than it is to kill foam. Also, when foam is broken down, it still leaves a mist which can cause coking in the bottom of the Fractionator.

2.2.4. Coker Fractionator

The Fractionator or combination distillation tower separates the coker overheads into gases, gasoline, diesel, heavy coker gas oil (HCGO), and recycle **(see P&IDs Coker Fractionator-Middle Part, Figure 2.13** and **Coker Fractionator-Bottom Part, Figure 2.14).**

An oversized Fractionator can be used to maximize the amount of diesel product and minimize the heavy coker gas oil to the FCCU. Hot overhead vapors can cause coking in the lower section of the Fractionator if trays are not kept washed (wet). The major amount of heat is removed in the heavy coker gas oil section by trapping out the oil and then extracting the heat with heat exchangers or steam boilers. This pump-around HCGO is then pumped back into the tray above the trap-out tray. Some of the HCGO is sprayed below the trap-out tray to wash and cool the hot vapors. Trap-out trays can be used to catch some of this oil and reduce the amount of recycle oil going back to the furnace. Packing can be used in fractionators to reduce the pressure drop, but it is critical to keep the packing wet to prevent coking in the packing. The pressure in the Fractionator and also the coke drums is controlled by the gas compressor at the top of the Fractionator.

The fresh feed from the vacuum distillation (VRC) should go directly to the bottom of the tower since the effective temperature of distillation is higher than in the Fractionator. Originally when some cokers were designed to coke atmospheric reduced crude, the feed was sprayed into the Fractionator above the vapor inlet to fractionate out more light ends in the feed. If VRC is injected above the vapor it condenses out part of the HCGO into the bottom of the Fractionator increasing the recycle to the coker furnace. The bottom of the Fractionator should be operated at as high a temperature as possible without causing coking in the bottom in order to keep the tube furnace duty low. Normally the temperature in the bottom ranges from 343 ° C (650 °F) to 382 °C (720 °F) without coke formation in the bottom of the Fractionator. A slotted stand pipe in the bottom of the Fractionator feeds the furnace charge pump.

2.2.5. Hydraulic Coke Cutting System

Cut Water Pump High pressure water is used to cut the coke out of the drum. Water pressures range from 86 bars (1250 psig) to 275 bars (4000 psig) and flow rates range from 2.8 cubic meters per minute (750 GPM) to 4.7 cubic meters per minute (1250 GPM). Cut water pumps are multistage barrel type or split case multistage pumps which were originally developed for feed water pumps for steam boilers. The pumps are usually powered with an electric motor, but some older units use steam-driven turbines.

Cutting Equipment Derricks are built on top of the drum so that the drill stem (5 to 6 inch extra heavy pipe) can be moved with a winch and cable. The high pressure water flows through an API 10,000 psi drilling hose to the top of the drill stem. The drill stem is rotated with an air motor at the top through a rotary joint. The cutting nozzles are the pilot bit with down facing nozzles and the cutting bit with nozzles facing outward. New units have both nozzles incorporated into a single drilling head.

Coke Cutting Technique A pilot hole approximately one meter in diameter is drilled from the top of the drum to the bottom. The pilot hole must be cut down through the coke with minimum weight on the bit, since if pushed; the bit can follow the main channel in the coke drum, bend, and stick the drill stem in the coke. After completing the pilot hole, the pilot bit is changed to the cutting bit, and the bottom of the hole is belled out and opened up to around two meters in diameter to prevent plugging. The bit is then pulled to the top of the drum and cutting begins by spiraling downward at four to six RPM with vertical movement of one-half meter per revolution of the drill stem. Usually a vertical four meter section will be cut by moving the drill stem up and down until the coke is all cut out of the section. Normally around 15 to 20 minutes are required to drill out the pilot and three to four hours to cut the coke. The coke can be cut directly into rail cars, cut into a crusher car and the coke pumped hydraulically, or cut into a pit or pad with cranes or end loaders moving the coke.

2.3.Sample Block Flow Diagram (Figure 2.4)

This block flow diagram shows in a snapshot all the flow of streams into or out of each section of delayed coker unit. The centre part of this block flow diagram is the main Fractionator as the heart of unit that produces many draw off streams for further processing in the same unit (e.g. Vapor Recovery Unit) or other refinery units (e.g. ISOMAX, UDD, Unifiner, etc.) as well as pump around circuits.

2.4. Sample PFDs

- **Furnace and Coke Drum Section (Figure 2.5)**

This PFD shows the flow direction from main charge pump and its split among the heaters.

- **Main Fractionator Section (Figure 2.6)**

This PFD shows an overview of main Fractionator and its inflows and outflows.

- **LCGO/HCGO Product Section (Figure 2.7)**

This PFD shows the stacked side strippers of two main draw offs in the middle section of main Fractionator.

- **Wet Gas Compressor Section-Part 1 (Figure 2.8)**

This PFD shows the Main Fractionator vapor overhead flow that includes the overhead condensers and receivers.

- **Wet Gas Compressor Section-Part 2 (Figure 2.9)**

This PFD shows the flow direction of wet gas outgoing from overhead receivers into the Wet Gas Compressor.

- **Absorber/Stripper Section (Figure 2.10)**

This PFD shows the split of overhead receivers drum into vapor/liquid and directing the vapor into absorber and liquid into stripper for further rectifications.

- **Debutanizer Section (Figure 2.11)**

This PFD shows the first stage of overhead gas coming from absorber to separate the C4 +.

- **Closed Blowdown Section (Figure 2.12)**

This PFD shows an overview of closed Blowdown column and its incoming/outgoing streams.

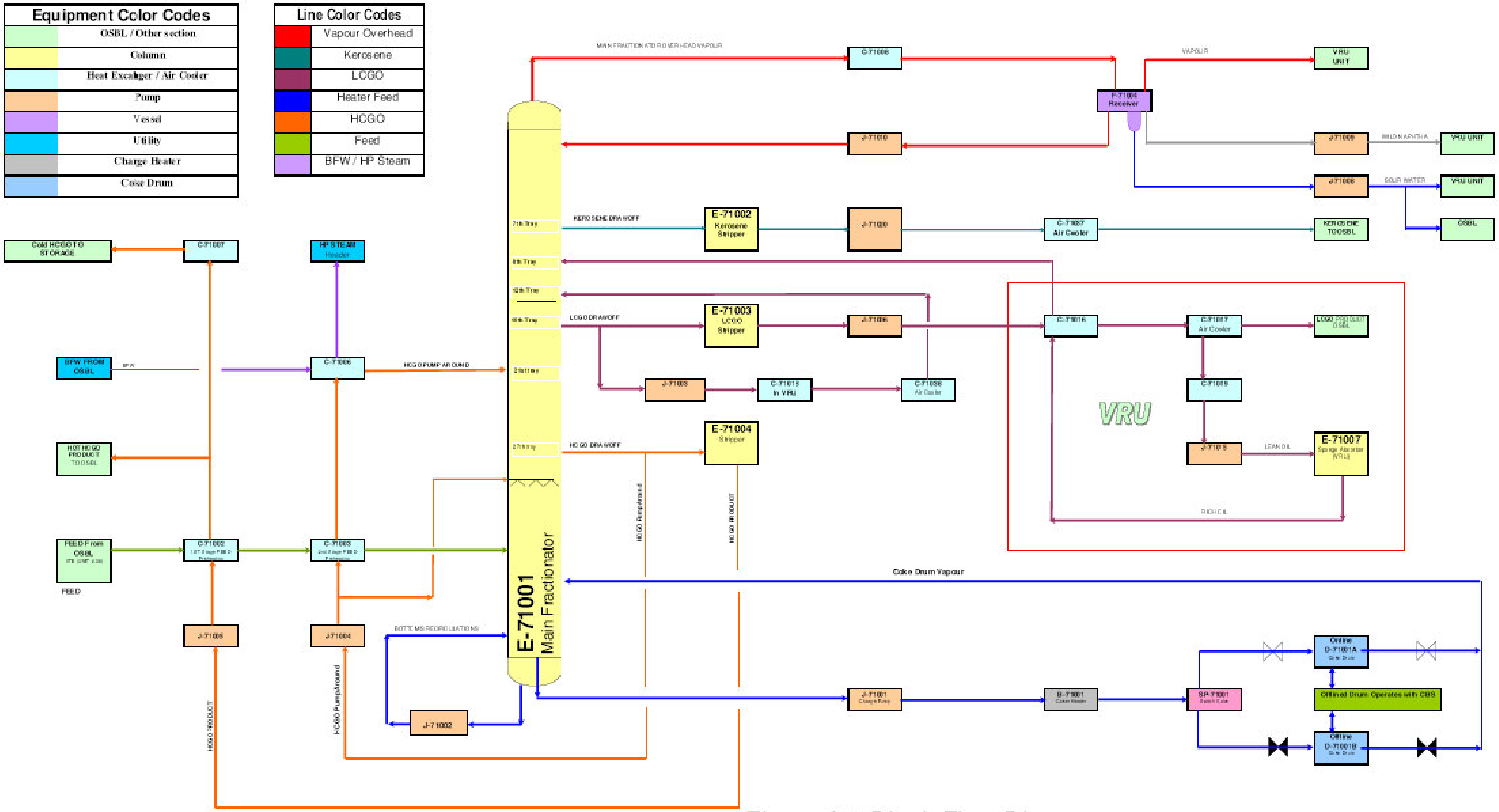


Figure 2.4 Block Flow Diagram

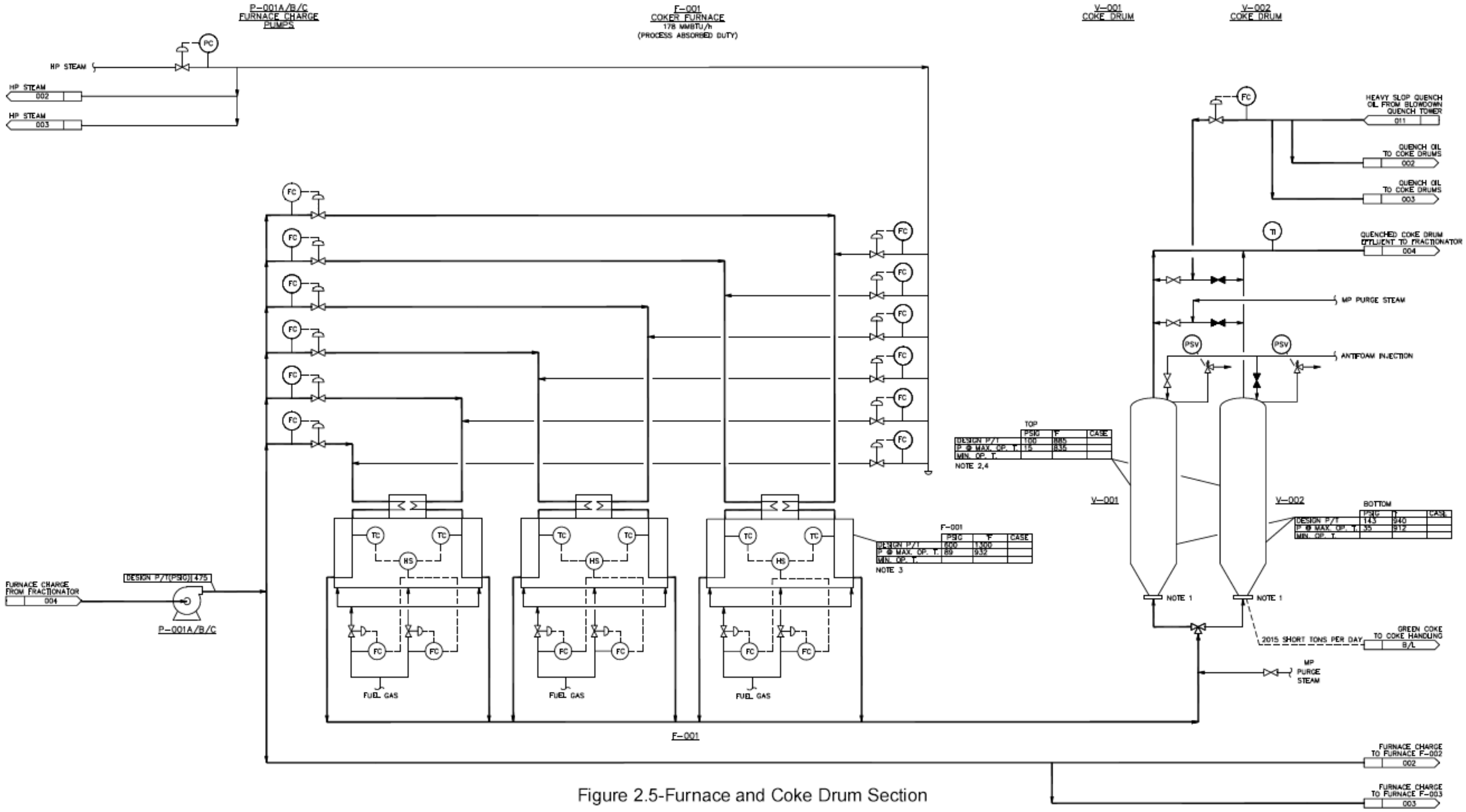
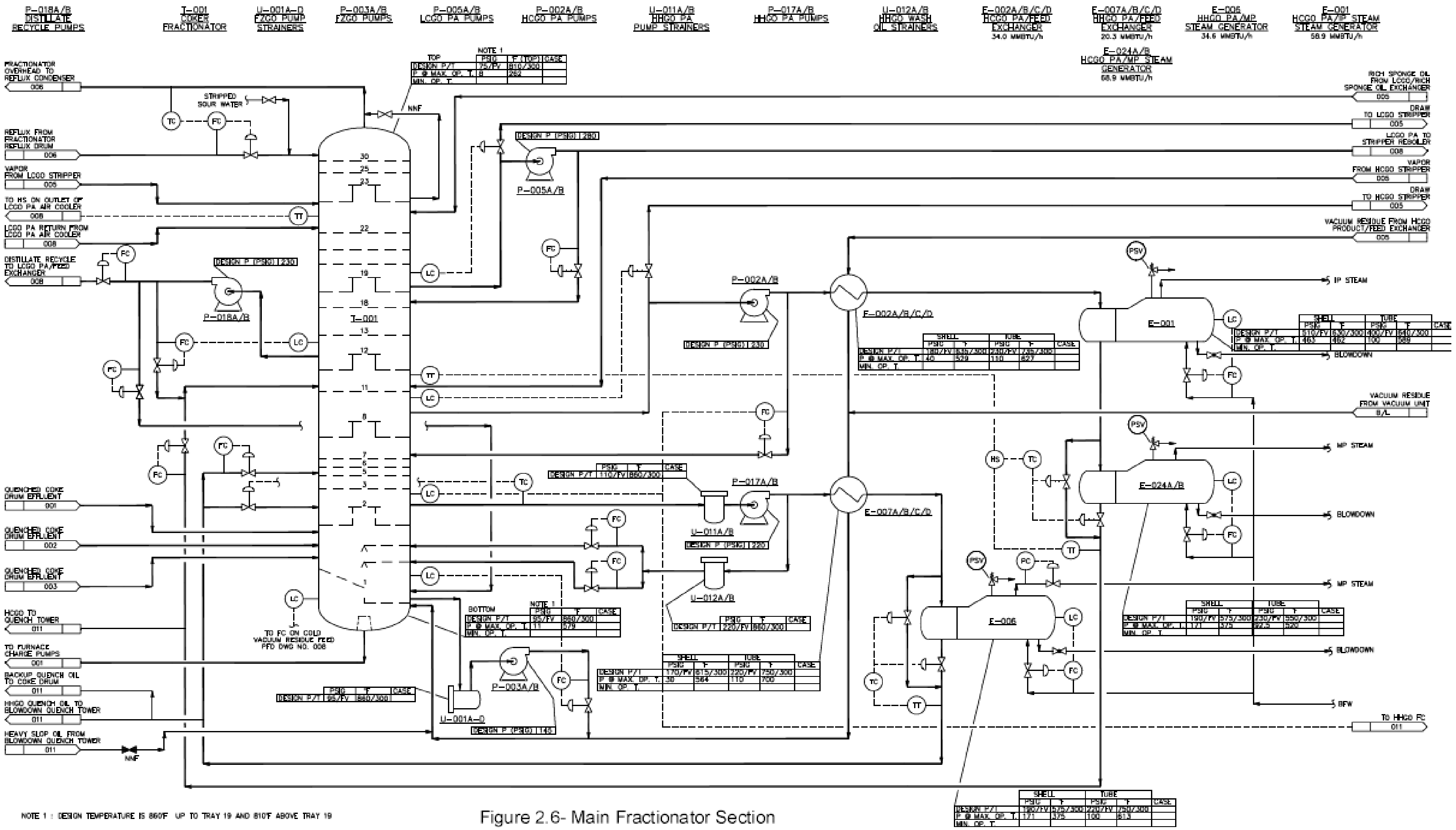


Figure 2.5-Furnace and Coke Drum Section



NOTE 1 : DESIGN TEMPERATURE IS 860°F UP TO TRAY 19 AND 810°F ABOVE TRAY 19

Figure 2.6- Main Fractionator Section

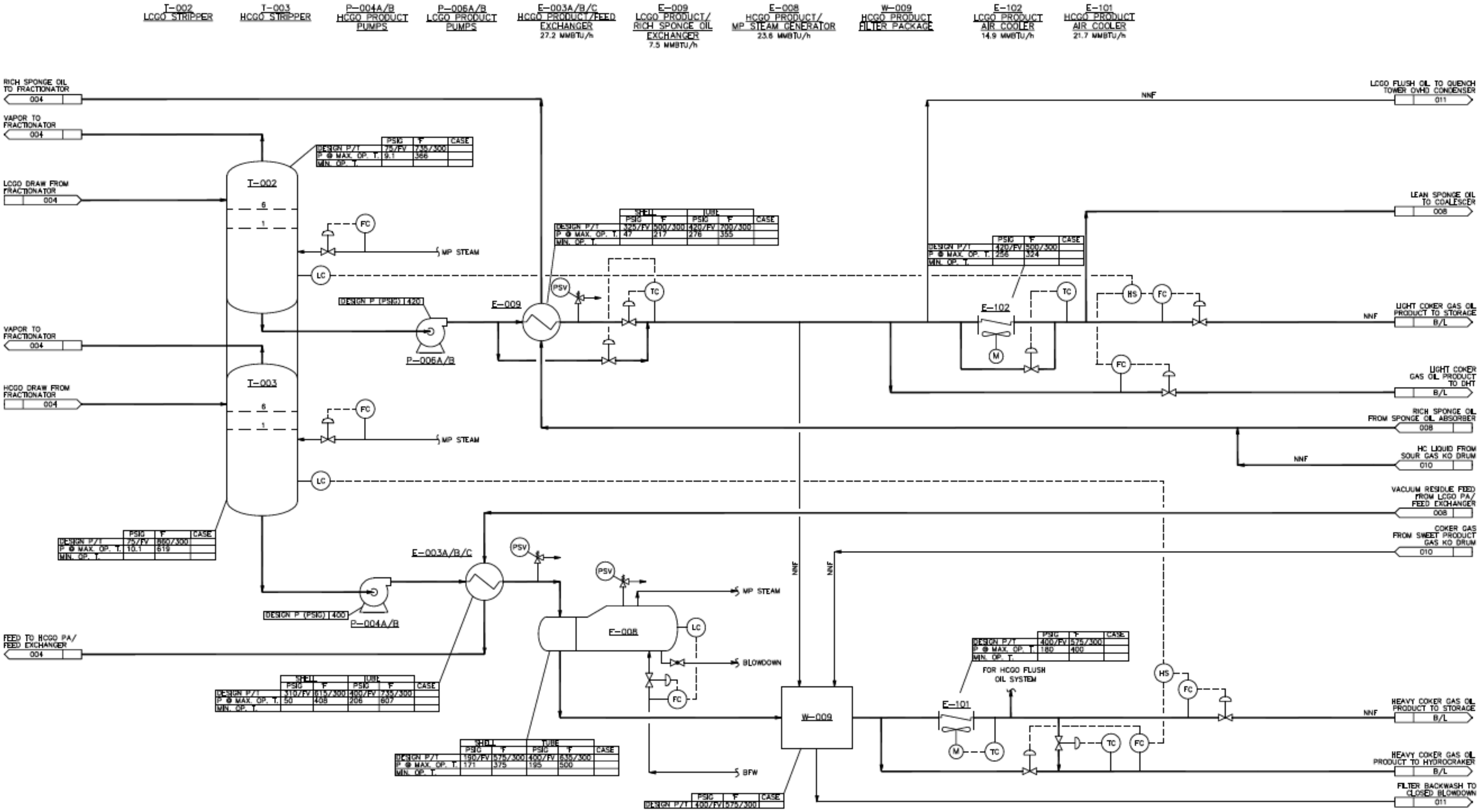


Figure 2.7-LCGO/HCGO Section

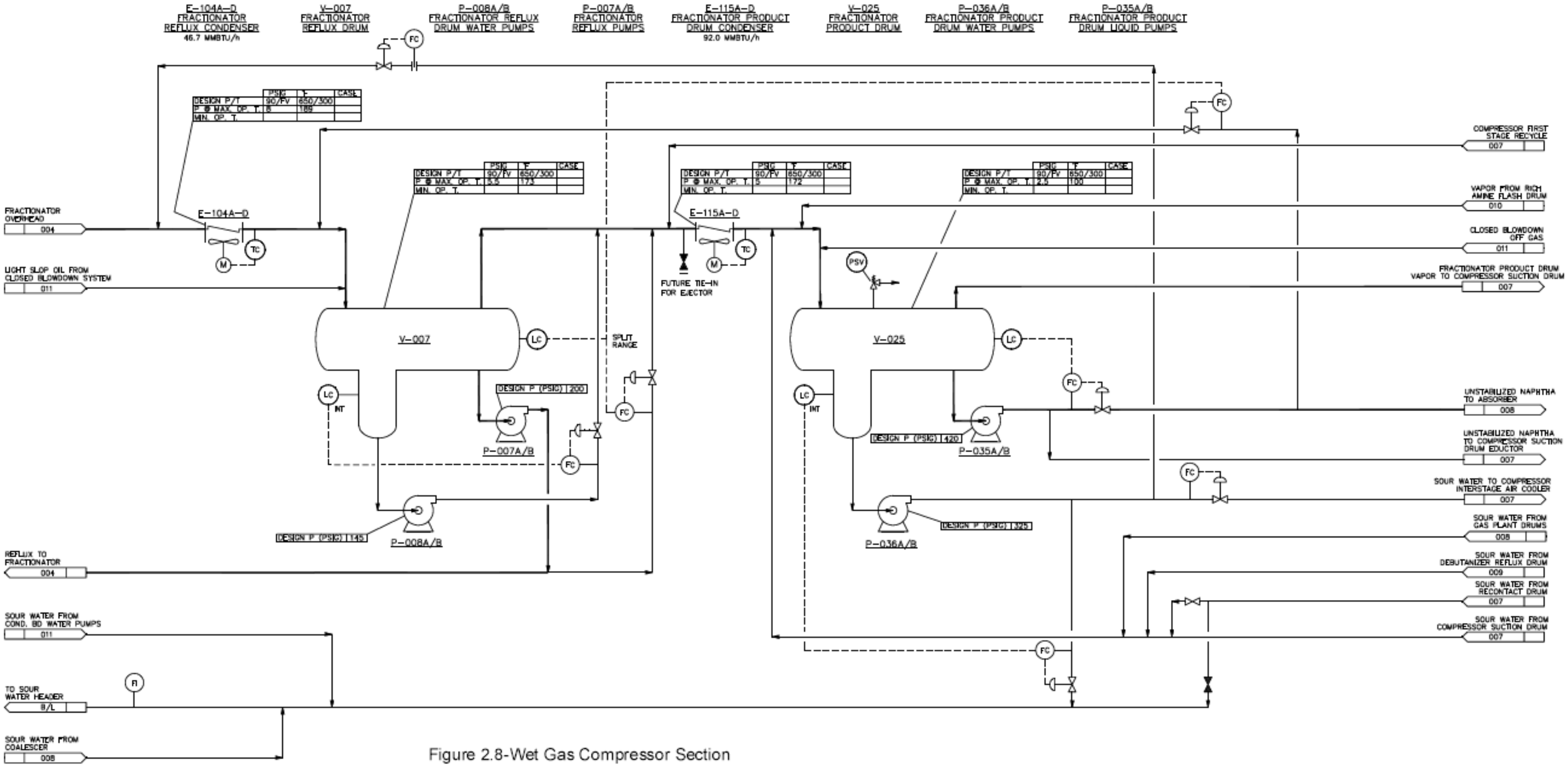


Figure 2.8-Wet Gas Compressor Section

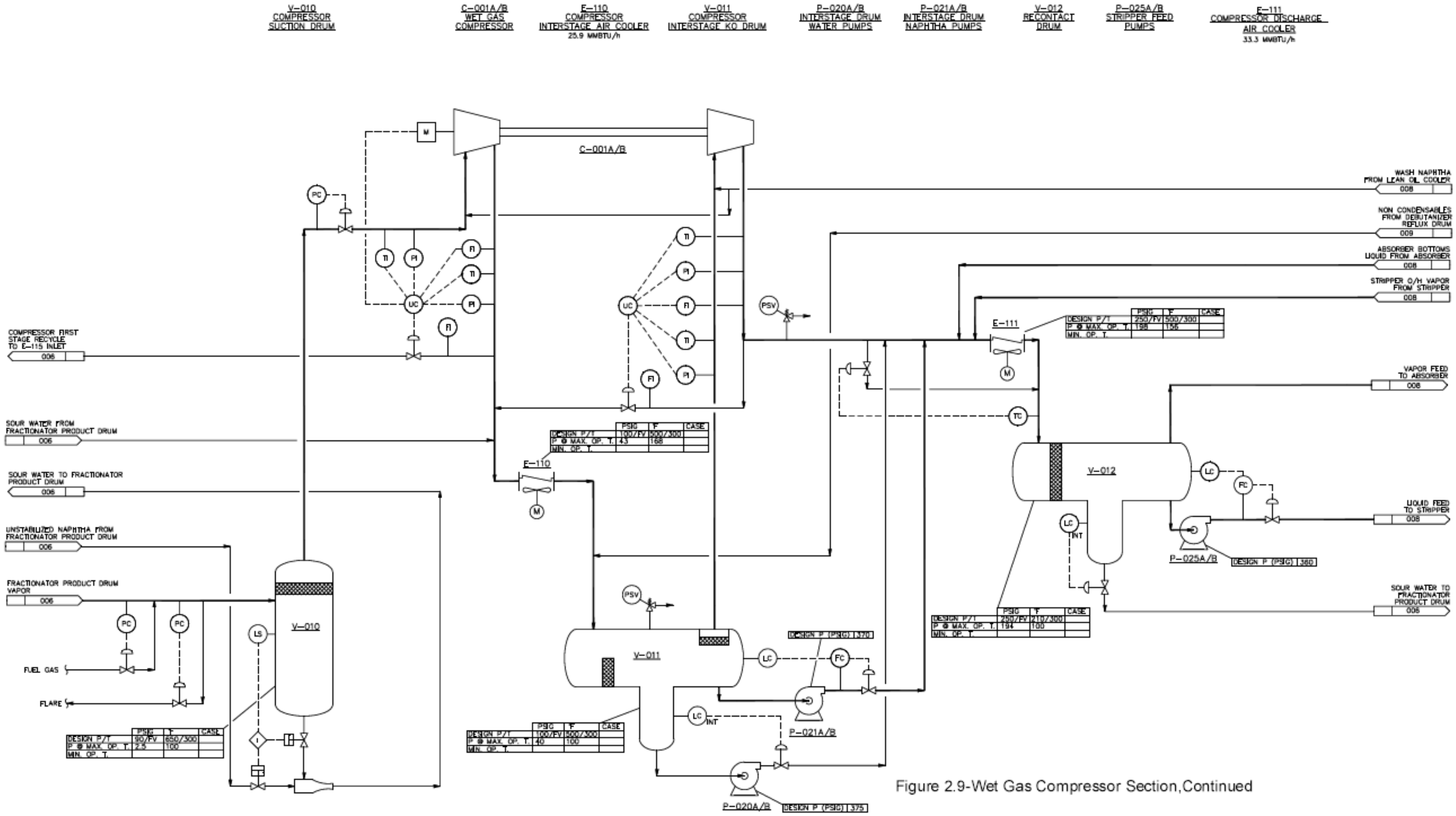


Figure 2.9-Wet Gas Compressor Section,Continued

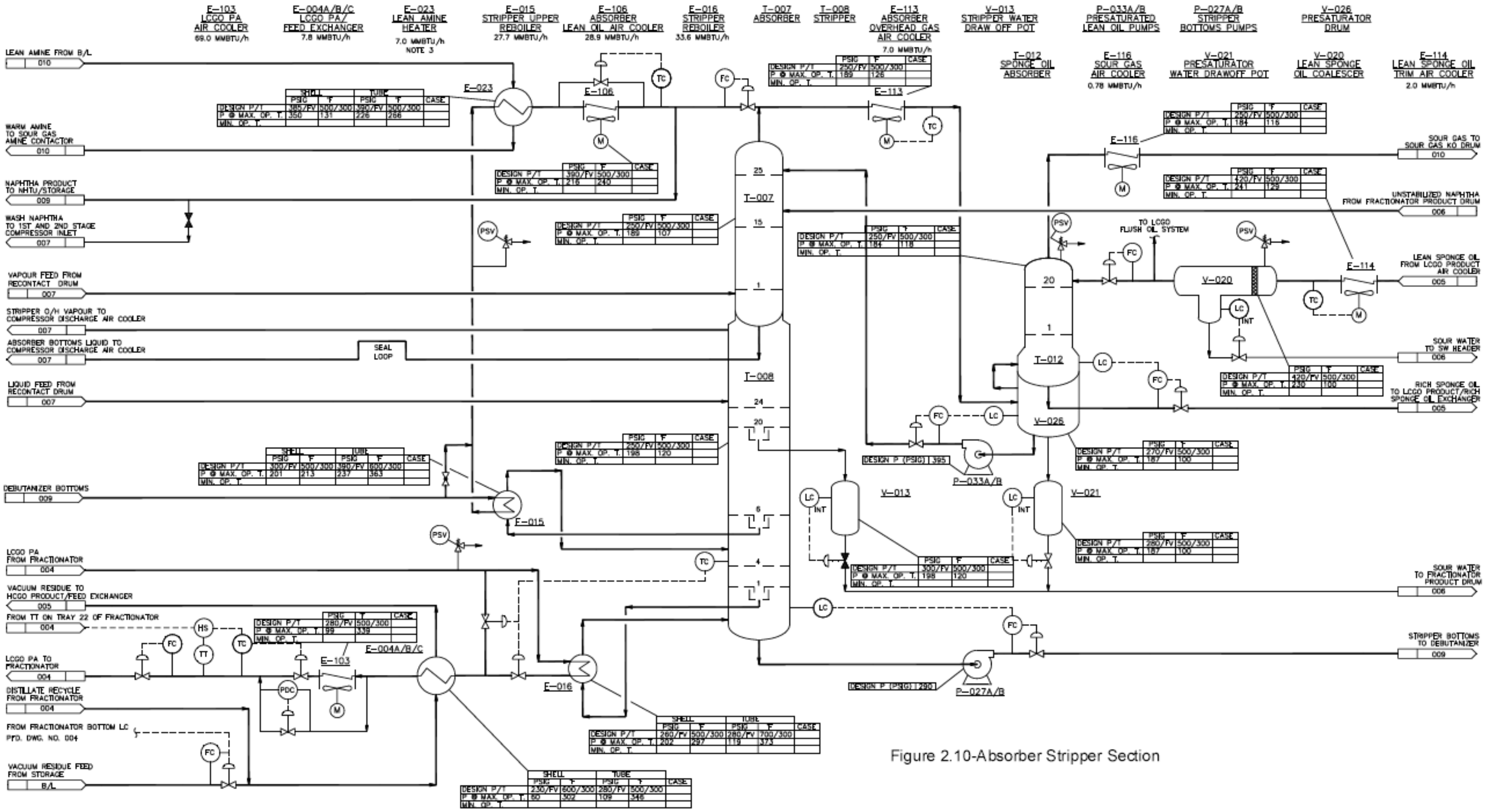


Figure 2.10-Absorber Stripper Section

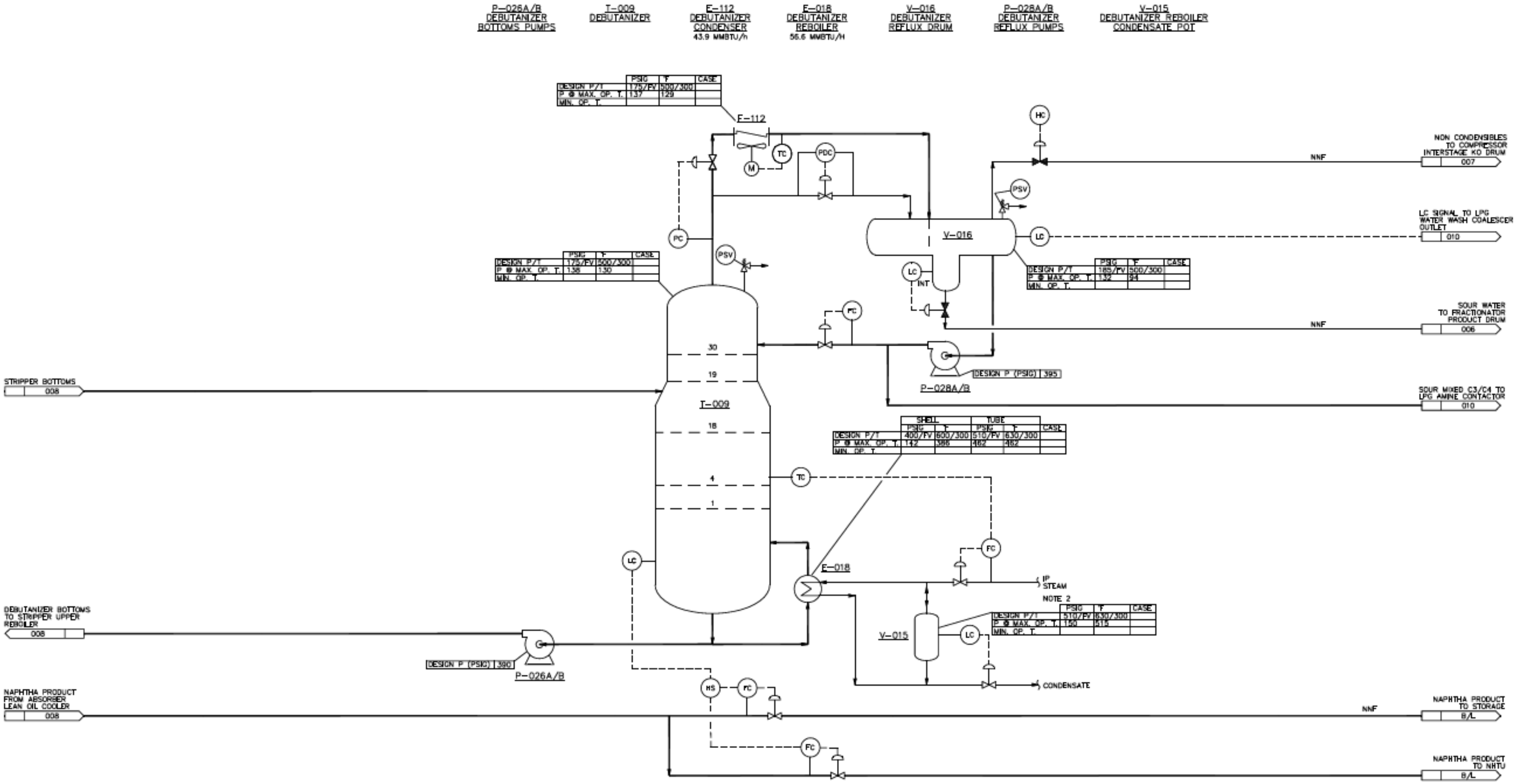


Figure 2.11- Debutanizer Section

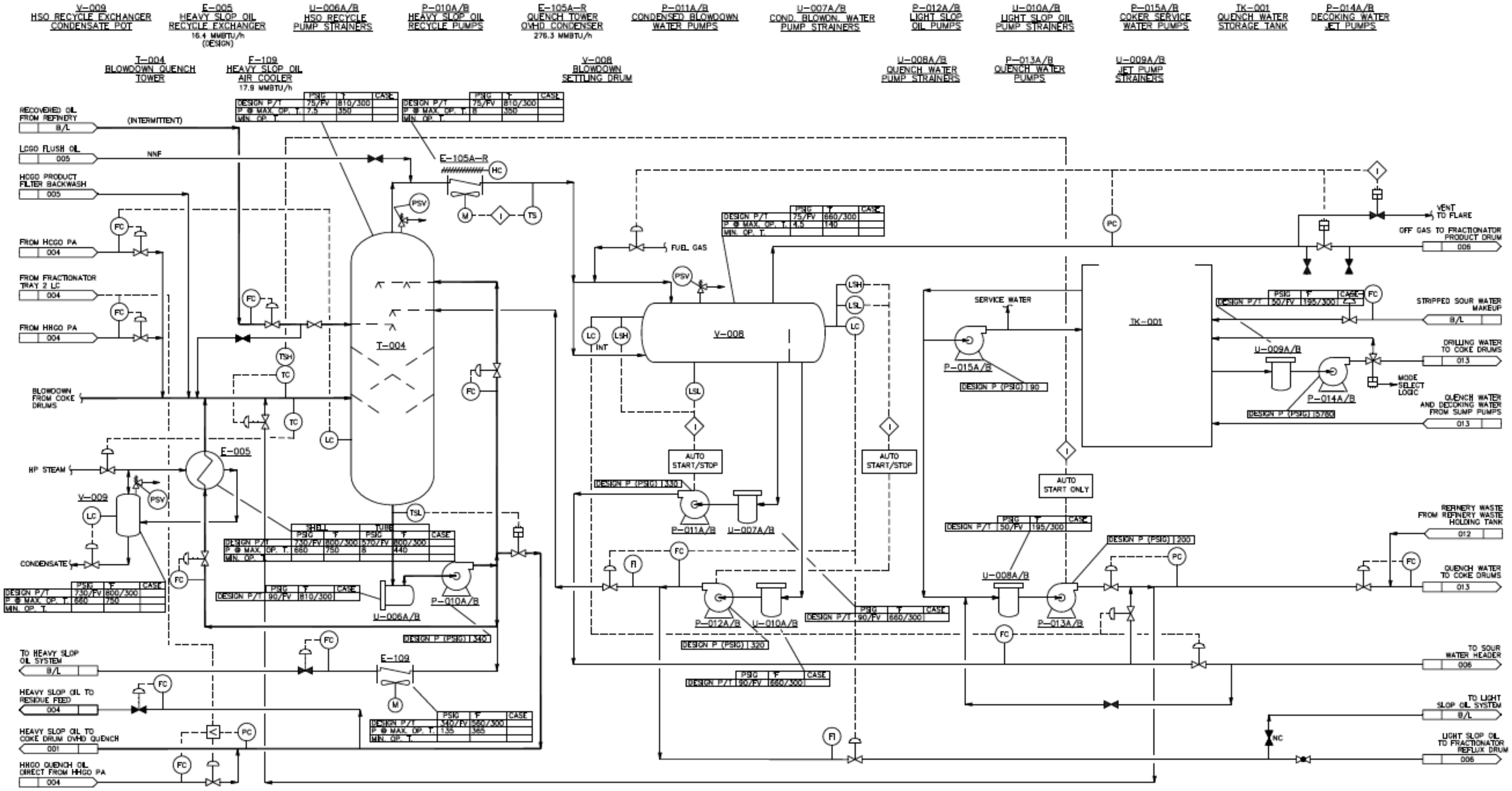


Figure 2.12-Closed Blowdown Section

2.5. Sample P&IDs

- **Coker Fractionator-Middle Part (Figure 2.13)**

This P&ID shows the detail piping and instrumentation of middle part of main Fractionator that mainly includes the HCGO draw off to split into HCGO product and Pump around that maintains a main source of continuous heat removal from main Fractionator which is coming from Coke Drum overhead vapor. Any disruption of this draw off will result to rapid overpressure of main Fractionator and hence PSV relieves.

- **Coker Fractionator-Bottom Part (Figure 2.14)**

This P&ID shows the detail piping and instrumentation of bottom section of main Fractionator that mainly includes two important circuits. The first circuit is the draw off from a chimney roof type porous filter to supply to charge pumps. The other circuit is the continuous recirculation of bottoms of main Fractionator to remove coke fines on a continuous basis with basket filters on the suction side of its recirculation pump. This circuit will help a lot to increase the turn around cycle of a coker unit for up to five years.

- **Switch Valve (Figure 2.15)**

This P&ID shows the detail piping and instrumentation of the bottom part of coke drums structure. It includes the piping system to both online and off line drums plus all different utility supplies as well as drain system for different modes of operation of offline drum. In this P&ID the valves and their open/close status for each step of operation plays an important role in the safe operation. Therefore DCS and even higher level of safety (PCS) are in charge to monitor the valves status and maintain a set of permissive to proceed to the next step. There are rigorous procedures in place to override the logic of operation of the valves. This P&ID also shows the specialized four way valve the main the flow of feed from heater into only one of the coke drums at any time. Most of the valves using in this P&ID are specialized exotic type of material with continuous steam purge to clean the valve from coke fines as the circuit is highly susceptible of coke fine formation and will result of very rapid malfunction of the valving system. Section 4.5.2 will discuss in detail about mode of operations of piping and valving system in this P&ID.

- **Coke Drum Overhead Lines (Figure 2.16)**

This P&ID shows the detail piping and instrumentation of top part of coke drum structure. It includes the piping system of both online and offline coke drums on the top. The importance of piping and valving system as well as the control logic of their operation in this P&ID is as important as figure 2.15. Most of the valves using in this P&ID are specialized exotic type of material with continuous steam purge to clean the valve from coke fines as the circuit is highly susceptible of coke fine formation and will result of very rapid malfunction of the valving system. Section 4.5.2 will discuss in detail about mode of operations of piping and valving system in this P&ID.

- **Coke Drum A (Figure 2.17)**

This P&ID shows the detail piping and instrumentation of all incoming and outgoing flows into Coke Drum A. It includes both online and offline mode of operation. The importance of piping and valving system as well as the control logic of their operation in this P&ID is as important as figure 2.15. Most of the valves using in this P&ID are specialized exotic type of material with continuous steam purge to clean the valve from coke fines as the circuit is highly susceptible of coke fine formation and will result of very rapid malfunction of the valving system. Section 4.5.2 will discuss in detail about mode of operations of piping and valving system in this P&ID.

- **Coke Drum B (Figure 2.18)**

This P&ID shows the detail piping and instrumentation of all incoming and outgoing flows into Coke Drum B. It includes both online and offline mode of operation. The importance of piping and valving system as well as the control logic of their operation in this P&ID is as important as Figure 2.15. Most of the valves using in this P&ID are specialized exotic type of material with continuous steam purge to clean the valve from coke fines as the circuit is highly susceptible of coke fine formation and will result of very rapid malfunction of the valving system. Section 4.5.2 will discuss in detail about mode of operations of piping and valving system in this P&ID.

- **Main Fractionator Overhead Condenser (Figure 2.19)**

This P&ID shows the detail piping and instrumentation of overhead vapor coming from top part of main Fractionator and going to overhead condenser (Water cooler type) to maintain a temperature of 100℉ before entering the overhead receiver at three phases. This P&ID also shows the PSV locations in the event of an overpressure occurring in the main Fractionator. The utilities circuits containing water injection as well corrosion inhibitor and type of insulation and also temperature of overhead vapor coming from top of main of main Fractionator are very crucial to smooth operation of this unit.

- **Main Fractionator Overhead Receiver (Figure 2.20)**

This P&ID shows the detail piping and instrumentation of overhead receiver that acts as a three phase separator to separate the phases of light hydrocarbon vapors as the feed of wet gas compressor at 3 psig and Naphtha as the source of reflux to main Fractionator and also source of absorbing oil in the absorber column that already discussed in the PFD section. The last phase is sour water coming out of the boot of this receiver. The column pressure at the top of main Fractionator is essential to smooth operation of wet gas compressor and hence a very complicated and dedicated control system is in place. Sizing of this vessel is one of the challenging engineering designs in this unit as the amount carry over sour water is variable in different modes of operation of both online and offline coke drums.

- **Coker Heater Charge Pumps (Figure 2.21)**

This P&ID shows the detail piping and instrumentation of Heater Charge Pump which is coming from bottom of Main Fractionator. This pump in a delayed coker unit is the biggest pump and should provide sufficient discharge at worst case scenario that usually define after five years of continuous operation of unit and contains lots of coke fine deposits in the transfer lines as well heater tubes. Although heater tubes are under steam spalling every six months as well as pigging operation every 2 years (with turndown conditions of operation of unit) but still the possibility of residue formation on the pipes and heater tubes are very high and therefore calculating a realistic pressure drop on the heater and transfer lines is very important. Shut off pressure of this pump will maintain the design pressure of heater tubes at their deign temperature.

- **Coker Charge Heater-Cell A (Figure 2.22)**

This P&ID shows the detail piping and instrumentation diagram of one of the heater cells (Cell A) that covers two passes of four passes of heater tubes. It contains the radiation section, heat shield and convection section. Each pass enters the convection section and goes to cross over and finally goes to radiation section. The piping and valving material in this circuit is highly exotic material to work with high design pressure and pressure. It is typical to split the heater into at least two cells to let the unit operate at turn down condition while the other cell is at pigging operation every two years. Heater is normally designed to operate for five years before any overhaul shutdown.

- **Coker Charge Heater-Cell B (Figure 2.23)**

This P&ID shows the detail piping and instrumentation diagram of one of the heater cells that covers the other two passes of four passes of heater tubes (Cell B). It contains the radiation section, heat shield and convection section. Each pass enters the convection section and goes to cross over and finally goes to radiation section. The piping and valving material in this circuit is highly exotic material to work with high design pressure and pressure. It is typical to split the heater into at least two cells to let the unit operate at turn down condition while the other cell is at pigging operation every two years. Heater is normally designed to operate for five years before any overhaul shutdown.

- **Blowdown Tower (Figure 2.24)**

This P&ID shows the detail piping and instrumentation diagram of Closed Blow Down section that plays an important role of cooling down the newly offline drum as well heating up the cleaned offline coke drum and make it ready for operation in the next cycle. It also acts a important heat sink to receive the vapor coming out of online drum in the event of upset conditions. Chapter 3 will discuss about this incident in detail. Section 4.5.2 will discuss in detail about mode of operations of piping and valving system in this P&ID. Since this section has dual functionality and responsibility therefore the reliability of equipment and control system is relatively high that is determined by SIL (Safety Integrated Level) analysis and is usually above 1 (Depending on SIL review team analysis to consider all available credits to be taken).

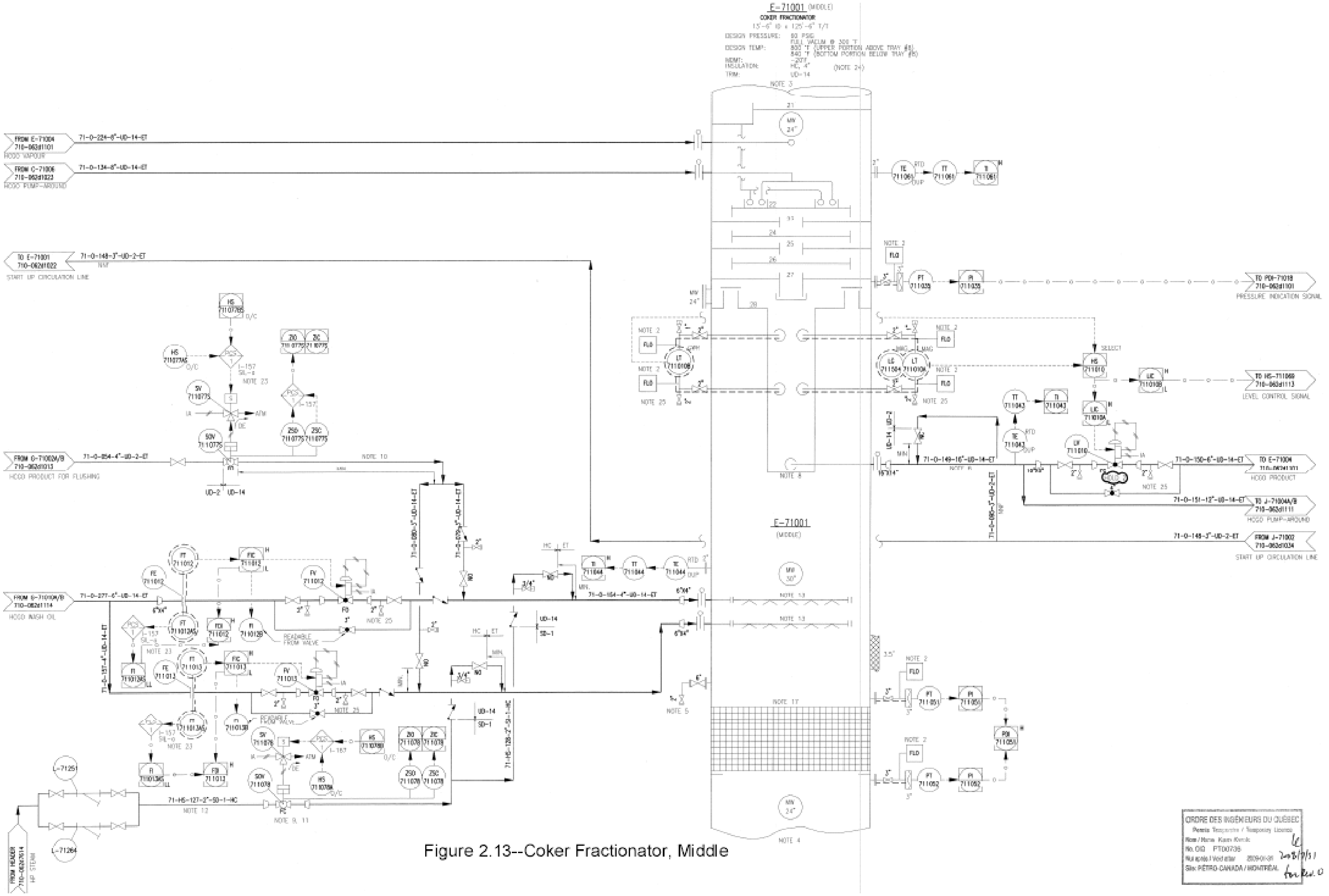
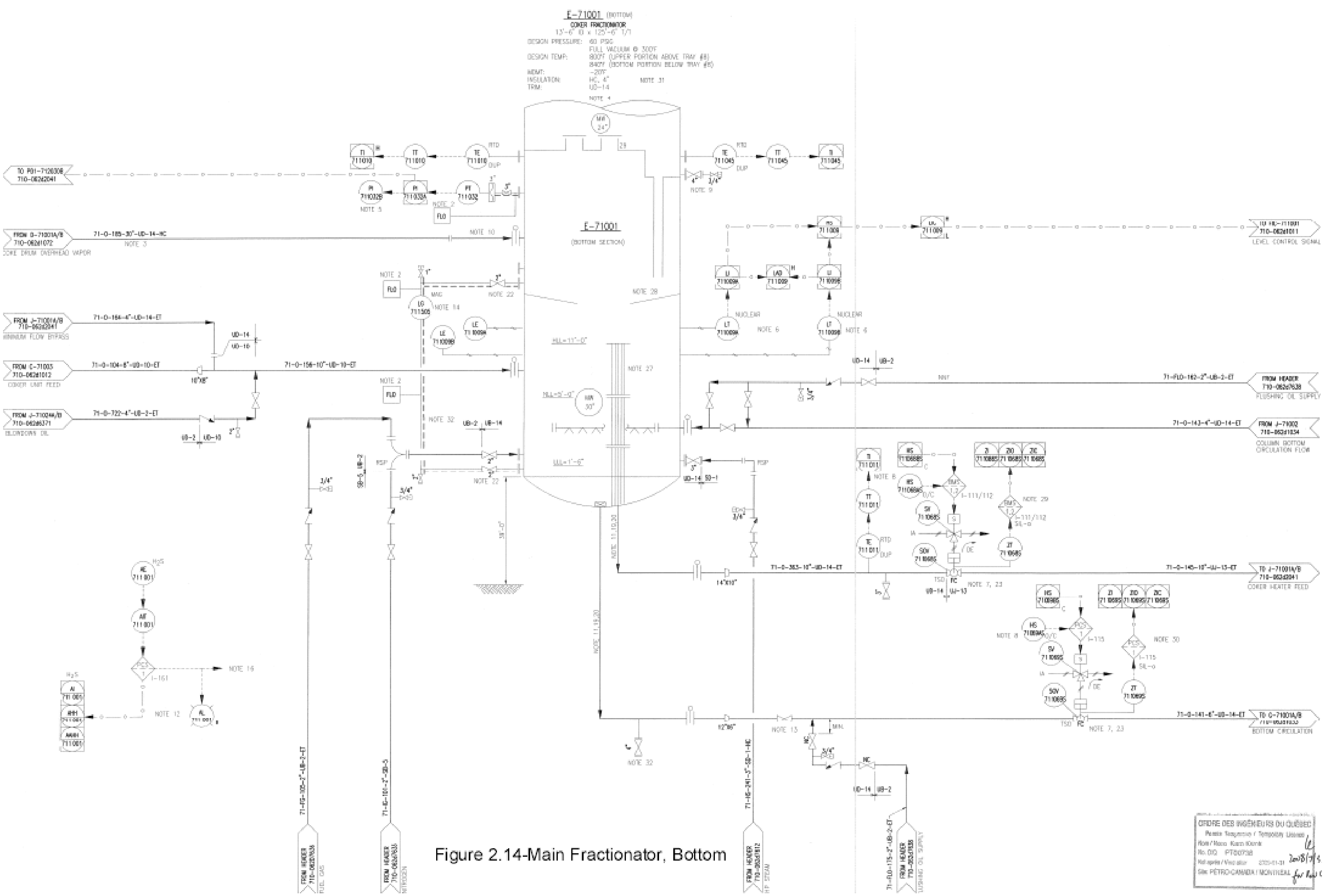


Figure 2.13--Coker Fractionator, Middle



ORDRE DES INGÉNIEURS DU QUÉBEC

Site: PÉTRO-CANADA / MONTRÉAL

Figure 2.14-Main Fractionator, Bottom

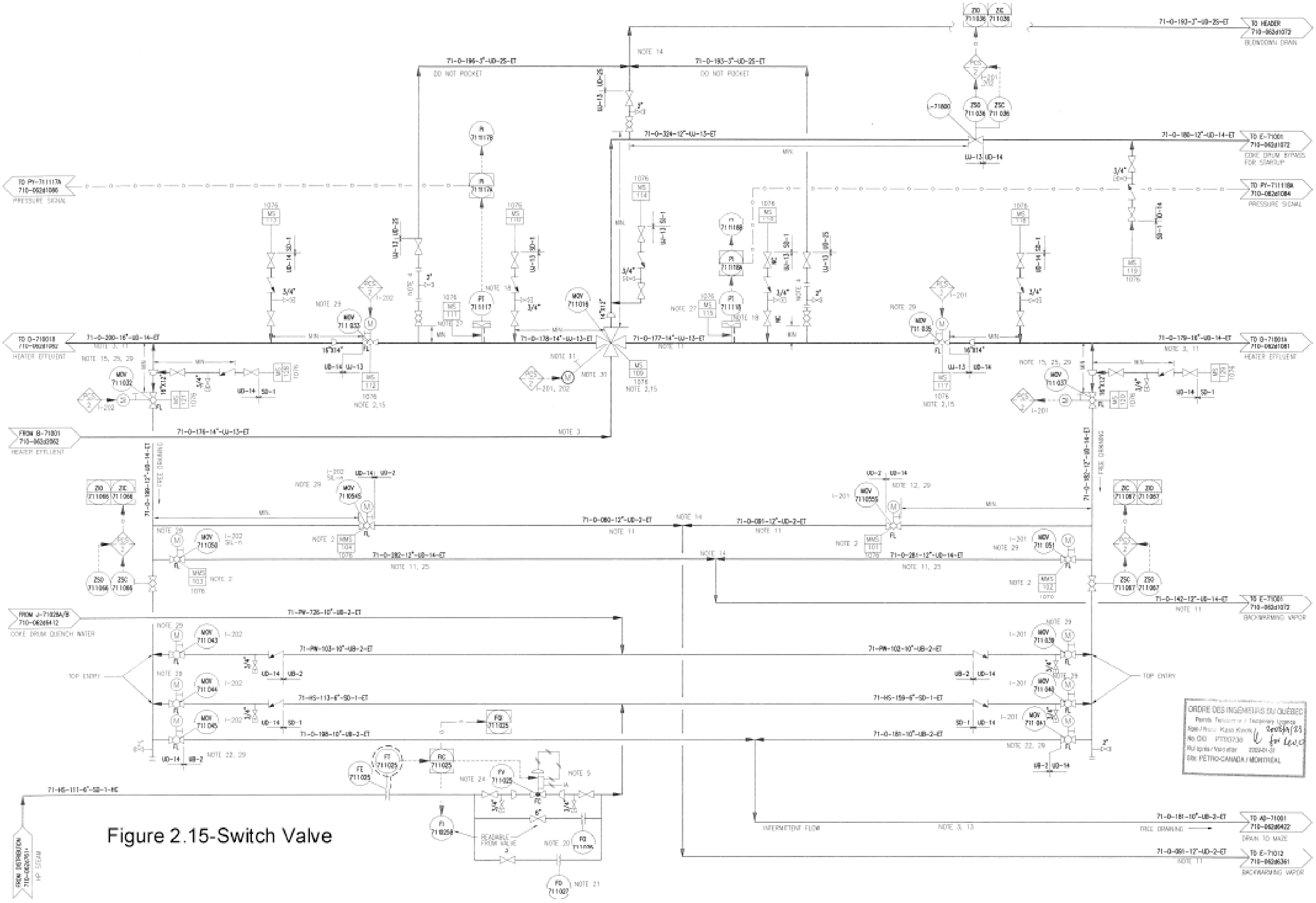


Figure 2.15-Switch Valve

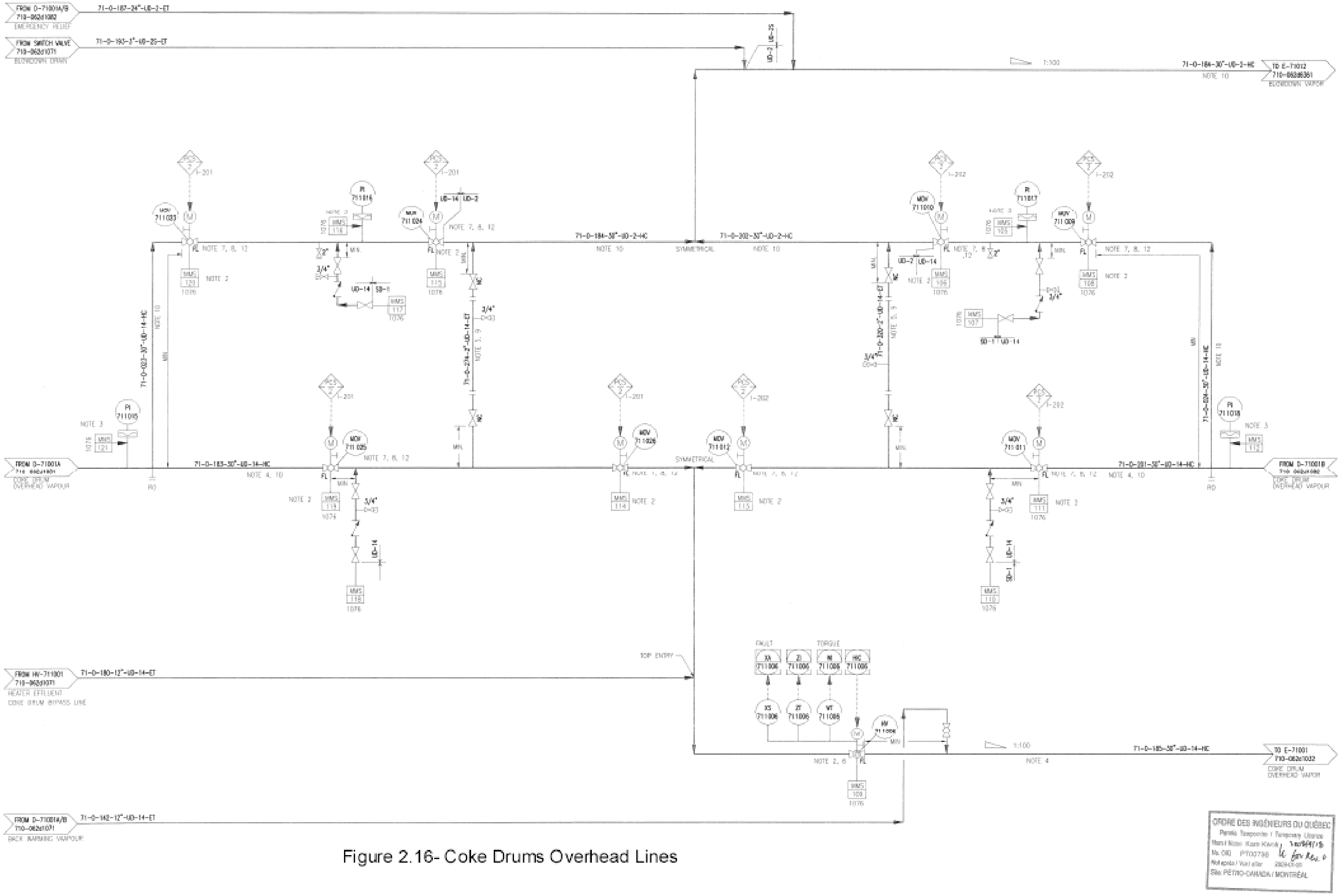


Figure 2.16- Coke Drums Overhead Lines

ORDRE DES INGÉNIEURS DU QUÉBEC
Permis Temporaire / Temporary License
Nom / Name Kam Kwok
No. OIQ PT00739

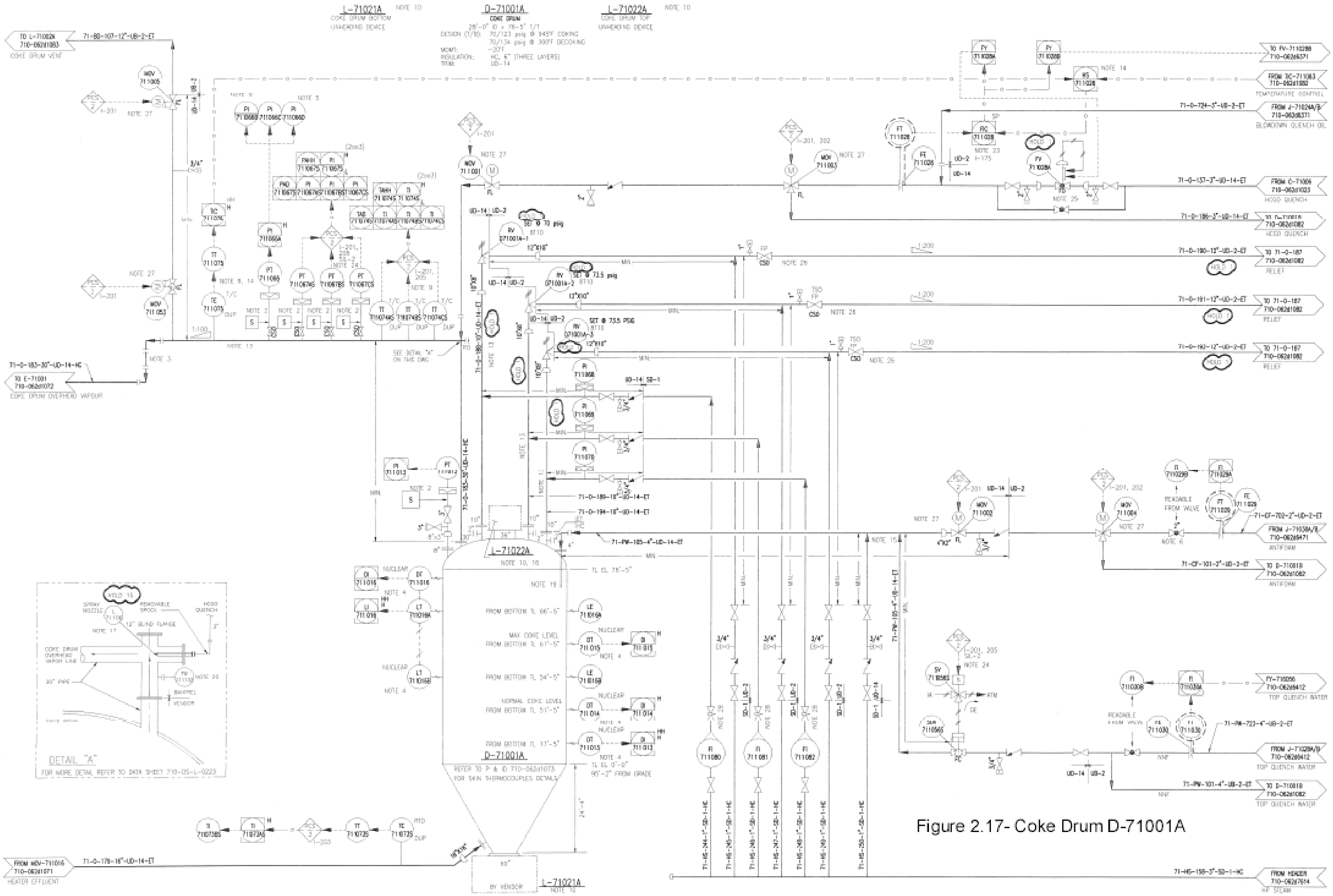


Figure 2.17- Coke Drum D-71001A

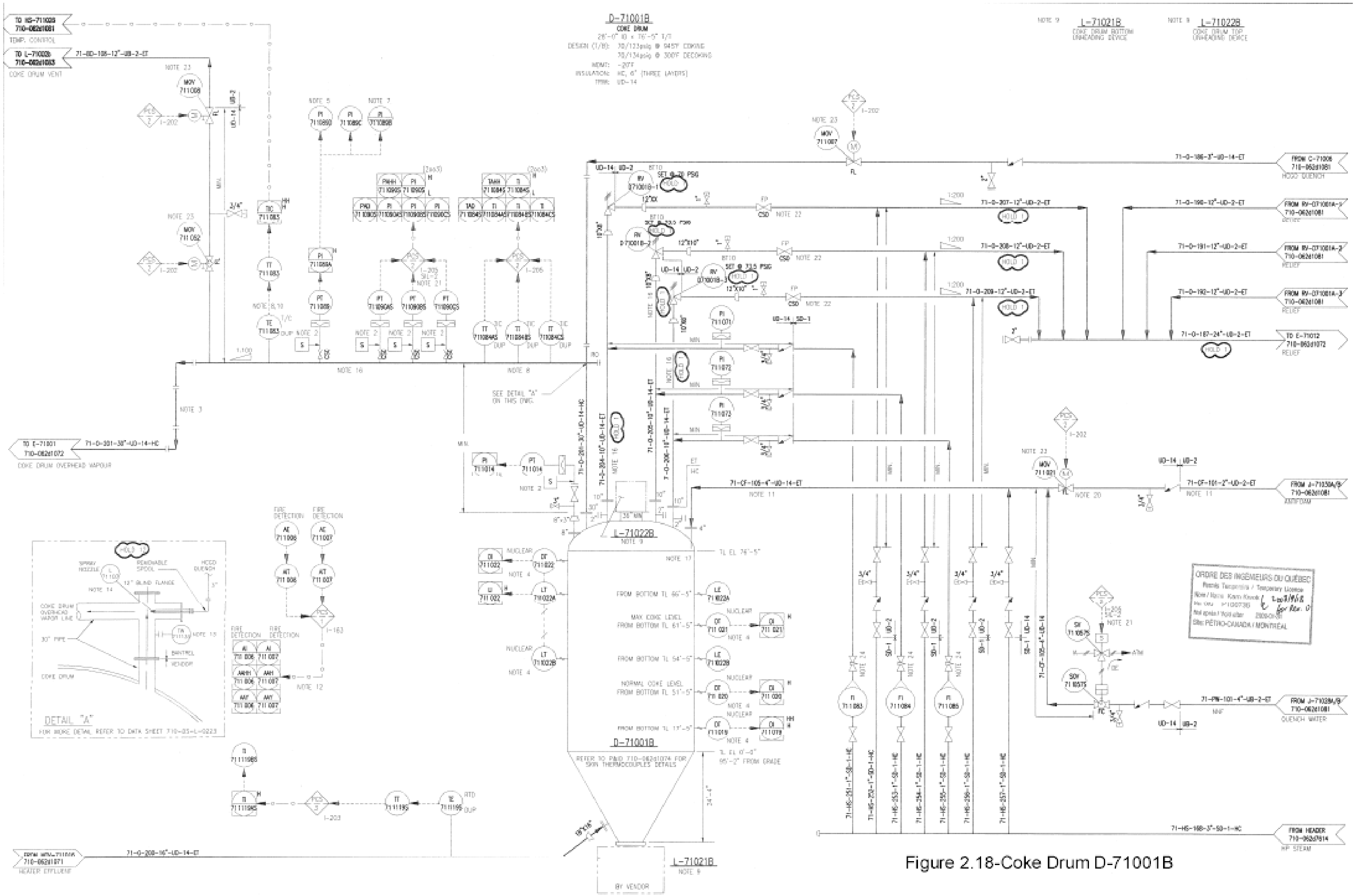


Figure 2.18-Coke Drum D-71001B

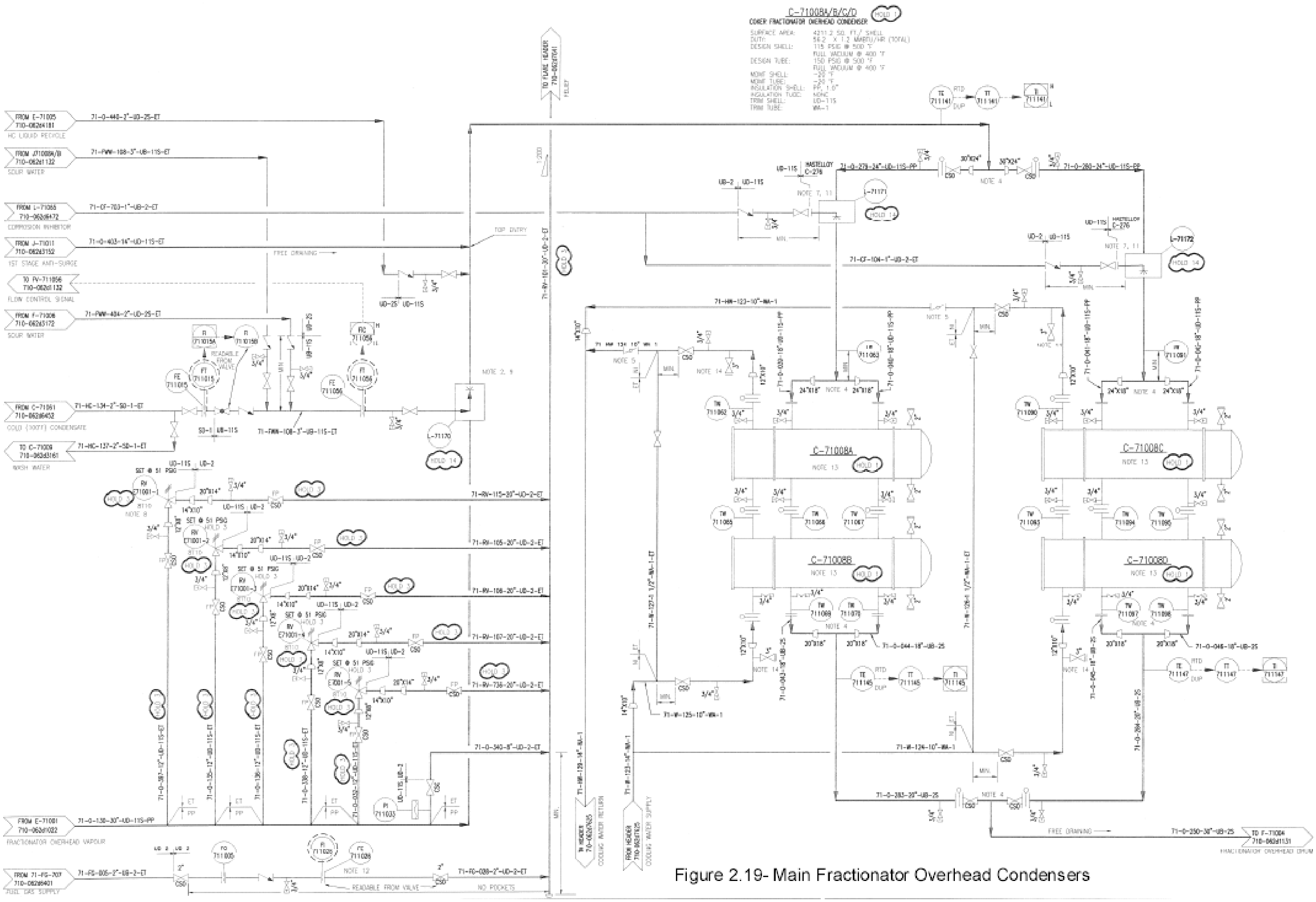


Figure 2.19- Main Fractionator Overhead Condensers

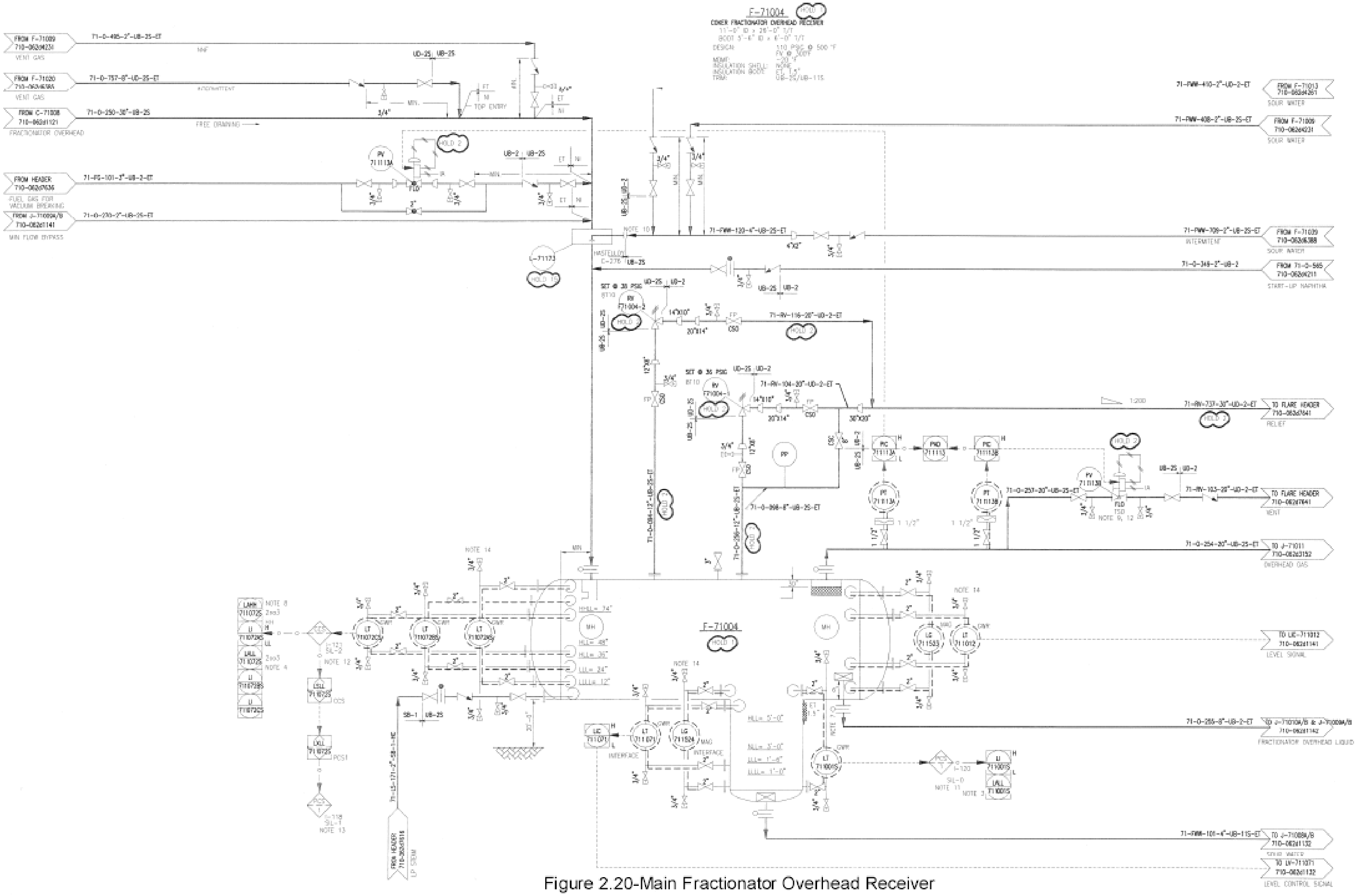


Figure 2.20-Main Fractionator Overhead Receiver

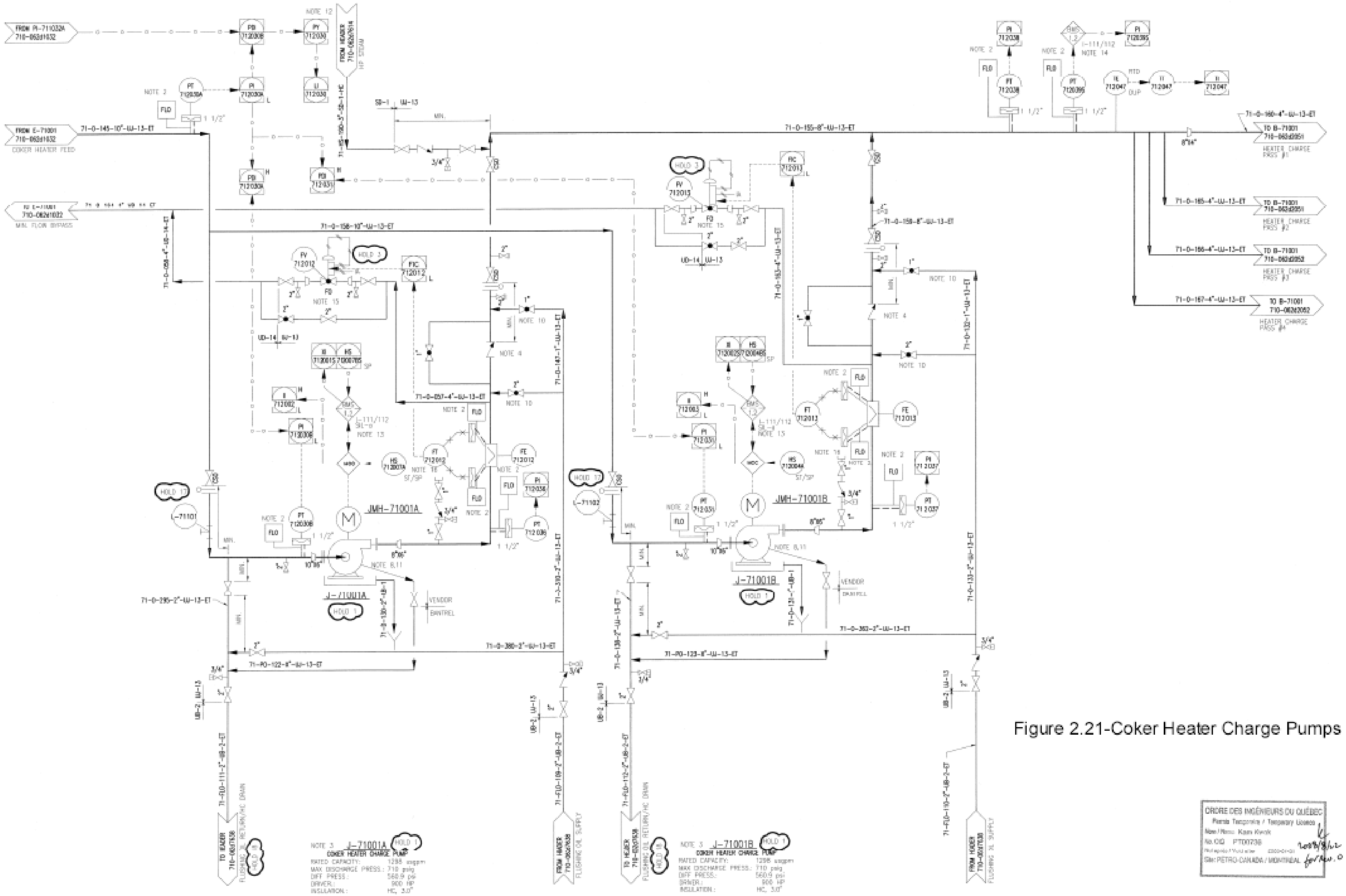


Figure 2.21-Coker Heater Charge Pumps

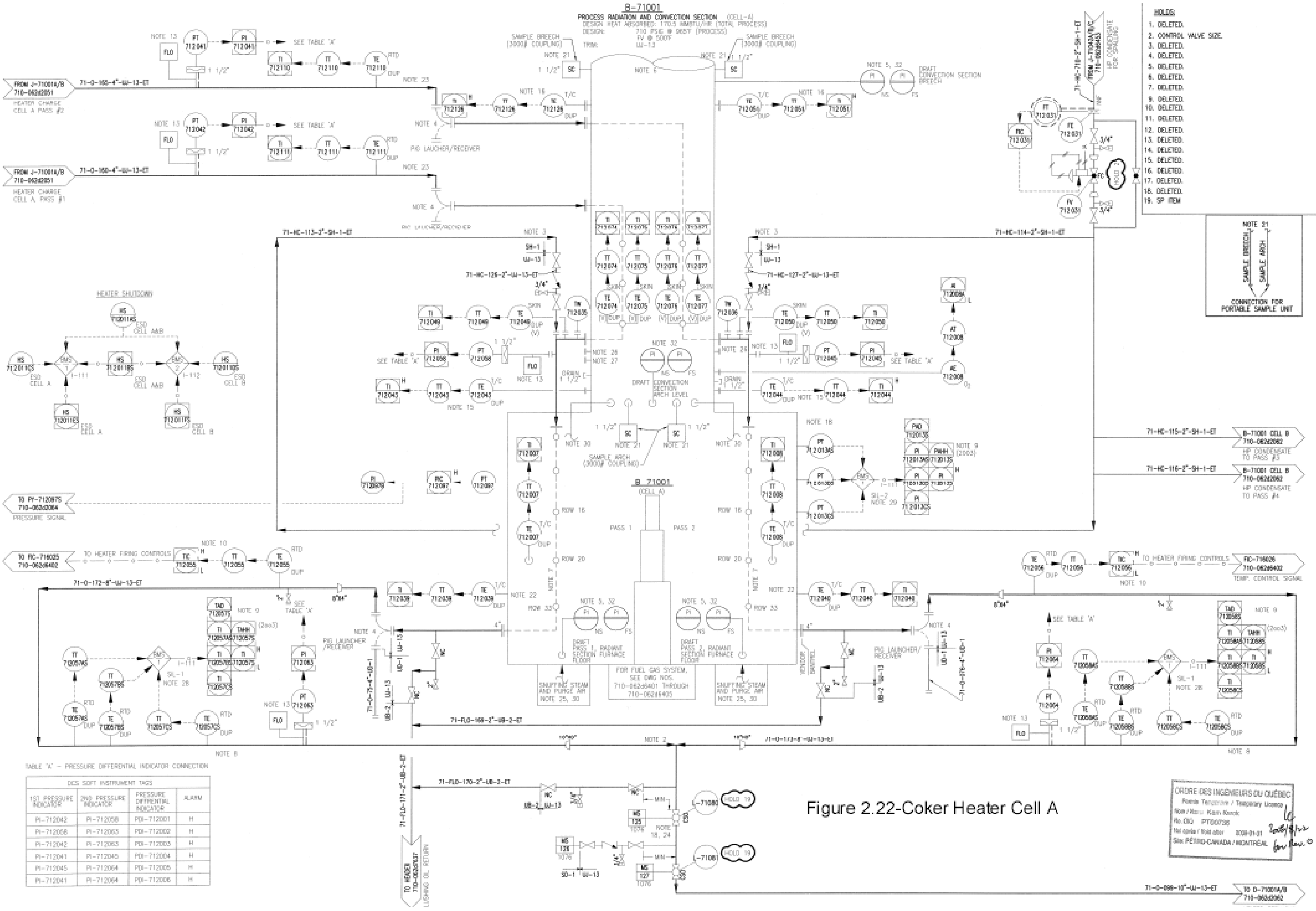
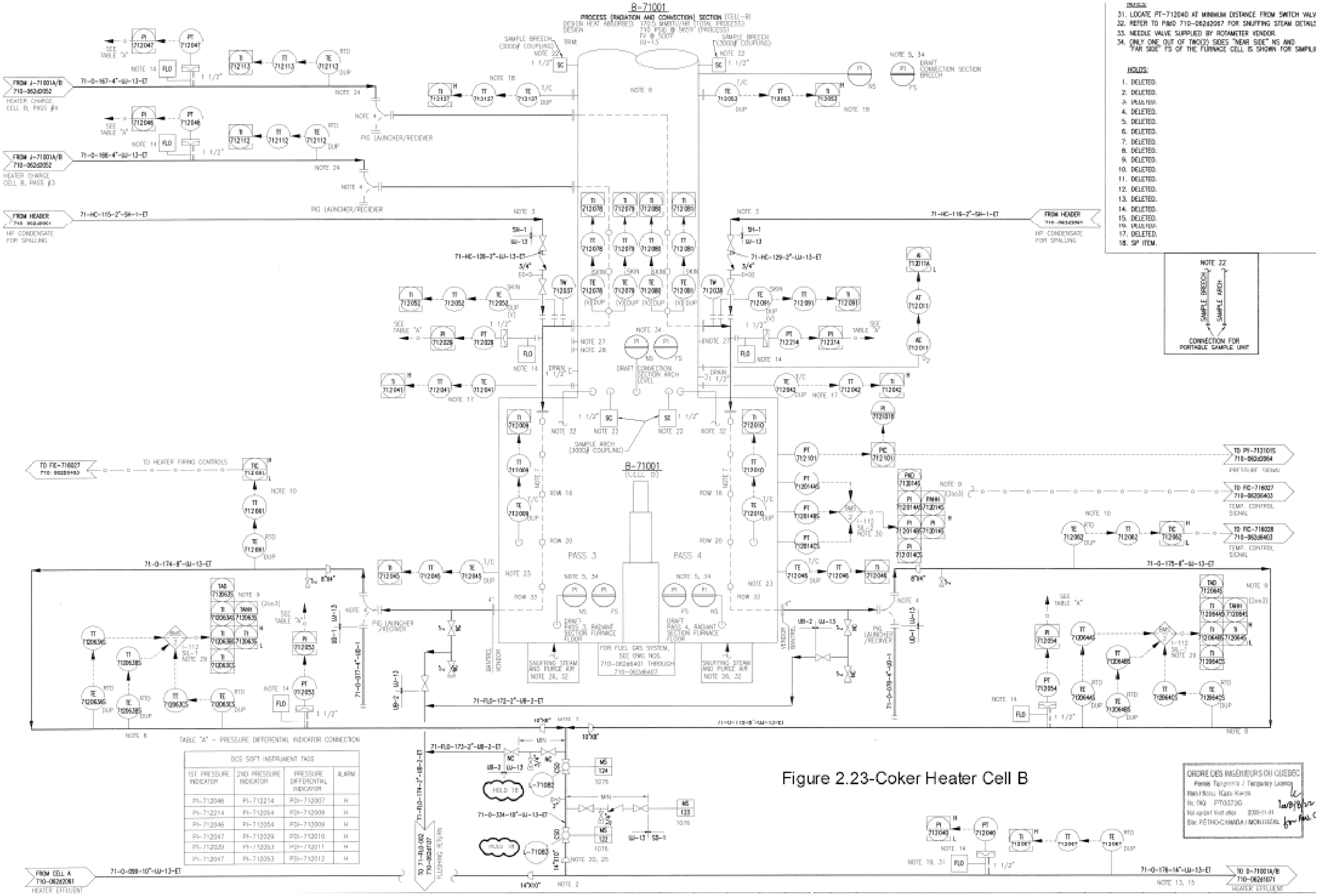


TABLE 'A' – PRESSURE DIFFERENTIAL INDICATOR CONNECTION

DCS SOFT INSTRUMENT TAGS			
1ST PRESSURE INDICATOR	2ND PRESSURE INDICATOR	PRESSURE DIFFERENTIAL INDICATOR	ALARM
PI-712042	PI-712058	PDI-712001	H
PI-712058	PI-712063	PDI-712002	H
PI-712042	PI-712063	PDI-712003	H
PI-712041	PI-712045	PDI-712004	H
PI-712045	PI-712064	PDI-712005	H
PI-712041	PI-712064	PDI-712006	H

Figure 2.22-Coker Heater Cell A

ORDRE DES INGÉNIEURS DU QUÉBEC
Permis Temporaire / Temporary Licence
Nom / Name: Kevin Kwok
No. OIQ: PTF00728
Nul après / Void after: 2008-01-31
Site: PÉTRO-CANADA / MONTRÉAL



NOTES:

31. LOCATE PT-712040 AT MINIMUM DISTANCE FROM SWITCH VALV
32. REFER TO P&ID 710-062d2067 FOR SNUFFING STEAM DETAILS
33. NEEDLE VALVE SUPPLIED BY ROTAMETER VENDOR.
34. ONLY ONE OUT OF TWO(2) SIDES "NEAR SIDE" NS AND "FAR SIDE" FS OF THE FURNACE CELL IS SHOWN FOR SIMPLI

HOLDS:

1. DELETED.
2. DELETED.
3. DELETED.
4. DELETED.
5. DELETED.
6. DELETED.
7. DELETED.
8. DELETED.
9. DELETED.
10. DELETED.
11. DELETED.
12. DELETED.
13. DELETED.
14. DELETED.
15. DELETED.
16. DELETED.
17. DELETED.
18. SP ITEM.

TABLE "A" - PRESSURE DIFFERENTIAL INDICATOR CONNECTION

DCS SOFT INSTRUMENT TAGS			
1ST PRESSURE INDICATOR	2ND PRESSURE INDICATOR	PRESSURE DIFFERENTIAL INDICATOR	ALARM
PI-712046	PI-712214	PDI-712007	H
PI-712214	PI-712054	PDI-712008	H
PI-712046	PI-712054	PDI-712009	H
PI-712047	PI-712029	PDI-712010	H
PI-712029	PI-712053	PDI-712011	H
PI-712047	PI-712053	PDI-712012	H

Figure 2.23-Coker Heater Cell B

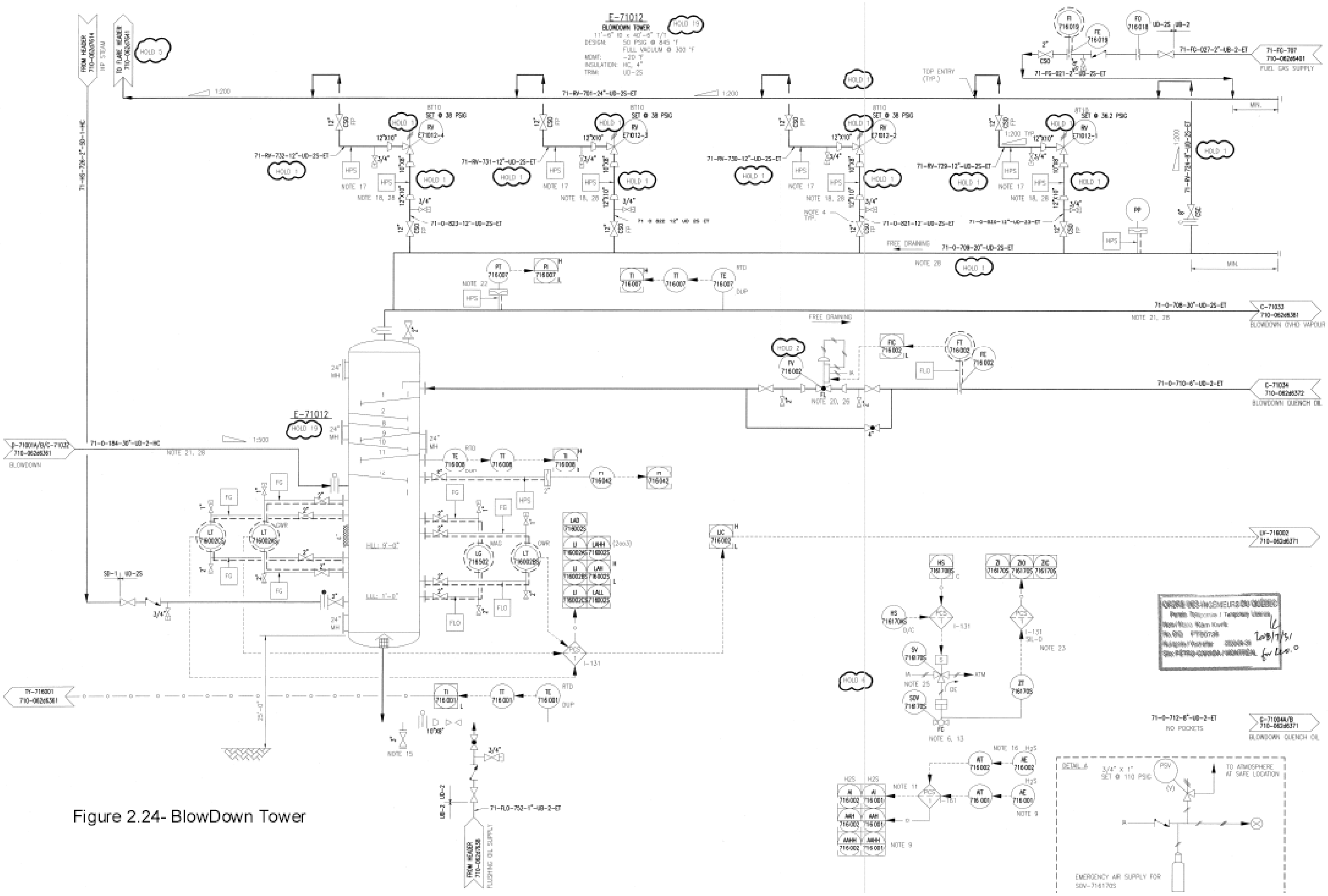


Figure 2.24- BlowDown Tower

Chapter 3: Troubleshooting Rules

3.1. Introduction:

This chapter will focus on developing the credible scenarios of coke drums relief and analyses the ones that results in the maximum relief capacity with highest backpressure to establish the sizing basis of Process Safety valve. However, there are some credible scenarios that will result less relief rate but incurs higher temperature. This is also important for the analysis of time amount of relief that will impact the equipment/piping material specifications. In the meantime the basic difference of relief in coke drums (Cascade Relief) with other usual relief will be discussed.

3.2. Upset Conditions in Coke Drums

- **Coke Drums Relief Alternatives:**
  - As shown on Figure 4.4 in section 4.5.2 any isolation valve on the online path could be blocked (e.g., either of valves 1025, 1026 or HV-1006) during its operation cycle and will cause the pressure build up in the online coke drum. This is the governing case of relief valve calculations for coke drums in below sections:
  - The accumulated pressure shall be relieved through installed PSVs on the top of coke drum at a certain pressure, which is usually set at 70 psig.
  - Once the relief happens, the temperature is 870℉ and pressure is 70 x 1.16 psig.
  - There are 3 alternatives that the relieved materials can be routed:

    - Through the main Fractionators
    - Through the CBS
    - Directly to the flare stack

• Advantages and Disadvantages of Alternatives:

- Alternative number 3 naturally is not an optimum solution as we relieve the hot and valuable materials into the flare stack to be burnt and disposed to the environment and obviously it creates lots of air pollution issues.
- This way will also cause to use more exotic materials (i.e., more expensive) as the material of specifications for equipment and piping in the circuit of relief becomes hotter. It has also more environmental impacts due to release of hydrocarbons to the flare.
- We should also consider that the relief will not stop or decay until an operator intervention (it has an allowance of 10 to 15 minutes) happens as the feed comes continuously into the online drum.
- Alternatives number 1 and 2 are both attractive solutions and each have their pros and con's.
- Alternative number 1 is good as it is always available as a heat sink to cool down the hot materials with P/A circuits and reflux within the operation of main Fractionator. In other words it is more reliable at such an incident.
- It can cool down the relieved materials to 500°F prior to relieving to the flare stack.
- This will also result to lower relief rate.
- However, this alternative will finally end up pushing the PSVs to pop on the main Fractionator.
- This will lead to a relatively high backpressure (main Fractionator PSV set pressure is usually set at 50 to 60 psig versus 70 psig for coke drums) and hence, this will substantially increase the PSV size on the coke drums.
- At the beginning of relief in the coke drum to the Fractionator, it also maintains a very high velocity vapor in the main Fractionator that may cause mechanical damage to the trays and its internals.
- Alternative number 2 is also attractive although the available heat sink in the main Fractionator is relatively more than CBS.

- The above mentioned backpressure is relatively lower in CBS. PSV set pressure is usually set at 30 to 36 psig versus 70 psig at the coke drums.
- However, CBS heat sink is not always available, as it is in idle mode at different stages that is about 30% of 18 hours cycle of offline drum.
- This simply results the same relief temperature as it relieves directly to flare stack.
- Once the number coke drum pairs are increased to 2 to 3 (i.e. 4 to 6 coke drums), this issue of idle mode is almost diminished as at any time one cone or two coke drums are in their either quench mode or Backwarm mode.
- The future trend for refiners might be the case to purchase and import VTB to increase the DCU capacity fairly high to increase the number the number of coke drums, as the smallest economical capacity is 15000 to 25000 barrel per day of VTB for a two coke drum standard size of diameter and height.
- This trend can be also handled with larger scale capacity of refineries like above 200,000 barrels a day of crude oil that will result a yield of VTB up to 30%.

Relief Scenarios (to Closed Blowdown Section):

1. **Block Outlets**

   a.**Normal Quench / Backwarm / steam test in operation:** Blocked Outlet at the Blowdown Settling drum vapor line (Pressure control valve fails closed) causes relief through the relief valves at the Blowdown Settling Drum only. The Coke Drum will continue to operate as normal**.** Relief is not required at the Coke Drums.

   b.**Coke Drum being filled with Coke; other coke drum is either idle, or backwarming to the main Fractionator:** Flow from one of the live coke drums to Main Fractionator is blocked and feed continues to the live Coke Drum. The scenario initiating this event is the closure of the overhead isolation valve from the live coke drum causing an overpressure that lifts the live Coke Drum relief valves. Hydrocarbon vapor flow from the blocked coke drum to the Main Fractionator stops. The Coke Drum is pressurized, and relieves to the Closed Breakdown System. The required relief through the Coke Drum relief valves is equal to 100% of the normal Coke Drum effluent vapor. Coke Drum relief flows enter the Blowdown Quench Tower. For this scenario, it is assumed that the Closed Blowdown System is handling neither a water quench, steam stripping, nor a backworm cycle. Therefore, the operating pressure in the Closed Breakdown System will be lower than normal. The heavy slop oil recycles and HSO spray continues. Credit is not taken for the temperature switch on the tower inlet that would turn on the Quench Water pump. The Quench Tower OVHD condenser (air cooler) is assumed to have 2 bays (out of 8 total bays) are out of service to allow for fouling / maintenance. Usually, the total number of bays is to be confirmed during detailed engineering. To evaluate the heat transfer during relieving conditions, 80% of the U value from the condenser design is applied. Also, the overhead condenser louvers are assumed open with **no** fans running. Therefore, only credit for natural convection was taken. The flow exiting the condenser is routed to the Blowdown Settling Drum, which pressurizes. Credit is not taken for vapor flow exiting the Blowdown Settling Drum to the Fractionator or to the flare via pressure control. Vapor relief is required at the Blowdown Settling Drum relief valves for the rate equal to the non-condensed vapor from the Quench Tower Overhead Condenser. This relief is routed to the flare. Relief is not expected at the Blowdown Quench Tower relief valves. This scenario results in lower backpressure at the relieving Coke Drum relief valves than Scenario 1.C Blocked Outlet of a Coke Drum being filled while quenching in another is underway.

The Coke Drums are expected to have local and DCS pressure indication. Procedures to mange coke drum cycles are expected to be in place. It is expected that within 10 minutes, operation to personnel will see the increase in the Coke Drum pressure, and open the isolation valve to stop the Coke Drum relief.

c. **Coke Drum being filled with coke while simultaneously quenching another Coke Drum:** Flow from the live Coke Drum to the Main Fractionator is blocked. Since the quench cycle is in operation, the Blowdown Quench Tower Overhead Condenser is operating. Normal quenching is underway in one Coke Drum with steam and hydrocarbon flowing to the Blowdown Quench Tower. The over head hydrocarbon vapor from the live Coke Drum flows to the Main Fractionator. The scenario initiating this event is the closure of the overhead isolation valve from the live coke drum that results in an overpressure, which lifts the live Coke Drum relief valves. Hydrocarbon vapor flow from the blocked coke drum to the Main Fractionator stops. The live coke drum is pressurized, and relieves to the Closed Blowdown System. The required relief through the Coke Drum relief valves is equal to 100% of the normal Coke Drum effluent vapor. Quenching of the other Coke Drum is also occurring so the total flow to the Closed Blowdown System is the normal quench flow from the off-line Coke Drum plus the coke drum vapor flow from the live Coke Drum. Since the Quench Water pumps are normally operating during the quench cycle, it is assumed the pumps maintain normal rate during this scenario. The condenser is assumed to have 2 bays (out of 16 total bays) are out of service, and all other fans in the ‘ON’ position (normal for quench operation). Usually, the total number of bays is to be confirmed during detailed engineering. To evaluate the heat transfer during relieving conditions, 80% of the U value from the condenser design is applied. The overhead from the Blowdown Quench Tower is partially condensed in the overhead condenser. The duty is expected to be higher than the design duty because of higher LMTD as a result of the hot Coke Drum relief. Fluid not condensed in the overhead air cooler flows to the Blowdown Settling Drum. The drum pressurizes. Vapor relief to flare is required at the Blowdown Settling Drum for the fluid not condensed in the overhead condenser. Credit is not taken for vapor flow exiting the Blowdown Settling Drum to the Fractionator or to the flare via pressure control. Vapor relief at the Blowdown Quench Tower PSVs, which also relieve directly to the flare header, is not expected. Hydrocarbon liquid level in the settling drum increases assuming the LSO pump is off. The corresponding fill time from the top of the baffle to the top tangent will be greater than 10 minutes. Therefore, with operator intervention, hydrocarbon liquid relief is not expected at the Blowdown Settling Drum. This scenario results in the highest backpressure at the relieving Coke Drum relief valves.

The Coke Drums are expected to have local and DCS pressure indication. Procedures to manage coke drum cycles are expected to be in place. It is expected that within 10 to 15 minutes, operations will see the increase in Coke Drum pressure, and open the isolation valve to stop the Coke Drum relief.

2. Abnormal Heat Input

Furnace Fuel Gas: control valve (FC) to Single Pass fails open. Heat input into the system increases and excess vapor is generated, which will flow to the Main Fractionator. Relief is not required at the Coke Drums.

3. Spilt Exchanger Tube

This case is not applicable as there is not any heat exchanger in this circuit that will lead to release the high pressure material into the Coke Drum, hence this case is dismissed.

4. Auto Control Failure (Single Event)

The following two cases are presented because they are typically important for sizing relief valves in Delayed Coker Unit.

Auto control failures are considered as single control valve failure events (incorrect signal from DCS broken spring, local air failure to control valve):

	Control Valve	Consequence of Fail Open	Consequence of Fail Closed
A1	Quench water to Coke Drums (FC)	Quench water to the coke drums are controlled with two flow control valves, one main control valve and a second valve. The main valve controls water flow during initial quenching while the second valve is used after the initial quench when large quantities of water are added to fill the drum. The second valve is manually operated control valve from DCS, which has a permissive that allows it to be opened only when the main control valve has reached 100% open status. There is also a temperature permissive on the second control valve that allows it to be opened only when the quench steam from the Coke Drum being quenched is less than 400°F. The main control valve fails open during beginning of coke drum quench operation. Quench water flow to the hot coke drum increases to a maximum of 700 GPM **(The Control Valve is designed for a maximum flowrate of 700gpm during a CV fail open case).** The quench water is vaporized and sent to the Blowdown Quench Tower. Based on back pressure calculations, the set pressures of the Coke Drum relief valves are not reached. Therefore, relief does not occur at the Coke Drum. However, relief does occur at the Blowdown Settling Drum.	Valve fails closed during coke drum quench operation. Quench water flow to coke drums decreases. System is not pressurized. Relief is not required.

	Control Valve	**Consequence of Fail Open**	**Consequence of Fail Closed**
A2	Quench water to Coke Drum Control Valves Bypass (LC)	Bypass is LC. Producers are expected to be in place regarding opening this bypass valve. See scenario 4A.1 above for consequences of control valve failing open.	Bypass is normally closed (LC). Relief is not required.
B	Coke Drum Overhead to Fractionator isolation valves (Motor Operated)	Coke Drum vapor isolation valves are normally open during coking operation. Coke Drum vapor to the Fractionator continues. <u>Relief is not required.</u>	Valve failing closed results in the blockage of Coke Drum vapor flow to the Fractionator. Coke Drum pressure will increase and relief is required. <u>Worst-case scenario is the same as Scenario 1.C, Blocked Outlet of one coke drum while quenching at the other coke drum.</u> Relief at the live Coke Drum is required for a rate equal to 100% of normal Coke Drum effluent vapor. (**<u>CONTROLLING CASE)</u>**

5. **Reflux Failure**

   Not Applicable.

6. **Loss of Feed**

   Feed to the Coke Drum is lost. System pressure will not increase. <u>Relief is not required</u>.

7. **Fire**

   In case of fire, relief is required for the relief load generated from that portion of protected equipment that is wetted by its internal liquid and is equal to or less than 25 feet above the source frame. The Coke Drum elevation is greater than the specified 25 feet. However, the un-heading deck could hold some liquid. Therefore, a fire is possible at the Coke Drums. The Coke Drums are heavily insulated and normally do not normally have a wetted surface for vapor generation. For this scenario, the inlet and outlet of the Coke Drum is assumed blocked. Thus, the rate of vapor generated will decay during a fire. Therefore, relief, if, any, will be less than the controlling scenario 1.C., Blocked Outlet.

8. Cooling Water Failure

Not Applicable.

9. Power Failure

A.Individual Power Failure

Credit is not taken for motor-operated spare pumps.

1.**Motor-driven Quench Water Pump stops**, losing quench water feed flow to the Coke Drum. Residual steam/hydrocarbon flow from the coke drum to Closed Blowdown System will be minimal. The Coke Drum is not pressurized. Relief is not required.

2.**Quench Tower Overhead Condenser:** Since the electrical layout of the unit is assumed to consist of two electrical buses only one half of the fans will stop, losing half of the fans on the condenser. Credit for natural convection is taken. Fluid not condensed in the condenser increases pressure in the system. The Coke Drum operating pressure will likely increase, but not reach the set pressures of the Coke Drum relief valves. Relief is not required at the Coke Drums. However, relief is required in the Closed Blowdown System. See the Blowdown Quench Tower / Blowdown Settling Drum relief calculations for additional details about relief in the Closed Blowdown System.

3.Furnace Charge Pumps STOP, LOSING FEED TO THE Coker Furnaces

Furnace emergency sweep steam starts but without sufficient flow to overpressure the Coke Drums. Relief is not required.

B.Local Power Failure

The electrical layout of the unit is assumed to consist of two electrical buses. In the event of a local bus failure, the worst case is to assume the Furnace Charge pump continues, the Quench Water pump continues while half of the Quench Tower Overhead Condenser fans stop. This scenario is the same as Scenario 9.A.2, Individual Power Failure. Relief is not required at the Coke Drums. See the Blowdown Quench Tower / Blowdown Settling Drum relief calculations for details about the relief in the Closed Blowdown System for this scenario.

C.General Power Failure

Under this general power Failure scenario, the Furnace Charge pump, the Quench Water pump, and all other motor-driven pumps in the Closed Blowdown System stop. The Quench Tower Overhead condenser fans also stop. Coke Drum from the live drum will continue to be produced. This scenario is covered in the Coker Fractionator relief scenario narrative. Relief is not required at the Coke Drums. A minimal amount of steam / hydrocarbon from any off-line Coke Drums lined up to the Blowdown System will continue to feed the Closed Blowdown System.

10. Other Contingencies

None identified.

3.3. Credible Scenarios for Coke Drums Relief:

The relief system on Cokers is different than almost any other plant. For cokers, the relief valve outlet goes to other equipment which then in turn must relieve (Cascade Relief) though their relief valves. The reason it is done this way is that the relief from a coker is very hot and it would impose a lot of stress on the flare header. By relieving through other equipment, the gas is first cooled by sprays and by air coolers before going to the flare header.

The cases for a coke drum relief are:

- Blocked outlet (coke drum is being filled while other coke drum is idle and the live coke drum is blocked in). The relief flow is the full coke drum overhead flow.
- Another coke drum relief case is Coke drum is being filled while the other one is being quenched and the live coke drum is blocked in. The relief flow is the full coke drum overhead flow. Also a significant flow of steam from the drum being quenched also adds to the backpressure and total flow to be relieved in downstream relief valves.

An important difference in the two cases is that in the first case no fan in the quench tower overhead condenser is assumed to be working where in the second case the fans are assumed to be working. Regardless of whether they are assumed to be working or not, 2 bays are assumed to be out for maintenance, and the remaining bays are assumed to be so fouled that only 80% of the normally fouled heat transfer of that remaining area can be obtained.

- Coke drum is filled with coke and while backwarming the other coke drum the outlet from the live coke drum is blocked. The fan is assumed to be working but similar fouling and maintenance is assumed. The relief flow is only 85% of the first blocked outlet case is to be relieved.
- Fire Case

Chapter 4: Simulations and Calculations

4.1. Introduction

Chapter three discussed about troubleshooting rules with a focus and emphasize on all credible scenarios that would lead to relief in the operating (or online) Coke Drum. It also discussed about the available alternatives to relieve into three different destinations (heat sinks). Among these discussions it was shown that Blocked outlet condition of online Coke Drum will result in the highest relief load to size the PSVs of Coke Drums, and also among different alternatives, it is chosen that relief into Closed Blow Down Section would be the best or somewhat the most common choice among different licensed designs. In fact, this choice could save the main Fractionator from many disruptions if it was chosen as the alternative to handle a high pressure relief material with a high back pressure in the main Fractionator.

Generally speaking, the more Coke Drums in the operations (i.e., 4 or 6 coke drums in Delayed Coker unit) the better handle of relief into Closed Blow down Section with less relief temperature (as at any condition there is no idle mode for offline drums and closed blown section is running to quench an offline drum before starting coke cutting). However, due to exceptional nature of this relief which is a cascade relief type, a network of relief shall be designed for these PSV calculations. This means that the PSV relief calculations would not end to size only the Coke drums PSVs and in reality it should be continued to closed Blowdown section with piping system and this relief would also disrupt the normal operations of Blowdown section accordingly. Since Blowdown section is mainly designed to handle the materials coming from off line coke drum to whether cool it down or heat it up (backwarming step), therefore depending on which step the Blowdown section is in operation the consequent relief load in Blowdown PSVs and condition would be different accordingly.

4.2. Simulation Steps:

As already explained there are two instances in Coke Drum blocked outlet relief that one specifies the maximum relief load (for the purpose of PSV sizing) while the other specifies the maximum relief temperature which is not necessarily coincidental with the first instance. The following simulation model has been laid out to determine the abovementioned instances:

- As per Figure 4.4 shown in this chapter (section 4.5.2), if any out of two valves **1025** or **1026** get closed (assuming Coke Drum A is in operation), then Coke Drum outlet would be blocked to let the coke drum overhead vapor flows toward main Fractionator while feed is still coming into the coke drum and it will lead to an overpressure inside the coke drum, hence PSV relief.
- A compressor model is used to calculate the coke drum PSV relief temperature. Due to the endothermic nature of reaction in the coke drum, the relief temperature won't exceed more than 890℉ which is not much higher normal temperature (i.e. 840℉).
- The relieved materials are directed to closed blow down column and will experience pressure drop. A pipe model is chosen to calculate the pressure loss.
- At this stage the simulation is split into two cases:
    - Relief happens when the other offline drum is at slow quench **(Figures 4.16 to 4.32)** and is bringing a continuous flow of mainly steam at 510℉ and mixes with relieved materials plus a continuous recycle of bottom of closed Blowdown column.
    - Relief happens when other offline drum is at backwarming **(Figures 4.33 to 4.50)** mode. Therefore the relieved materials will be just mixed with recycle of closed Blowdown column.
    - In either case stream _164 represents the inlet condition of closed Blowdown column.

- In any of either abovementioned scenarios, the relieved material coming from opened PSVs of Coke Drum A would incur a very fast overpressure in the Blowdown column and hence the relief would happen accordingly in the blow down PSV column as well as column overhead receiver.
- Stream _168 represents the column overhead vapor condition that experiences some pressure loss through piping before splitting into two following open paths:
    - Column PSV sub header represented by stream _168_5.
    - Column overhead condenser and finally column overhead receiver represented by stream _168_4. This stream will finally cause the PSV on the overhead receiver to pop and would be finally mixed with PSV relieved materials from blow down column.
- Stream "_169 Final Load" represents the final relief condition.
- Stream _164 will start changing the column condition represented by stream _163A and also increasing the column relief temperature monitored by stream _168.
- Every two minutes these changes are predicted by a new simulation and report the column condition at the recycle stream as well as closed Blowdown column overhead temperature and hence final load temperature.
- Since the volume of bottom section (from High Liquid level to the tangent of bottom of column) is 5374 US Gallons and circulation rate of bottom draw off is 418 USgpm, therefore the amount of hot liquid generation is calculated within 2 minutes increments to calculate the new temperature condition for mixing of stream _163A and relieved material in the mixing model.
- Hence, this simulation model will predict the temperature increase as well as relief rate which stays almost same from beginning till end of time interval.
- Same pattern of simulation model kept for both cases.

4.3. Simulations and Calculations Algorithm

Among the different steps that Closed Blowdown section can be in operation, two steps were chosen to develop the relief calculations:

- Quench mode
- Heat up (Backwarming) mode

A semi dynamic simulation has been developed for each step. This simulation model will predict the gradual temperature increase as well as relief load. The simulation calculates the temperature and relief load/rate in the time increments of 2 minutes (in general) and stops at 15 minutes. The detail diagram as well as process streams and equipment conditions are shown in one individual diagram for every 2 minutes time slice starting from t=0 to t=14 and the final minute at t=15. The whole simulation can be categorized into two parts:

1. Quench mode that includes the simulation results from t=0 to t=15 in **Figures 4.16 to 4.32.**
2. Backwarm mode that includes the simulation results from t=0 to t=15 in **Figures 4.33 to 4.50.**

The reason behind stopping at 15 minutes is due to taking credit of operator intervention to intervene and start some procedural steps to mitigate and finally stop the relief. This assumption is pretty reasonable considering the fact that DCS system will notify the operators about the changes of pressure. The pressure will show a sudden increase in the Blowdown overhead receiver and also the relieved materials will go to Blowdown section and not anymore to main Fractionator, therefore the pressure of main Fractionator overhead will drop suddenly that has an immediate impact on wet gas compressor section. In the meantime all Pumps around circuits will be affected by loss of level from their respective draw off trays that will result in emergency shut down of pump around as well as product pumps.

This calculation will also specify the set pressure of Blowdown section overhead PSV to determine the backpressure in the Coke Drum PSVs. In fact the lower PSV set pressure on the Blowdown section the lower PSV size for Coke Drums, but there are limitations/constraints to be considered in Blowdown PSV set pressure:

- It should be higher enough than the normal operating pressure to avoid any PSV chattering (if bellows type is selected).
- It should be also high enough to let the relieved material flows up to the flare knock out drum. Therefore the hydraulic calculations on the flare header will specify the PSV pressure.

The greater result of abovementioned criteria/constraint will specify the PSV set pressure on the Blowdown section, hence the PSV set pressure on the Coke drum as well as their size and hydraulic calculation on the connecting piping.

4.4. Methodology

CALCULATION OBJECTIVES:

- To specify the maximum probable relief temperature from Delayed coker Unit.
- To define the Blowdown Tower and Blowdown Receiver PSVs set pressures.
- To specify the relief load from the Blowdown Tower and the Blowdown Receiver at the following scenarios:
    1. Coke Drum Blocked Outlet when the Blowdown System is in quenching mode
    2. Coke Drum Blocked Outlet when the Blowdown System is in Idle / Heat-up mode

CALCULATION BASIS:

- Coke Drum vapor has the highest temperature in this unit (840° F). In the event of a blocked outlet on the on-line Coke Drum Vapor line, the relief temperature could be even higher than the above mentioned value.
- In order to cool down the relief temperature and also reduce the relief load, it is decided to direct the coke drum relief load to the Closed Blowdown System.
- The cooling / condensing capacity of the Closed Blowdown overhead column condenser could be utilized to condense a portion of the relieved material and mitigate the ultimate load and temperature.
- In this calculation, Coke Drum relief load is directed to the CBS at two modes of CBS operation:

  1. When CBS is at off-line coke drum quenching mode,
  2. When CBS is at Idle / off-line coke drum heat-up mode.
- The first scenario gives the highest relief load, and the second scenario gives the highest relief temperature.
- In order to arrive at the final answer (on the ultimate relief temperature), these two scenarios should be analyzed simultaneously. The highest load and therefore the piping/equipment pressure drop restriction will lead us to define the Blowdown Tower/ Blowdown Receiver PSV set pressures.
- Having the set pressures defined, running the model for the "Idle/Heat-up mode" case will provide the ultimate relief temperature.

ASSUMPTIONS:

- At CBS idle case (scenario # 1); credit is not taken from the overhead condenser in reporting the relief temperature.
- Blowdown System condenser will continue working with one bay out of 8 bays of air coolers is still working at scenarios # 2.

- A semi-dynamic model is used to simulate (with HYSYS) the system behavior during the first 15 minutes of relief (with 2 min. increments).
- The column bottom temperature changes (increases) during the relief due to the mixing of already existing "colder" liquid inside the column- and - the new generated "hot" liquid as a result of coke drum relief.
- A compressor model is used to predict the coke drum relief temperature at relieving pressure. The simulated model shows that the coke drum vapor temperature increases from 820°F to 891°F @ 81.2 psig.

SIMPLE BLOCK DIAGRAM:

Figure 4.1 shows a simple block diagram of relief scenario:

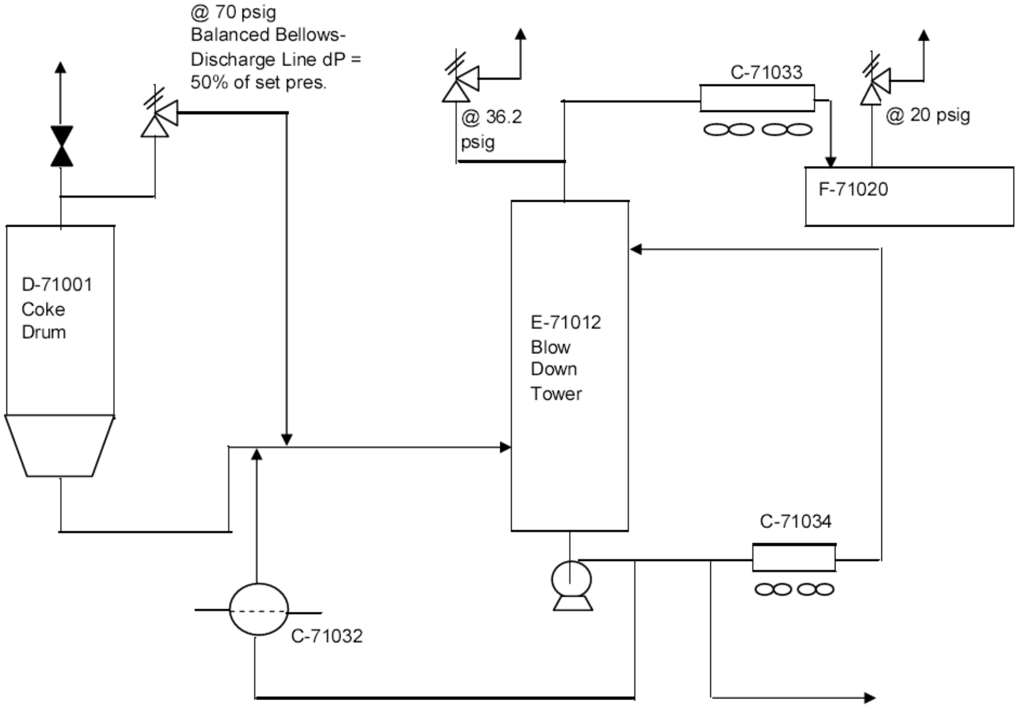


Figure 4.1-Simple Block Diagram of Relief Scenario

RELIEF SCENARIOS:

- Blocked Outlet at the on-line Coke Drum and Blowdown System at Idle mode (waiting for feed).
- Blocked Outlet at the on-line Coke Drum and Blowdown System at Back-warming mode.
- Blocked Outlet at the on-line Coke Drum and Blowdown System at Slow Quench mode.

Scenarios 1 and 2 will lead to the same ultimate result, because at Back-warming mode, 85% of on-line coke drum vapor is routed to the Fractionator Column and the remaining 15% is routed to the cold coke drum and then to the Blowdown Tower. Therefore eventually the same mass flow is directed to the Blowdown system. In Back-warming case, the combined temperature could be less than the idle case. By analyzing the system for idle case, the back-warming case is already covered.

Scenario # 3 gives the highest load to the Blowdown System. The load includes the total vapor rate from on-line coke drum and the generated steam due to slow quenching of the off-line coke drum.

SPECIFYING PSV SET PRESSURE:

1. Blowdown Receiver PSV set pressure (F-71020 as per Figure 4.1):

- Full credit is taken for the PSV(s) on this vessel (i.e., it relieves simultaneously with Blown tower PSVs).
- The whole idea of directing the coke drums relief load to the Blowdown system was based on using available cooling capacity of C-71033 (142 MMBTu/hr design duty). Therefore by cooling the hot relieved vapor from the on-line coke drum, the ultimate relieved vapor flow and temperature could be reduced.
- It is desirable that the ultimate relief takes place at the receiver PSV(s),

and prevent the Blowdown tower PSV(s) to react. The reason is to avoid relieving hot material as much as possible.

- To achieve that goal, the Blowdown receiver PSV(s) set pressure must be lower than the Blowdown tower PSV(s) set pressure (it is defined 20 psig as the initial guess considering sufficient backpressure to reach the flare network)
- On the other hand, the lowest set pressure must be high enough to overcome the relief header back pressure which is assumed 10 psig.

2. **Blowdown Tower PSVs set pressure (E-71012 as per Figure 4.1):**

- It is desirable to avoid using these PSVs (hot vapor relief is not desired).
- Therefore the set pressures of these PSV should be as high as possible. But the set pressure must be low enough- not to impose more than 60% superimposed back pressure on the coke drum PSV(s), which are set @ 70 psig.
- Blowdown Tower PSVs are therefore set at 30 psig (as an initial guess). Due to overhead system/piping restrictions, the Blowdown tower PSVs set pressure was increased to 36.2 psig, so that the maximum built-up back pressure on Coke Drum PSVs would be 67% of their set pressure (36.2 x 1.16 = 42 + 2.5 psi (Tower ΔP) + 2.27 psi(line friction loss)= 0.67 x 70 psig). Coke Drums PSVs should be de-rated to perform properly at this condition).
- These PSVs will open at the governing scenario, when Blowdown System receives the off-line coke drum slow quenching load and a blocked outlet happens at the on-line coke drum.
- The Blowdown overhead system (overhead piping/condenser ΔP) is restricting the flow towards the Blowdown receiver PSVs.
- Assuming 30 or 20 psig as set pressures at these locations, when a relief happens at receiver (accumulated pressure = 20 x 1.16 = 23.2 psig) - the

maximum affordable load for overhead system piping is a load which creates no more than 11.6 psi (30x 1.16 - 20 x 1.16) pressure drop.

- If the pressure drop exceeds the above mentioned value, Blowdown tower senses a pressure higher than first PSVs accumulation pressure

3. Coke Drums PSVs set pressure (D-71001 as per Figure 4.1):

Coke Drum PSVs set pressure should be set as high as possible for the following reasons:

- To maintain more flexibility on relieving to the Blowdown System- and eliminate back pressure limitation problems.
- To keep a safe margin/difference between the Fractionator Tower PSVs set pressure (55 psig) and the Coke Drum PSVs set pressure (70 psig)- so that in the event of a relief in Fractionator Tower, these PSVs remain closed as much as possible.
- Finally the Coke Drum design pressure sets the limit on how high we can select the PSVs set pressure. Cost considerations are apparently contributing to this selection.

CONCLUSIONS:

- The PSV calculation sheets for sizing of each case as per results shown in the simulation models are done or the following cases:
  - PSV sizing for Blowdown tower when it is at quench mode
  - PSV sizing for Blowdown receiver when Blowdown tower is at quench mode.
- Each PSV calculation sheets as per API 520 starts with calculation of flow regime to determine whether it is critical flow (i.e. Choke Flow condition). It is based on calculation of ratio P_{cf} / P1 (which is ratio of Pressure at critical flow by the back pressure of PSV outlet). If this ratio is above 1, i.e. P_{cf}>P1 therefore the flow is critical. Equation 4.1 is the governing formula (Isentropic Gas Expansion) to determine this ratio:

$$\frac{P_{cf}}{P_1} = \left(\frac{2}{k+1}\right)\wedge\left(\frac{k}{k-1}\right) \qquad \text{Eq. 4.1}$$

where $k = C_p / C_v$

- The calculated PSV orifice size is determined by equation 4.2:

$$A(calculated) = \frac{W}{(C \times K_d \times K_b \times K_c \times P_1) \times \sqrt{\frac{Z \times T}{MW}}} \qquad \text{Eq. 4.2}$$

where:

W: Mass Flow Rate (Relief Load) lb/hr

P_1: Upstream relieving pressure (Psia)

C: As per figure 32 of API 520. If k cannot be evaluated, use C = 315

K_d : (Coefficient of Discharge) is supplied by valve manufacturer. Initial guess is 0.975.

K_c = 1.0 for a PSV installed without a rupture disk

K_b = 1.0 for Pilot & Conventional valves, take value from Fig 30 of API 520 for balanced bellows valve.

MW: Molecular weight

Z: Compressibility Factor

T: Temperature (R)

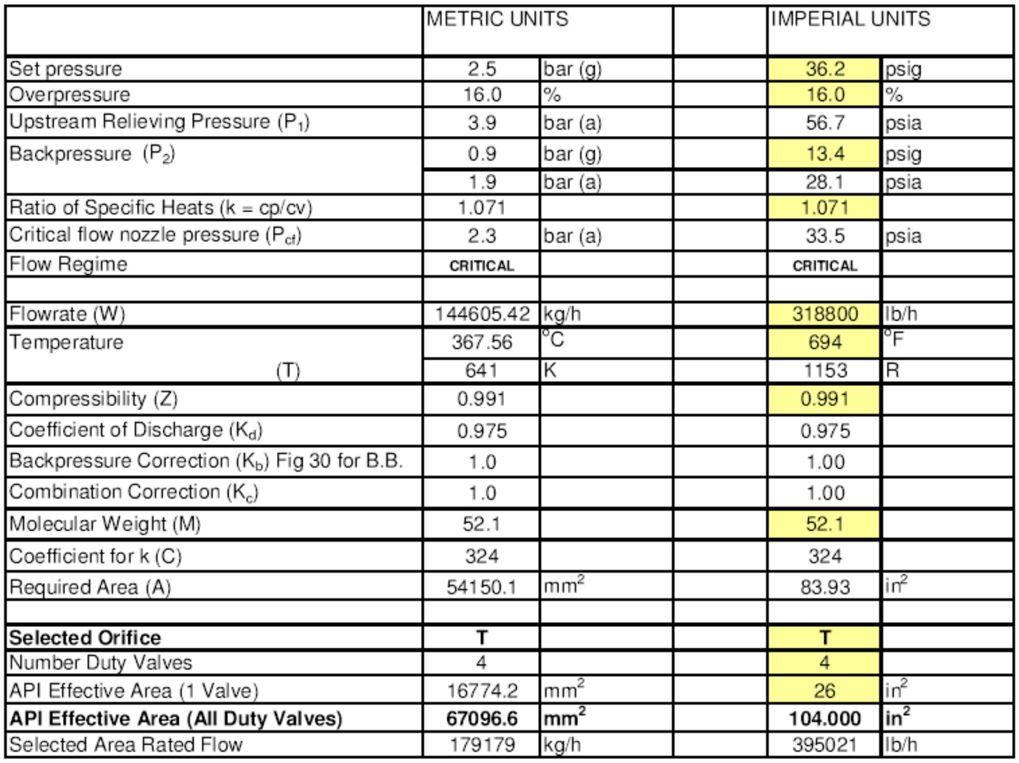
- Table 4.1 (as per API 526) is used to calculate the effective area, which is the nearest bore size on PSVs in the market and hence calculating the rated flow rate (relief load) as per effective area to calculate the hydraulics of piping system in both PSV upstream and down stream.

<u>Table 4.1: API Effective Areas API STD 526</u>

API Effective Areas API STD 526	
	in^2
D	0.11
E	0.196
F	0.307
G	0.503
H	0.785
J	1.287
K	1.838
2" x 3"	2.461
L	2.853
M	3.6
N	4.34
3" x 4"	5.546
P	6.38
4" x 6"	9.866
Q	11.05
R	16
6" x 8"	22.22
T	26
8"x10"x10"	38.9

- Table 4.2 shows the summary of calculation for PSV sizing for Blowdown tower when it is at quench mode

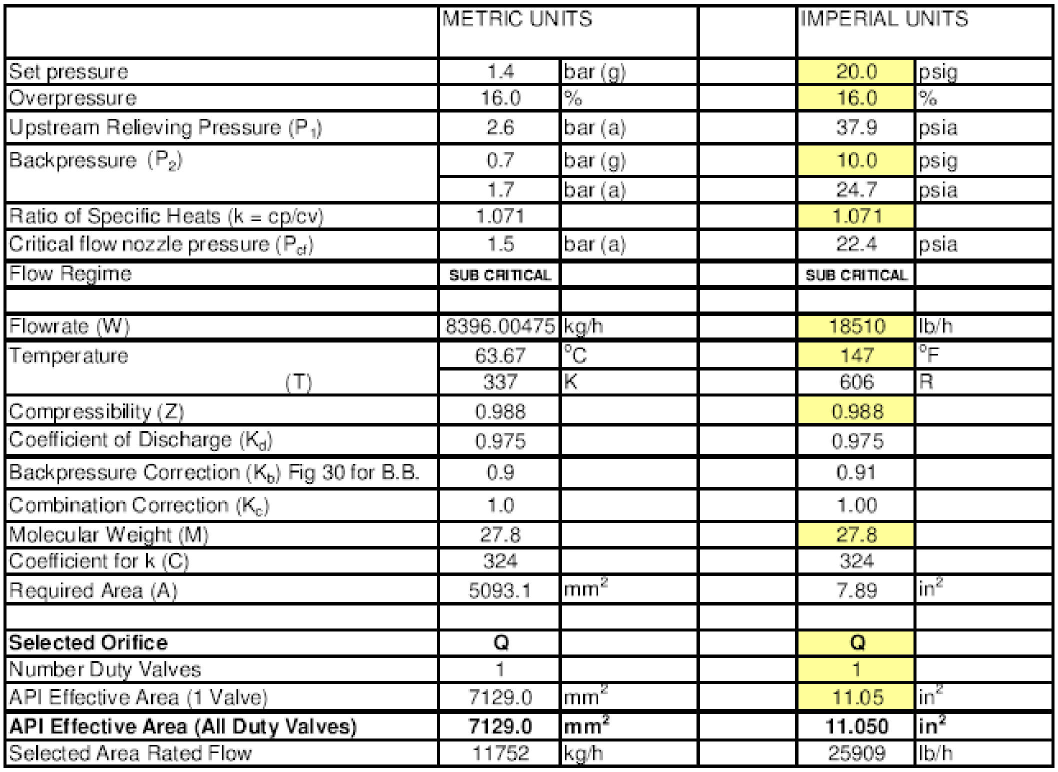
Table 4.2-PSV calculation Table of blow down tower



	METRIC UNITS			IMPERIAL UNITS	
Set pressure	2.5	bar (g)		36.2	psig
Overpressure	16.0	%		16.0	%
Upstream Relieving Pressure (P_1)	3.9	bar (a)		56.7	psia
Backpressure (P_2)	0.9	bar (g)		13.4	psig
	1.9	bar (a)		28.1	psia
Ratio of Specific Heats (k = cp/cv)	1.071			1.071	
Critical flow nozzle pressure (P_{cf})	2.3	bar (a)		33.5	psia
Flow Regime	CRITICAL			CRITICAL	
Flowrate (W)	144605.42	kg/h		318800	lb/h
Temperature	367.56	°C		694	°F
(T)	641	K		1153	R
Compressibility (Z)	0.991			0.991	
Coefficient of Discharge (K_d)	0.975			0.975	
Backpressure Correction (K_b) Fig 30 for B.B.	1.0			1.00	
Combination Correction (K_c)	1.0			1.00	
Molecular Weight (M)	52.1			52.1	
Coefficient for k (C)	324			324	
Required Area (A)	54150.1	mm^2		83.93	in^2
Selected Orifice	**T**			**T**	
Number Duty Valves	4			4	
API Effective Area (1 Valve)	16774.2	mm^2		26	in^2
API Effective Area (All Duty Valves)	**67096.6**	**mm^2**		**104.000**	**in^2**
Selected Area Rated Flow	179179	kg/h		395021	lb/h

- Table 4.3 also shows the summary of calculation for PSV sizing for Blowdown receiver when Blowdown tower is at quench mode

Table 4.3-PSV calculation Table of Blow Down Receiver



	METRIC UNITS			IMPERIAL UNITS	
Set pressure	1.4	bar (g)		20.0	psig
Overpressure	16.0	%		16.0	%
Upstream Relieving Pressure (P_1)	2.6	bar (a)		37.9	psia
Backpressure (P_2)	0.7	bar (g)		10.0	psig
	1.7	bar (a)		24.7	psia
Ratio of Specific Heats (k = cp/cv)	1.071			1.071	
Critical flow nozzle pressure (P_{cf})	1.5	bar (a)		22.4	psia
Flow Regime	SUB CRITICAL			SUB CRITICAL	
Flowrate (W)	8396.00475	kg/h		18510	lb/h
Temperature	63.67	°C		147	°F
(T)	337	K		606	R
Compressibility (Z)	0.988			0.988	
Coefficient of Discharge (K_d)	0.975			0.975	
Backpressure Correction (K_b) Fig 30 for B.B.	0.9			0.91	
Combination Correction (K_c)	1.0			1.00	
Molecular Weight (M)	27.8			27.8	
Coefficient for k (C)	324			324	
Required Area (A)	5093.1	mm^2		7.89	in^2
Selected Orifice	**Q**			**Q**	
Number Duty Valves	1			1	
API Effective Area (1 Valve)	7129.0	mm^2		11.05	in^2
API Effective Area (All Duty Valves)	**7129.0**	**mm^2**		**11.050**	**in^2**
Selected Area Rated Flow	11752	kg/h		25909	lb/h

- Blowdown Tower PSVs set pressure is defined at 36.2 psig. It should be noted that based on this value, Blowdown Tower relief pressure would be 42 psig (36.2 x 1.16), and considering the friction loss from the Coke Drum PSVs outlet to the Blowdown Tower, The total back pressure right after the Coke Drums PSV would be around 46.77 psig (which is 67% of the Coke Drums PSVs set pressure), therefore the Coke Drums PSVs should be de-rated to perform properly at this condition.
- Blowdown Receiver PSVs set pressure are defined at 20 psig.
- Four "**8 T10**" PSVs are required for the Blowdown Tower.
  (Staggered set pressures with 5% difference should be defined starting with 36.2 psig)
- One**" 6 Q 8"** PSVs or Two "**3 N 4**" PSVs are required at the Blowdown Receiver for Coke Drum Relief Scenarios.
- (Staggered set pressures with 5% difference to be defined, 20 and 21 psig in case the 3N4 size is selected)
- It is possible to reduce the PSVs inlet pressure drop by selecting two smaller PSVs instead of one large PSV.
- The combined relief load/temperature from Blowdown Tower/ receiver at quench scenario is **335800 lb/hr / 650°F** respectively.
- The combined relief load/temperature from Blowdown Tower/ receiver at idle/ Heat-up scenarios is **223200 lb/hr / 685°F** respectively.
- Assuming Blowdown Tower PSVs set @ 36.2 psig; the relief pressure would be 42 psig, (36.2 x 1.16) which creates a total back pressure of 46.77 psig at Coke Drum PSV outlet nozzle. This back pressure corresponds to 67% of Coke Drum PSVs set pressure of 70 psig. According to the available PSV vendor catalogues, we are most likely able to select a valve which performs properly at this condition.
- By considering only 60% total back pressure at Coke Drum PSVs outlet nozzles, we need to reduce the Blowdown Tower PSVs set pressure to 32 psig. In this condition an extra 8T10 size PSV would be required to pass the relief load from

the Blowdown Tower. The final relief load and temperature at coke Drum relief during the CBS Quench mode to the ISBL flare header would be **382000 lb/hr and 659℉** respectively.

- For Coke Drum relief at CBS Back-warming case (Blowdown Tower PSVs set pres.@ 36.2 psig), if we assume the number of available bays in C-71033 would be the same required number of bays at Back-warming condition (which is 1 bay out of 8 bays - please see Note 1), we expect the lowest cooling duty.
  The final relief load and temperature corresponding to this case would be **336100 lb/hr and 717℉** respectively.
- The un-mitigated load / Temperature at Coke Drum Relief and CBS idle case would be (Blowdown overhead vapor at Back-warming study) **365700 lb/hr and 727℉** respectively (Blowdown Tower PSVs set pressure @ 36.2 psig).

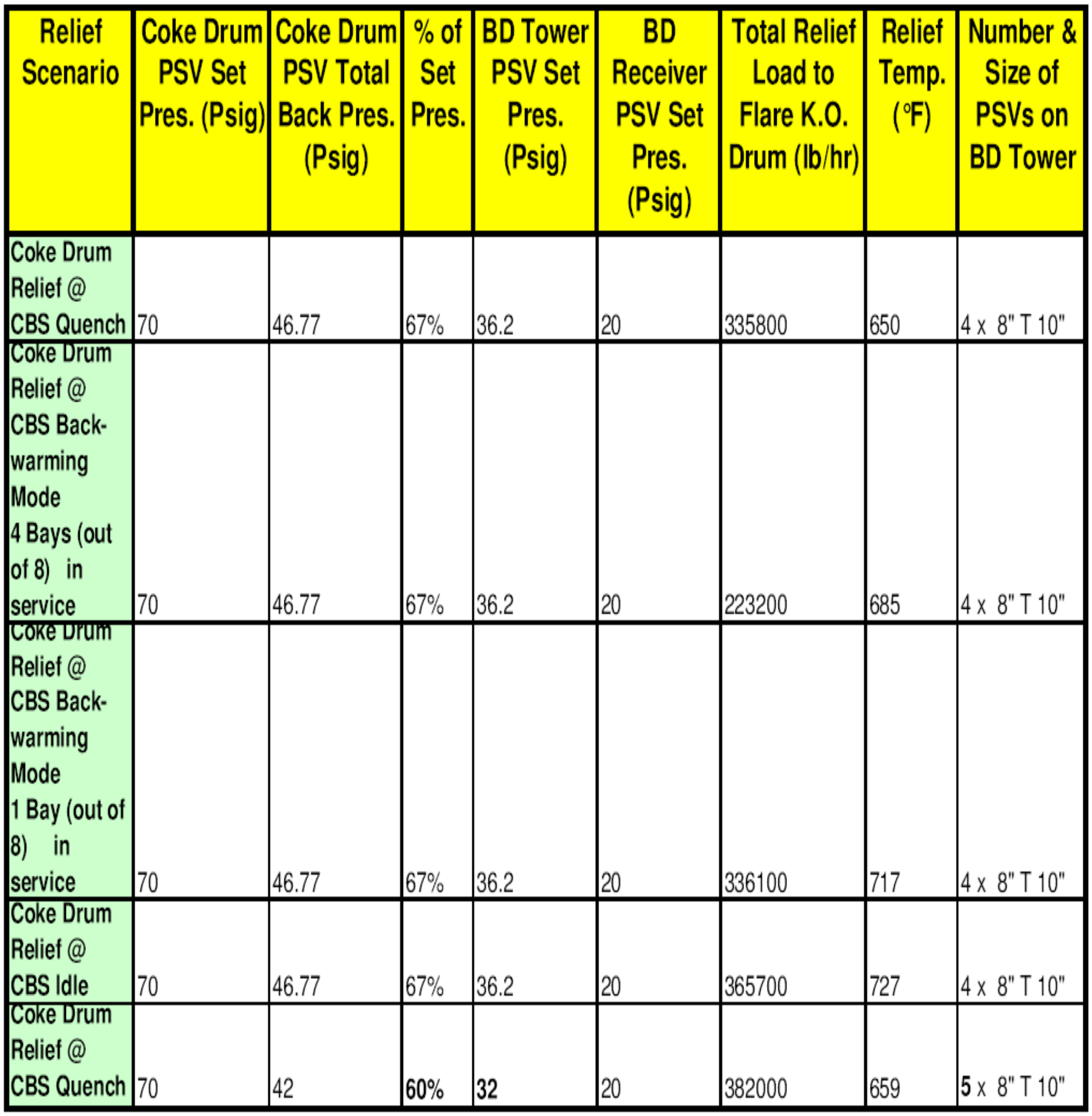
PROVISIONS AND CONSIDERATIONS:

- The overhead system in Blowdown section has a symmetric piping, and therefore works based on equal pressure drop concept at each parallel path.
- When the cooling requirement in regular CBS cycle is low (Back-warming cases), we may assume all the bays would pass an equal portion of flow, but with a low fan speed. Once the relief load is added to the regular Backwarming load (through the condenser), the flow portion to each bay would be increased and as a result, the temperature controller would increase the fans speed, and consequently condensation rate would be increased and therefore higher loads of vapor could be replaced (as a result of pressure gradient) and passed through the bays- and the cycle continues until the fans work on their full speed OR the ΔP across the condenser limits the vapor flow through these parallel paths (C-71033 eight bays).
- Based on the above assumption, it can be expected considerable cooling from C-71033 bays/ fans even at Backwarming or Idle cases (due to instrumentation response), **for which no credit is taken to keep the conservative approach in a relief system design**.

SUMMARY OF RESULTS:

Table 4.4 summarizes the calculations and simulation results taken from HYSYS as well as abovementioned PSV calculations. This table includes the calculated Coke Drum PSV backpressure, Blowdown PSV set pressure as well as receiver PSV set pressure considering the Coke drum PSV is set at 70 psig for each simulation case.

Table 4.4-Summary of PSV Calculations Results



Relief Scenario	Coke Drum PSV Set Pres. (Psig)	Coke Drum PSV Total Back Pres. (Psig)	% of Set Pres.	BD Tower PSV Set Pres. (Psig)	BD Receiver PSV Set Pres. (Psig)	Total Relief Load to Flare K.O. Drum (lb/hr)	Relief Temp. (°F)	Number & Size of PSVs on BD Tower
Coke Drum Relief @ CBS Quench	70	46.77	67%	36.2	20	335800	650	4 x 8" T 10"
Coke Drum Relief @ CBS Back-warming Mode 4 Bays (out of 8) in service	70	46.77	67%	36.2	20	223200	685	4 x 8" T 10"
Coke Drum Relief @ CBS Back-warming Mode 1 Bay (out of 8) in service	70	46.77	67%	36.2	20	336100	717	4 x 8" T 10"
Coke Drum Relief @ CBS Idle	70	46.77	67%	36.2	20	365700	727	4 x 8" T 10"
Coke Drum Relief @ CBS Quench	70	42	**60%**	**32**	20	382000	659	**5** x 8" T 10"

TEMPERATURE VARIATION OF STREAMS VERSUS TIME:

Table 4.5 and figure 4.2 show the temperature variations of important stream for slow quench mode at each time slot for important streams mentioned above:

Table 4.5

Slow Quench Mode

Time (Min.)	_163A			_164		_168		_169 Final Load	
	Temp. (°F)	Mass Flow Rate(lb/hr)	Hot Flow ratio	Temp. (°F)	Mass Flow Rate(lb/hr)	Temp. (°F)	Mass Flow Rate(lb/hr)	Temp. (°F)	Mass Flow Rate(lb/hr)
0	471.9	1.13E+04	0.0000	763.5	5.71E+05	666.8	5.54E+05	637.9	3.36E+05
2	471.6	1.28E+04	0.1559	764.6	5.71E+05	667.5	5.55E+05	638.7	3.36E+05
4	509.1	1.28E+04	0.1550	765.4	5.71E+05	668.1	5.56E+05	639.3	3.37E+05
6	543.7	1.28E+04	0.1680	766.2	5.71E+05	668.7	5.47E+05	638.9	3.30E+05
8	572.7	1.28E+04	0.1656	766.8	5.71E+05	671.8	5.49E+05	642.1	3.32E+05
10	597	1.28E+04	0.1637	767.4	5.71E+05	675.4	5.51E+05	645	3.34E+05
12	617.5	1.29E+05	0.1625	767.8	5.71E+05	676.9	5.52E+05	647.4	3.35E+05
14	634.9	1.29E+04	0.1615	768.2	5.71E+05	678.9	5.53E+05	649.4	3.36E+05
15	642.2	1.29E+04	0.0800	768.4	5.71E+05	679.8	5.53E+05	650.2	3.36E+05

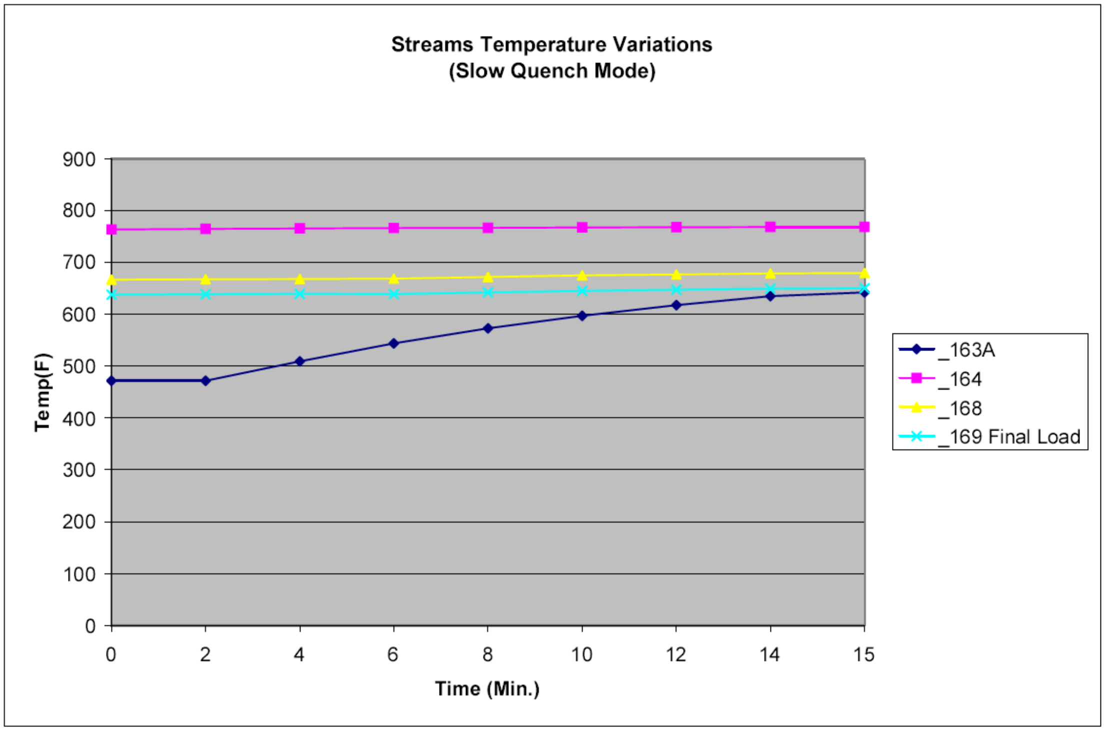


Figure 4.2-Stream Temperature Variations-Slow Quench

Table 4.6 and figure 4.3 show the temperature variations at back warm mode of important stream at each time slot for important streams mentioned above:

Table 4.6

Back Warm(Heat Up) Mode

Time (Min.)	_163A			_164		_168		_169 Final Load	
	Temp. (°F)	Mass Flow Rate(lb/hr)	Hot Flow ratio	Temp. (°F)	Mass Flow Rate(lb/hr)	Temp. (°F)	Mass Flow Rate(lb/hr)	Temp. (°F)	Mass Flow Rate(lb/hr)
0	491	1.10E+04	0.1573	829.2	4.31E+05	702.5	3.81E+05	663	2.33E+05
2	543.6	1.10E+04	0.1926	830.4	4.31E+05	703.4	3.82E+05	663.9	2.33E+05
4	590.3	1.11E+04	0.2054	831.5	4.31E+05	708.8	3.71E+05	667.2	2.26E+05
6	628.7	1.11E+04	0.2064	832.4	4.31E+05	714.1	3.71E+05	671.9	2.25E+05
8	655.2	1.12E+04	0.212	833.1	4.31E+05	718.2	3.71E+05	675.2	2.25E+05
10	685.6	1.12E+04	0.2073	833.8	4.31E+05	722.4	3.70E+05	679.5	2.25E+05
12	706.4	1.13E+04	0.209	834.4	4.31E+05	725.5	3.70E+05	682.4	2.25E+05
14	717.1	1.13E+04	0.2112	834.6	4.31E+05	727.3	3.68E+05	683.7	2.23E+05
15	722.1	1.13E+04	0.1060	834.8	4.31E+05	728.2	3.67E+05	684.4	2.23E+05

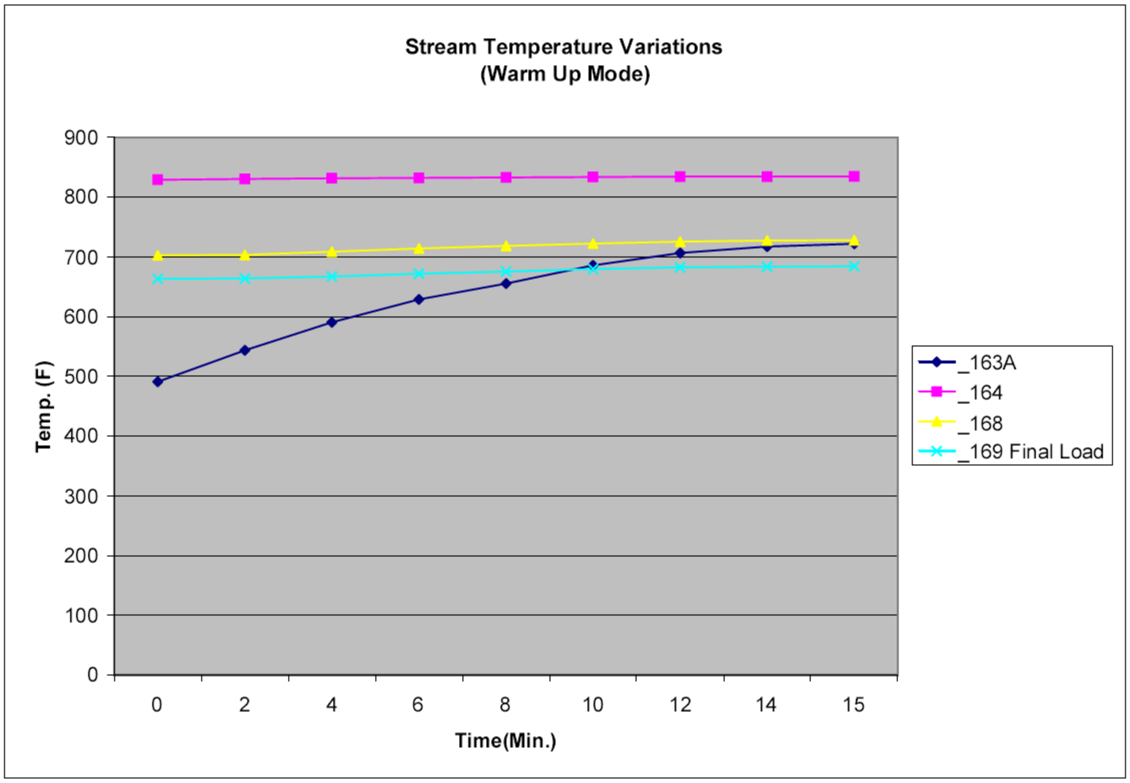


Figure 4.3-Stream Temperature Variations-Warm Up

4.5 Safety Considerations in Delayed Coker Unit

This section discusses about the importance of safety with an emphasis on Delayed Coker Unit. It mainly focuses on the Coke Drum operations as one of the most interesting safety considerations in this unit operation. It also brings the reader's attention about the means of safety analysis methods with an emphasis on cyclic behaviour of switching the coke drums. There are many diagrams are presented in this chapter to show each valve status (already identified in the P&IDs presented in chapter 2) of each step in order to meet permissive criteria for that particular step. In order to have comprehensive understanding about the valve positioning for each step, reader is encouraged to see these diagrams in conjunction with P&IDs shown in chapter 2.

At the end the concept of layer of protection is discussed to remind the reader that whatever means are provided in the set of permissive may not sufficient although they are necessary. Therefore, some other means of protections are usually added to safe design system to ensure if one layer of protection fails the next layer would control the subsequent events and so on. At one stage if the upset condition would progress to lead overpressure conditions, the Process Safety Valve system will protect the system to control the relief situation. At that condition we should have a good understanding and estimation of relief load as well as heightened temperature condition to ensure that PSV system will work as required and aimed for. However, relief mitigation nowadays is also a primary concern during the safe design of Delayed Coker Unit to reduce the severity of relief conditions and hence will help to reduce the capital investment spent on the exotic materials and size relief equipment/piping which is beyond the scope of this project thesis. At the end reader will get ready to understand chapter four that mainly discusses the credible relief scenario for only one specific condition which is Coke Drum relief.

4.5.1 Importance of Safety:

- **Overview**

Safety is an important aspect in the design and operation of any chemical process unit. However its importance is much more emphasized and highlighted as the type of processed materials in different phases can become any combination of hazardous, lethal, combustible, and explosive and contamination.

In almost every refinery units, hydrocarbons are being processed at high temperature (at either explosive limit or at auto-ignition temperature) and/or high pressure while carrying some extents of H_2S and other sulfur compounds that are lethal to operators for exposure at above their threshold limits. Then having a safe design and operation as well as maintenance procedure is essential to any refinery unit operation. Safety regulations nowadays require designers in different engineering disciplines to follow their safety regulations as well as design guides to ensure the safety concerns. In any refinery unit, design starts with process engineers to maintain the heat and material balance as per basis of design (BOD) agreed by client and engineering company. This heat and material balance, in general defines the throughput in the unit as well as feeds/products specifications that should match the design basis. Once this step is maintained, then equipment/line hydraulics design are started to ensure of their adequacy for materials handling at not only rated conditions as per design criteria but also for design conditions as analyzed during evaluation of upset scenarios.

Developing and analyzing the different upset scenarios is one the most challenging part of any unit process design, and some of them are unfortunate difficult and tough lessons learned from previous unit operations that led to some injuries/fatalities to learn how and why an upset condition can be happened and what will be the consequence of this incident that extends to an accident.

Once we could successfully analyze the upset scenarios, that usually needs one or combination of advanced techniques like Process Hazard Analysis (PHA), HAZOP analysis, FMEA (Failure Mode and Effect Analysis) and FTA (Failure Tree Analysis), then the severity of incident as well as frequency of probability of incident is quantified with ordinals from 1 to 10 (least to most). Such an analysis, for any part of process that is involved with different type of equipment (like pumps, compressors, fired heater, exchangers, air coolers and etc.), needs a team of different specialists to identify the common upset scenario as well as specific ones relevant to this part of process.

Once this analysis is held in different series of meetings, then the set of recommendations will be initiated to improve the process design and reduce the frequency of incident. Since the severity of some incidents would cause damages and fatalities, therefore a redundant and independent control system with high reliability will be maintained to prevent the occurrence of that incident.

- **Safety in Delayed Coker Unit**

What actually makes DCU different and somewhat unique from other refinery units is its semi batch operation in two sections of this unit, which is coke drum and closed Blowdown section. At any time of operation, there is only one Coke Drum (assuming, we are discussing about a two Coke Drum unit operation) in online mode and is interacting with main Fractionator and the other one is in offline mode interacting with Closed Blowdown Section. During the period that the Coke Drum is in offline mode it must go to different steps of cooling (by quenching with HP steam and then water at 150°F), Coke cutting and then back warming to get ready for the next cycle.

In order to ensure that different steps of operation on the offline drum won’t interfere the online drum operation or vice versa to induce any hazard condition (as it is working at very high temperature conditions). Then in addition to all subjects discussed above about the safety concerns and their considerations, this unit needs a panel that includes set of permissive signals that won’t let any step proceed unless the set of permissive signals are met their conditions.

4.5.2 Modes of Operations of Coke Drums:

The following figures are developed to demonstrate the different mode of operations and their interactions with other units of DCU. For ease of following each step which somehow typical for a nominal 25000 bbl/day capacity, the following points should be considered:

- Figure 4.4 shows an overall picture of coke drums structure of incoming and outgoing streams depends on mode of operation of each coke drum as well as step of offline drum operation.
- Each step is identified by in each Figure preceding the associated diagram.
- All other diagrams are simplified with hiding the streams that are not in service at that particular step.
- Black color stream represents the no flow stream.
- Colored stream represents the flowing streams while choosing a color signifies the relative hotness of fluid stream.

4.5.2.1. Part 1: Cooling down the newly Offline Coke Drum:

This part consists of the following steps for offline drum:

1. **Slow Steam out:**
   At this step, steam at 250 psig is running into the newly offline drum for 30 minutes to remove the remained hydrocarbons in the voids of coke bed with a rate of 10000 lb/hr. The overhead vapor coming out this offline drum will join the overhead vapor coming from the newly online drum to be diverted into main Fractionator. At this step the antifoam still injects into offline drum (since the online drum is empty and therefore there is no possibility of foaming inside it while the offline drum is more vulnerable to foaming issue). HCGO quench

injection should also continue into overhead vapor of offline drum as it is hotter than the effluent coming from newly online drum (newly online drum is putting into the next cycle at 650 °F while the drum is switched into the offline mode at 840 °F at the end of each cycle). Figure 4.5 is showing this step.

2. Fast Steam out:

At this step the steam rate is increasing into 20000 lb/hr (within 10 minutes) while the flow of offline coke drum overhead vapor is changing to the closed Blowdown tower. This step continues for an hour that mainly carries steam with it. Since the newly online drum temperature is increasing, therefore the HCGO quench start injecting the overhead of the online drum. The effect of temperature drop of the offline drum after this step is not expected to be high and the final temperature is usually in the range of 700 to 750 °F. Figure 4.6 is showing this step.

3. Slow Water Quench:

At this step, steam supply is switched to water supply at 150 °F. It is very critical to increase the water rate from 0 to 100 gpm within an hour to avoid of bulging problem on the skirt joints of coke drum structure. This step maintains the biggest temperature drop in the offline coke drum from 750 to 450°F. Figure 4.7 is showing this step.

4. Fast Water Quench:

At this step, the water rate is increasing gradually from 100 to finally 1300 gpm for duration of 180 minutes. During this period of time the temperature should reach to almost 200 °F. However, from safety point of view, if the temperature drops faster than it should be or the total amount water being supplied with this period of time is lower than a recorded historical average value, then this is an indication of presence of shot coke and also presence of hot spot that will explode during the coke cutting. If such a condition happens, the process of water quench will be extended adequately while other steps will proceed with much more cautions. At the end of this step the water quench supply will stop and the vapor from the offline coke drum overhead will be diverted to closed blow down tower till their pressure balances or till the pressure of overhead line reaches to almost 14 psig. Figure 4.8 is showing this step.

5. **Vent:**

At this stage the remaining vapor inside the offline coke drum is vented into the atmosphere through vent silencers to minimize the noise pollution. Once the pressure drops to 1 psig in the overhead line then venting can be stopped. Figure 4.9 is showing this step.

6. **Water Drain:**

By the time the water quench step finishes, the offline drum is full with water with voids of coke bed (that normally is 1/3 of total coke drum volume which is about 70000 ft^3). This step will continue 2 hours while the water is drained into maze. The collected water will finally be pumped back to a tank for reuse in the next cycle of quench. Figure 4.10 is showing this step.

4.5.2.2. Part 2: Coke Removal of Offline Coke Drum:

This part consists of the following steps for offline drum:

1. Un-heading the top and bottom valves of coke drum (36” and 60 respectively). The duration is 30 minutes.
2. Pilot drilling in the middle of coke bed with a diameter of 3 ft. The duration is about 30 minutes.
3. Coke cutting with water at 4000 psig. The duration is 210 minutes. A large amount of water is being used at this step that will be diverted into the maze and finally will be pumped back to a tank for next cycle reuse.

4. Re-Heading the top and bottom valves. The duration is 10 minutes.

   Figures 4.16 to 4.19 are showing these steps.

4.5.2.3. Part 3: Backwarming of Offline Coke Drum:

This part consists of the following steps for offline drum:

1. **Steam Purge:**

   At this step the offline coke drum will be purged of de-aired with steam at 250 psig with 20000 lb/hr for duration 15 minutes. During this period the overhead vapor will be sent to atmosphere through vent silencer. Figure 4.11 is showing this step.

2. **Steam Pressure Test:**

   At this step the all the valves of the top part of coke drum are closed to let the drum pressure increase to 38 psig and the steam supply will stop. During this period the temperature of coke drum increase to about 250 ℉ while the operators should check for any leak test with visual inspection. The duration of this step in total is 45 minutes. Figure 4.12 is showing this step.

3. **Condensate Drain:**

   At this step if the leak test proceeds with success result, the condensate collected inside the coke drum will be drained into the maze that very rapidly will turn into vapor due to its high temperature. The duration for this step is 10 minutes. Figure 4.13 is showing this step.

4. **Backwarming with Hydrocarbon:**

   At this step, the offline drum is being warmed up with splitting the flow of overhead hydrocarbon vapors of online drum into 85% (For online drum) and

15% (for offline drum). This split is happening with a pinching a highly specialized valve (ring type HV-1006) while all four valves at the top of the coke drums are opened (MOV-1011, 1012, 1025 and 1026). This step in total takes 4.5 hours to let the temperature of offline coke drum reaches to 650 °F in which it is almost the time of switching the drums again. However, this step includes two sub-steps as the following:

- The collected hydrocarbon in the offline drum at the bottom will be diverted to closed Blowdown tower. This sub-step will be continued till the temperature of effluent toward closed Blowdown tower reaches to 350 °F. This is due to free water presence in the hydrocarbons which is not adequate for main Fractionator bottoms operation. Figure 4.14 is showing this sub-step.
- The collected hydrocarbons in the offline drum will be diverted to the main Fractionator. Figure 4.15 is showing this sub-step.

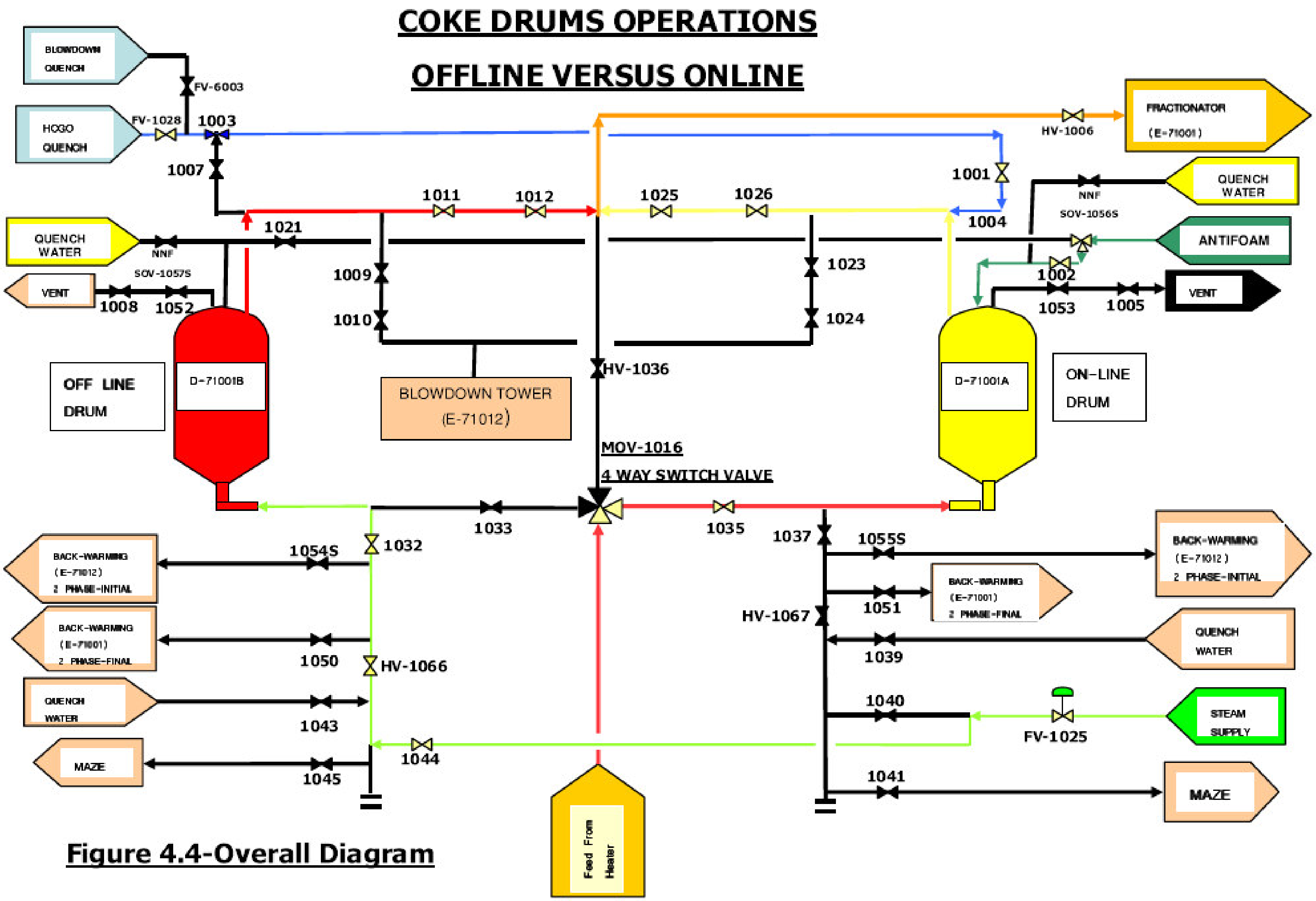
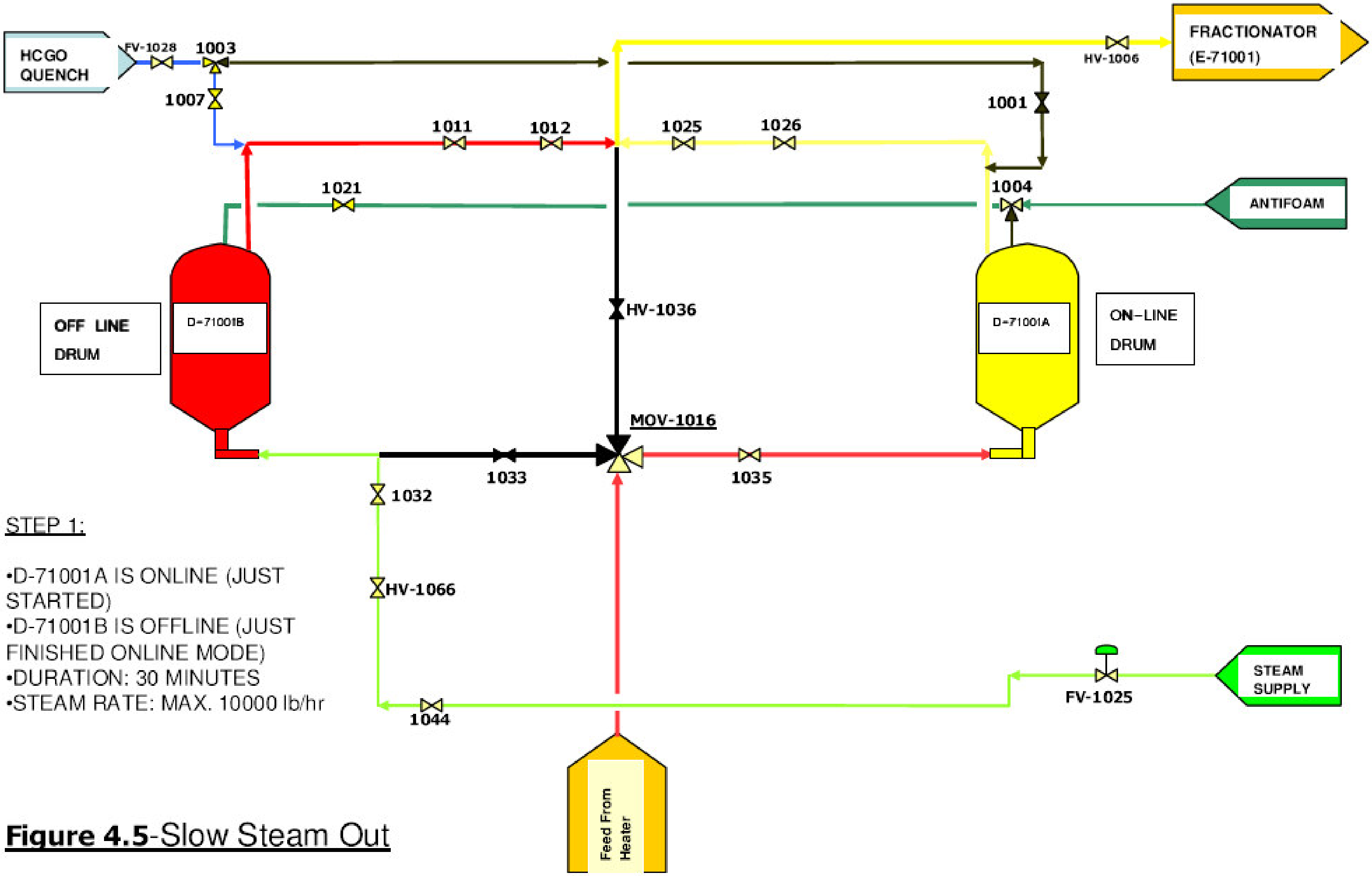


Figure 4.4-Overall Diagram

COOLING DOWN

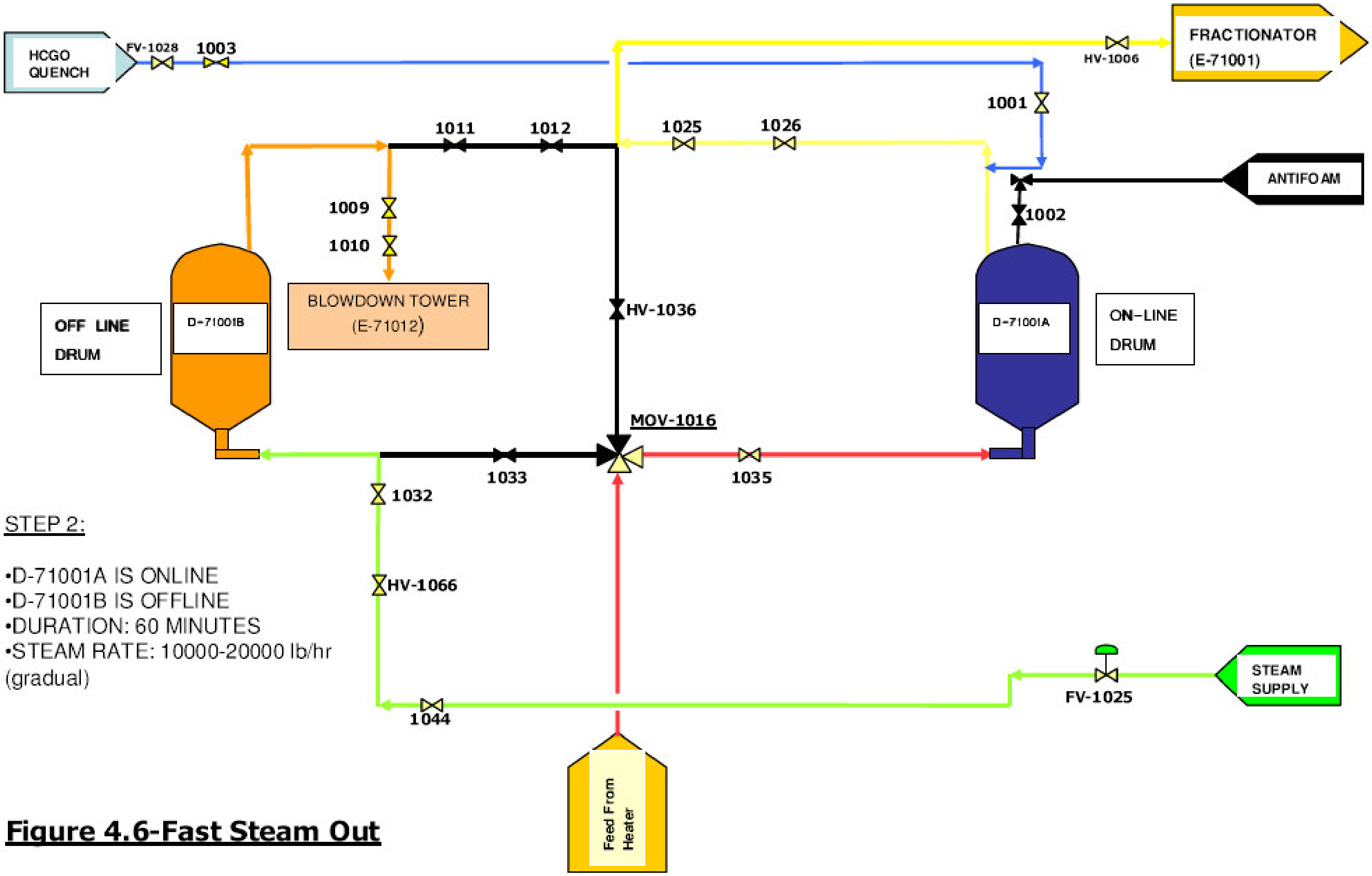


STEP 1:

- •D-71001A IS ONLINE (JUST STARTED)
- •D-71001B IS OFFLINE (JUST FINISHED ONLINE MODE)
- •DURATION: 30 MINUTES
- •STEAM RATE: MAX. 10000 lb/hr

Figure 4.5-Slow Steam Out

COOLING DOWN

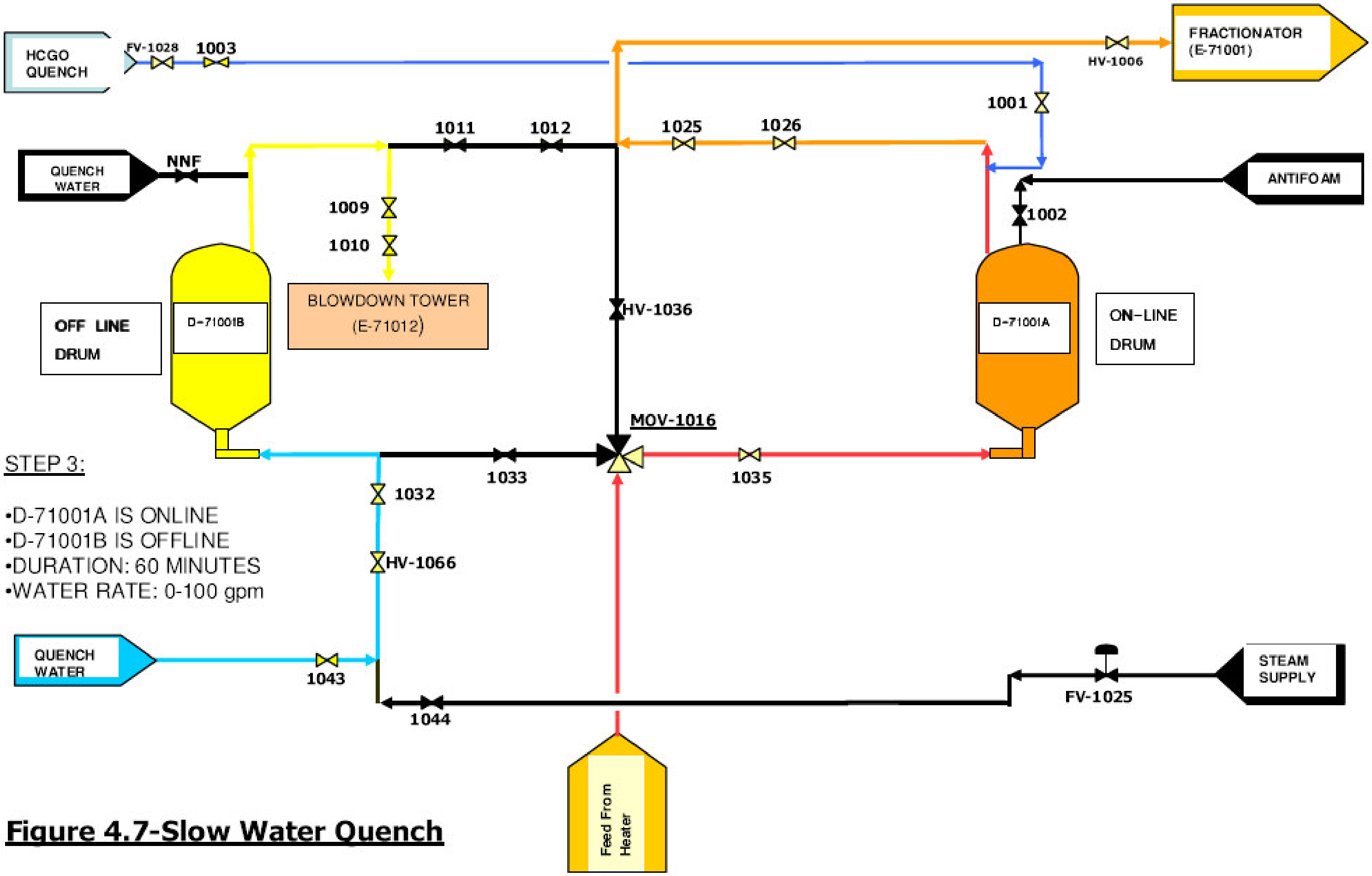


STEP 2:

- D-71001A IS ONLINE
- D-71001B IS OFFLINE
- DURATION: 60 MINUTES
- STEAM RATE: 10000-20000 lb/hr (gradual)

Figure 4.6-Fast Steam Out

COOLING DOWN

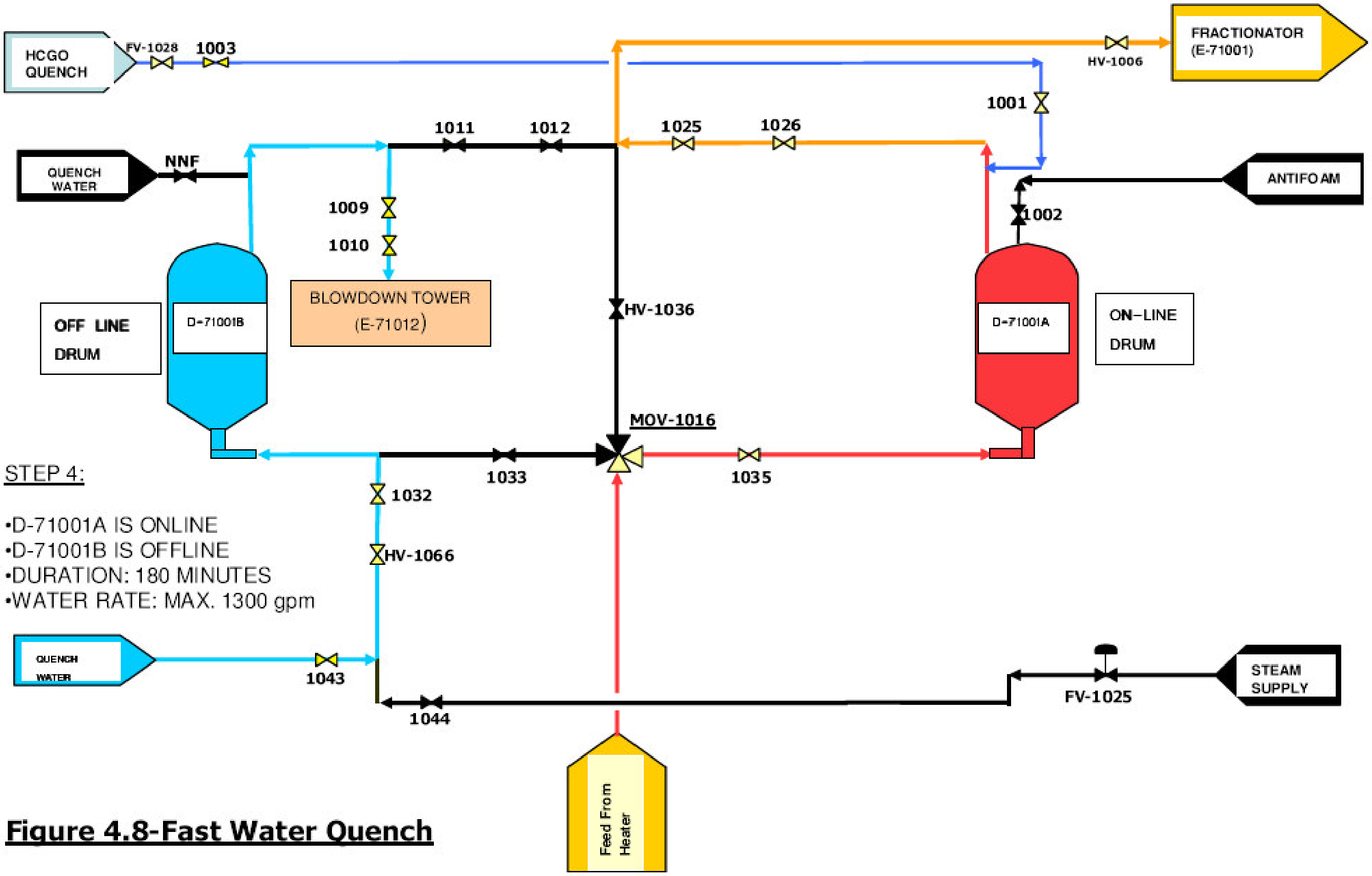


STEP 3:

- D-71001A IS ONLINE
- D-71001B IS OFFLINE
- DURATION: 60 MINUTES
- WATER RATE: 0-100 gpm

Figure 4.7-Slow Water Quench

COOLING DOWN

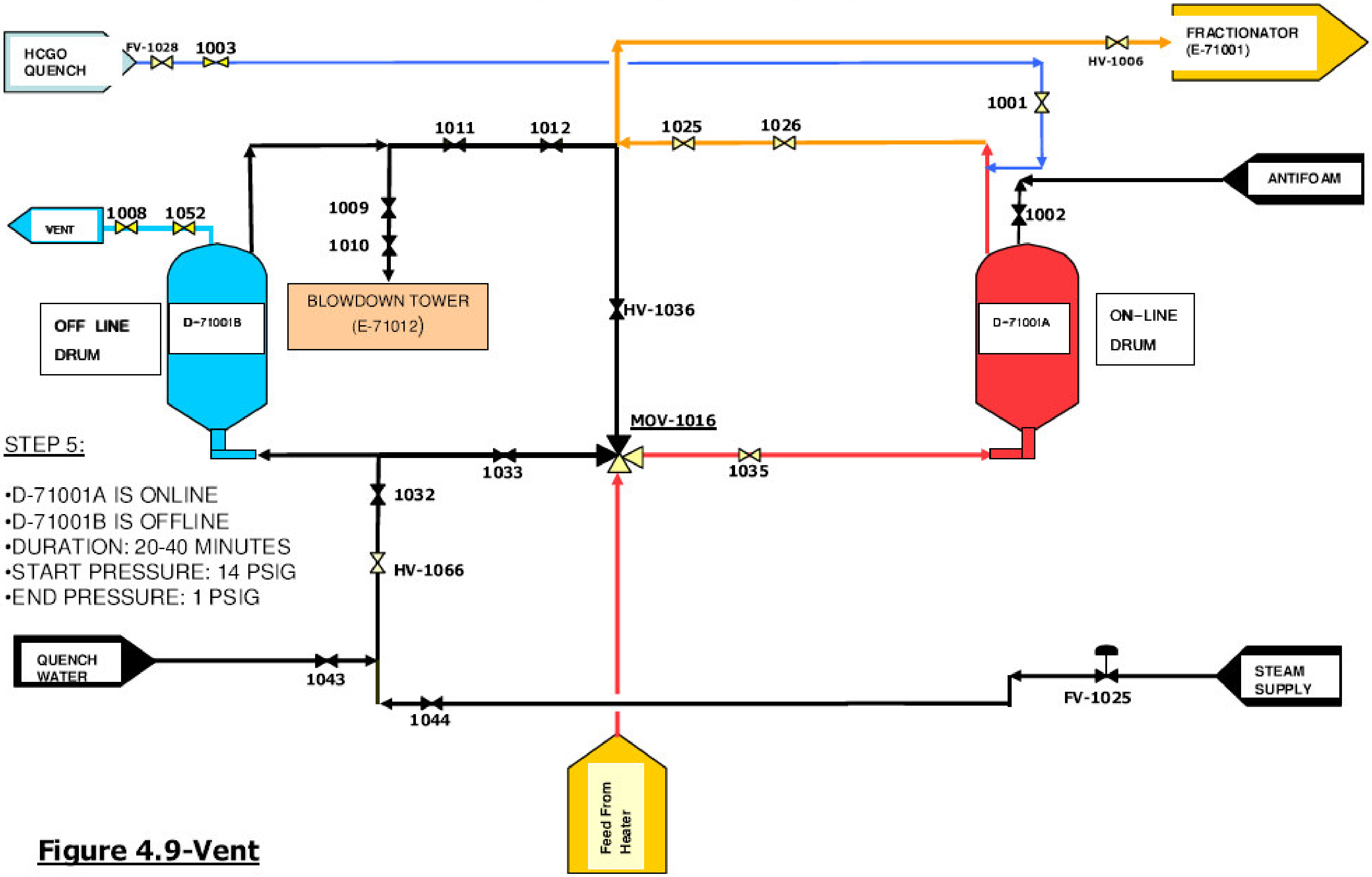


STEP 4:

- D-71001A IS ONLINE
- D-71001B IS OFFLINE
- DURATION: 180 MINUTES
- WATER RATE: MAX. 1300 gpm

Figure 4.8-Fast Water Quench

COOLING DOWN

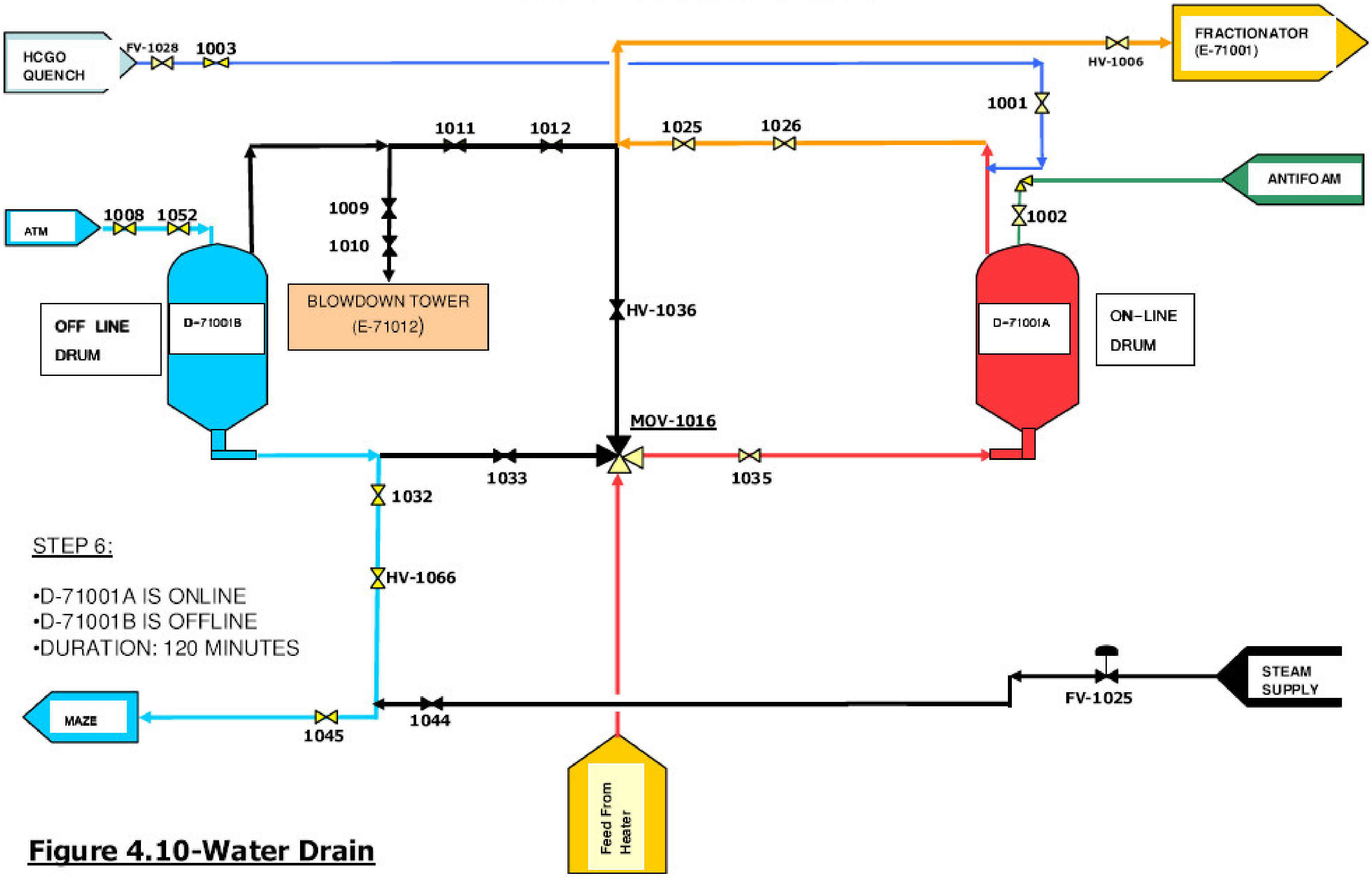


STEP 5:

- D-71001A IS ONLINE
- D-71001B IS OFFLINE
- DURATION: 20-40 MINUTES
- START PRESSURE: 14 PSIG
- END PRESSURE: 1 PSIG

Figure 4.9-Vent

COOLING DOWN

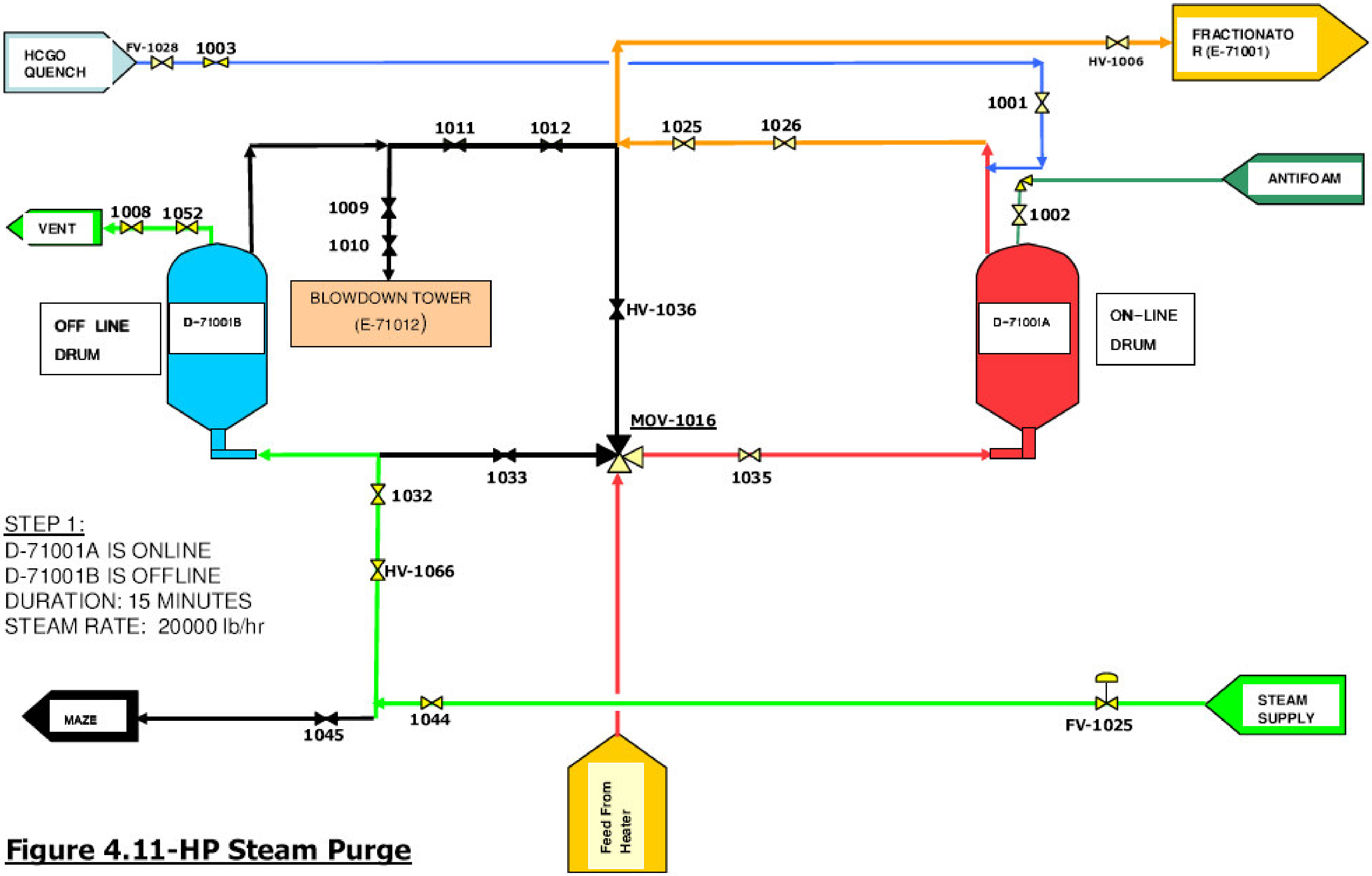


STEP 6:

- D-71001A IS ONLINE
- D-71001B IS OFFLINE
- DURATION: 120 MINUTES

Figure 4.10-Water Drain

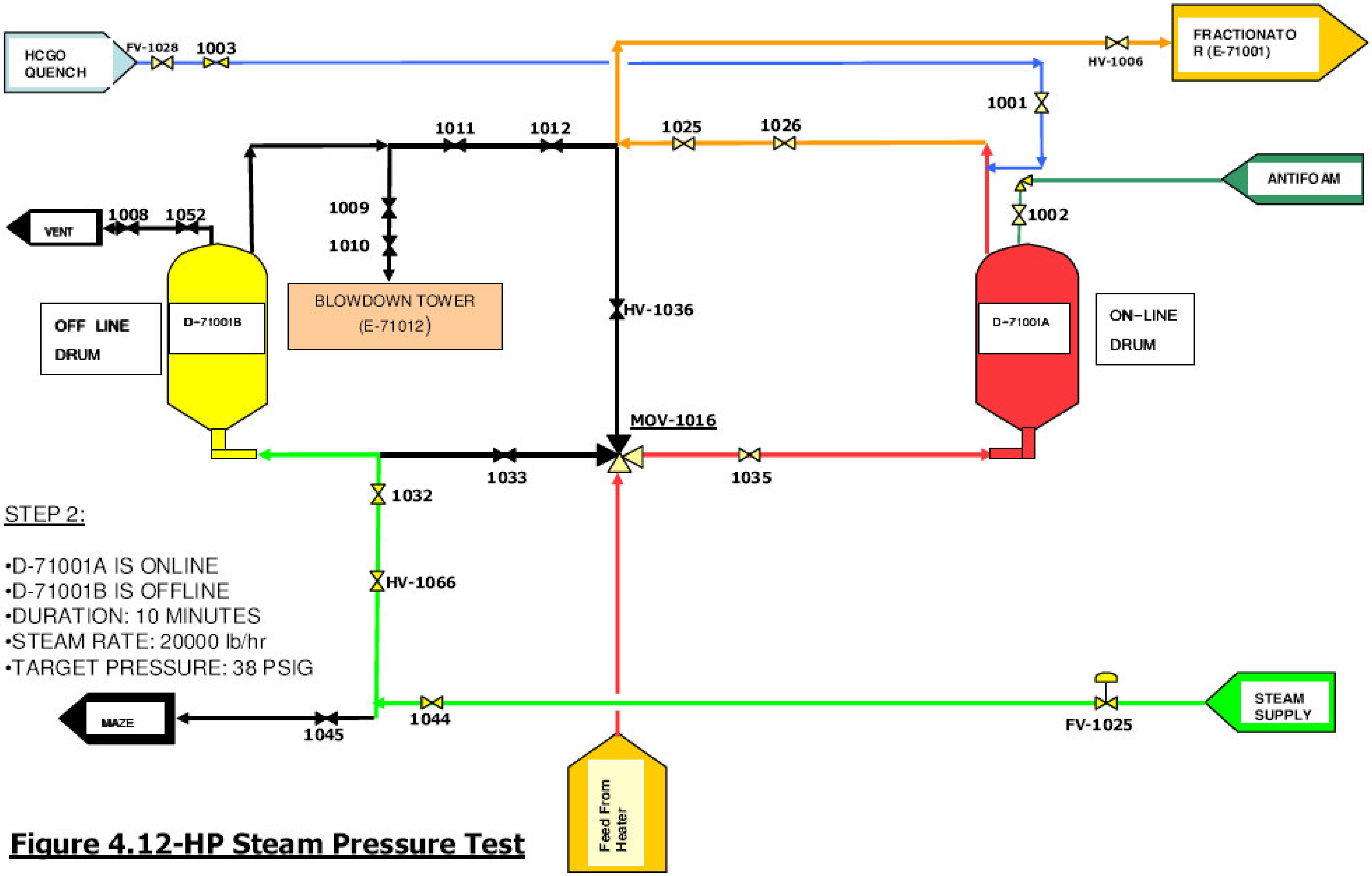
BACKWARMING



STEP 1:
D-71001A IS ONLINE
D-71001B IS OFFLINE
DURATION: 15 MINUTES
STEAM RATE: 20000 lb/hr

Figure 4.11-HP Steam Purge

BACKWARMING

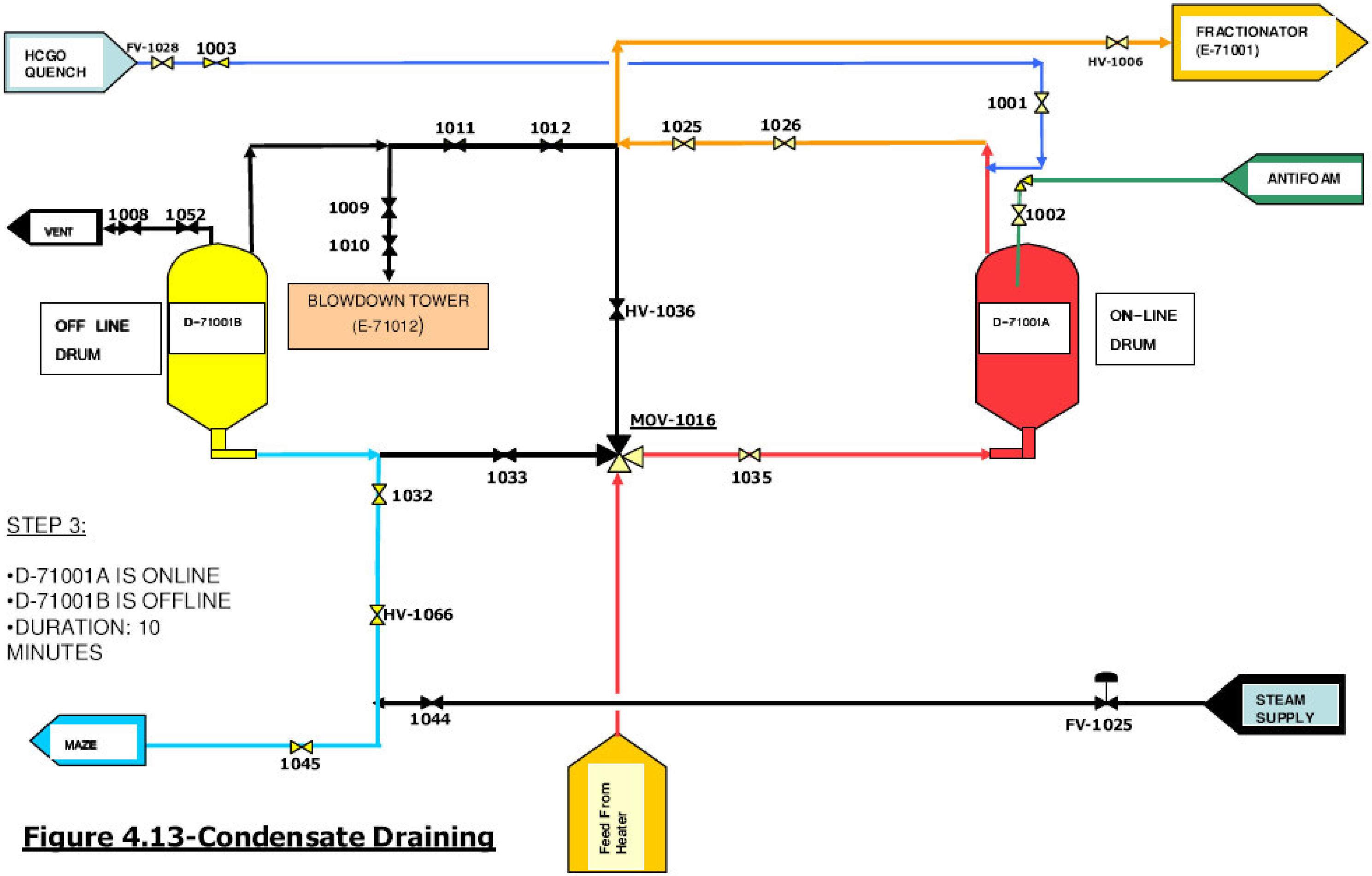


STEP 2:

- D-71001A IS ONLINE
- D-71001B IS OFFLINE
- DURATION: 10 MINUTES
- STEAM RATE: 20000 lb/hr
- TARGET PRESSURE: 38 PSIG

Figure 4.12-HP Steam Pressure Test

BACKWARMING

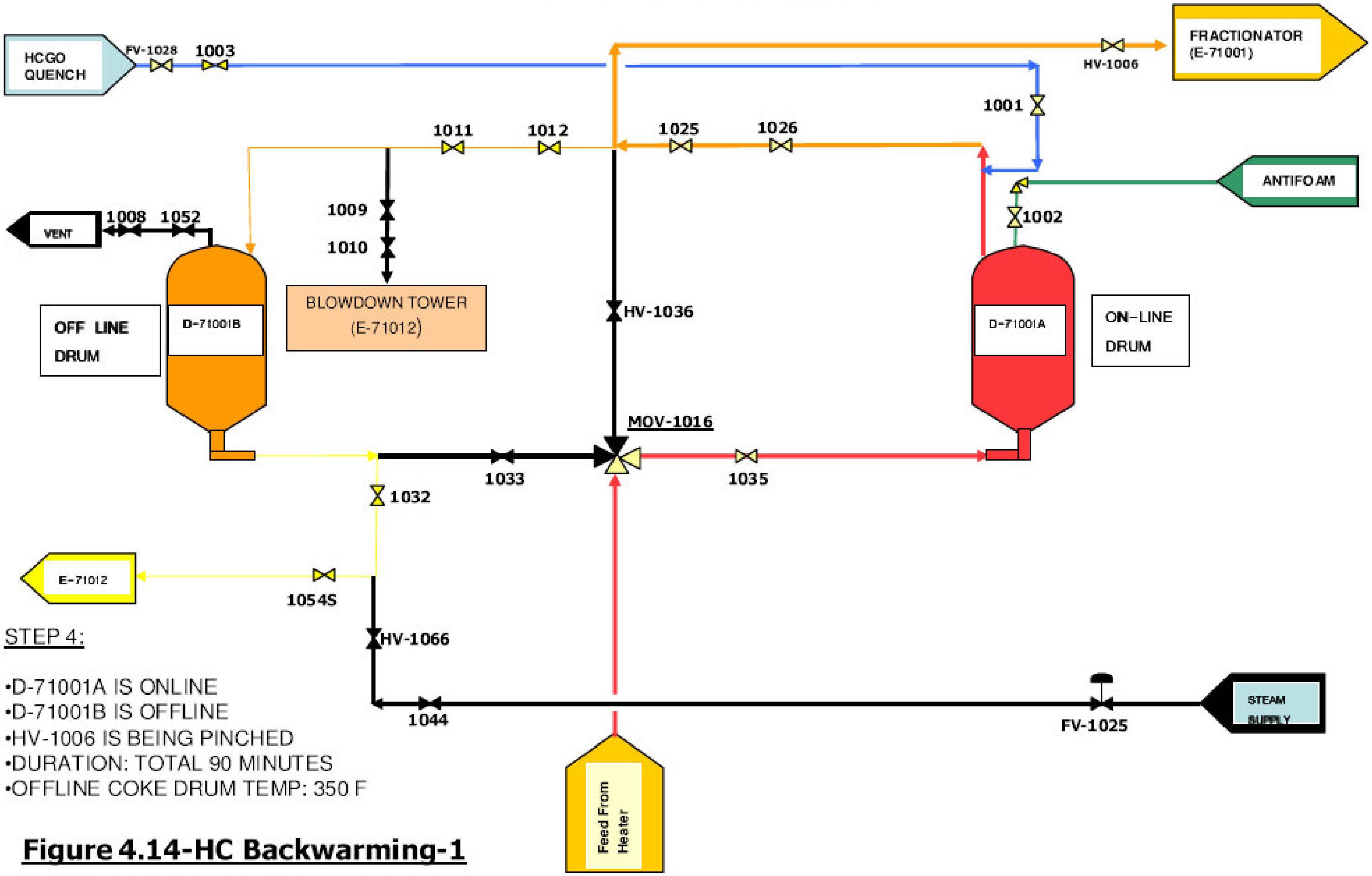


STEP 3:

- D-71001A IS ONLINE
- D-71001B IS OFFLINE
- DURATION: 10 MINUTES

Figure 4.13-Condensate Draining

BACKWARMING

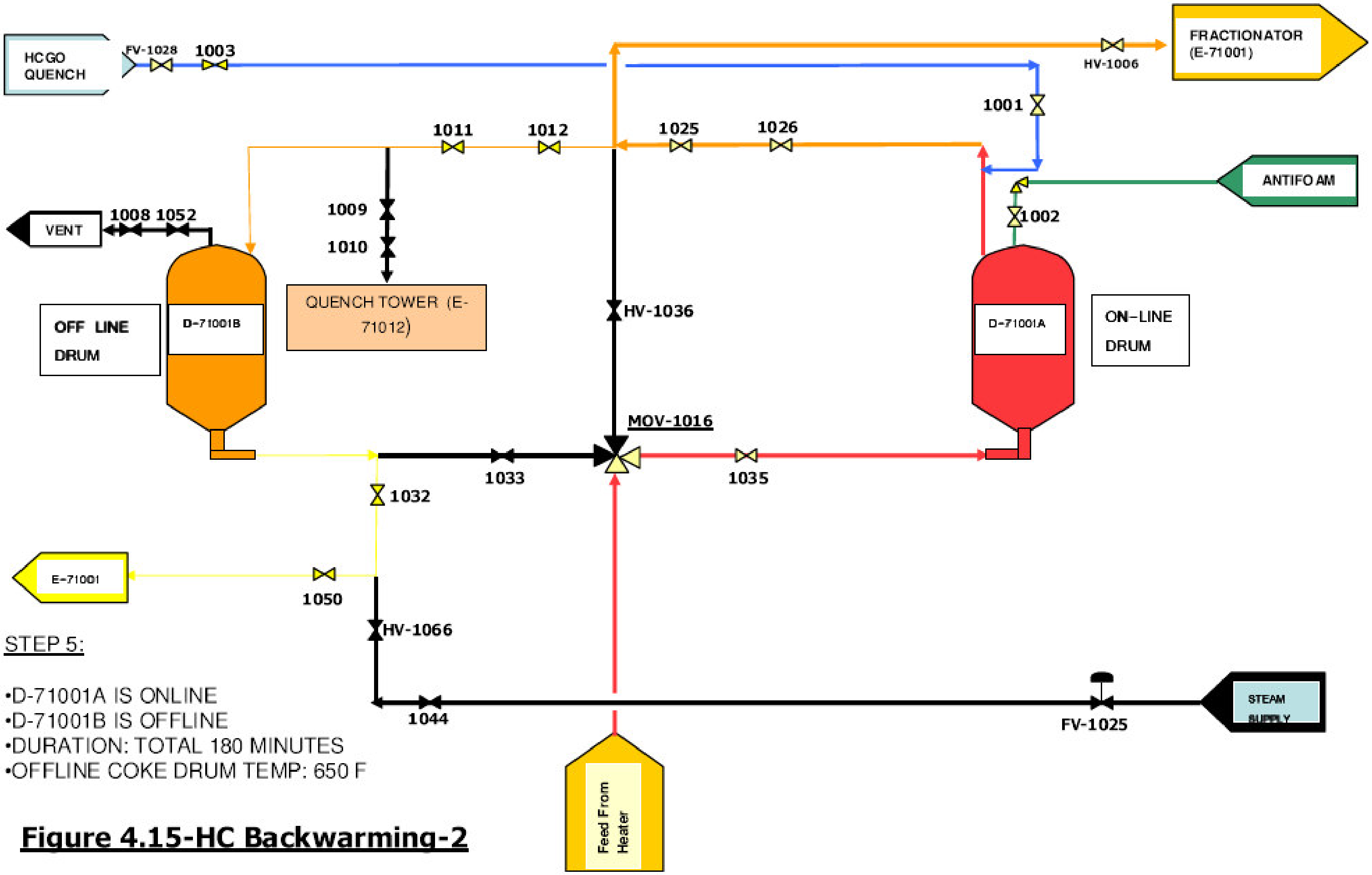


STEP 4:

- D-71001A IS ONLINE
- D-71001B IS OFFLINE
- HV-1006 IS BEING PINCHED
- DURATION: TOTAL 90 MINUTES
- OFFLINE COKE DRUM TEMP: 350 F

Figure 4.14-HC Backwarming-1

BACKWARMING

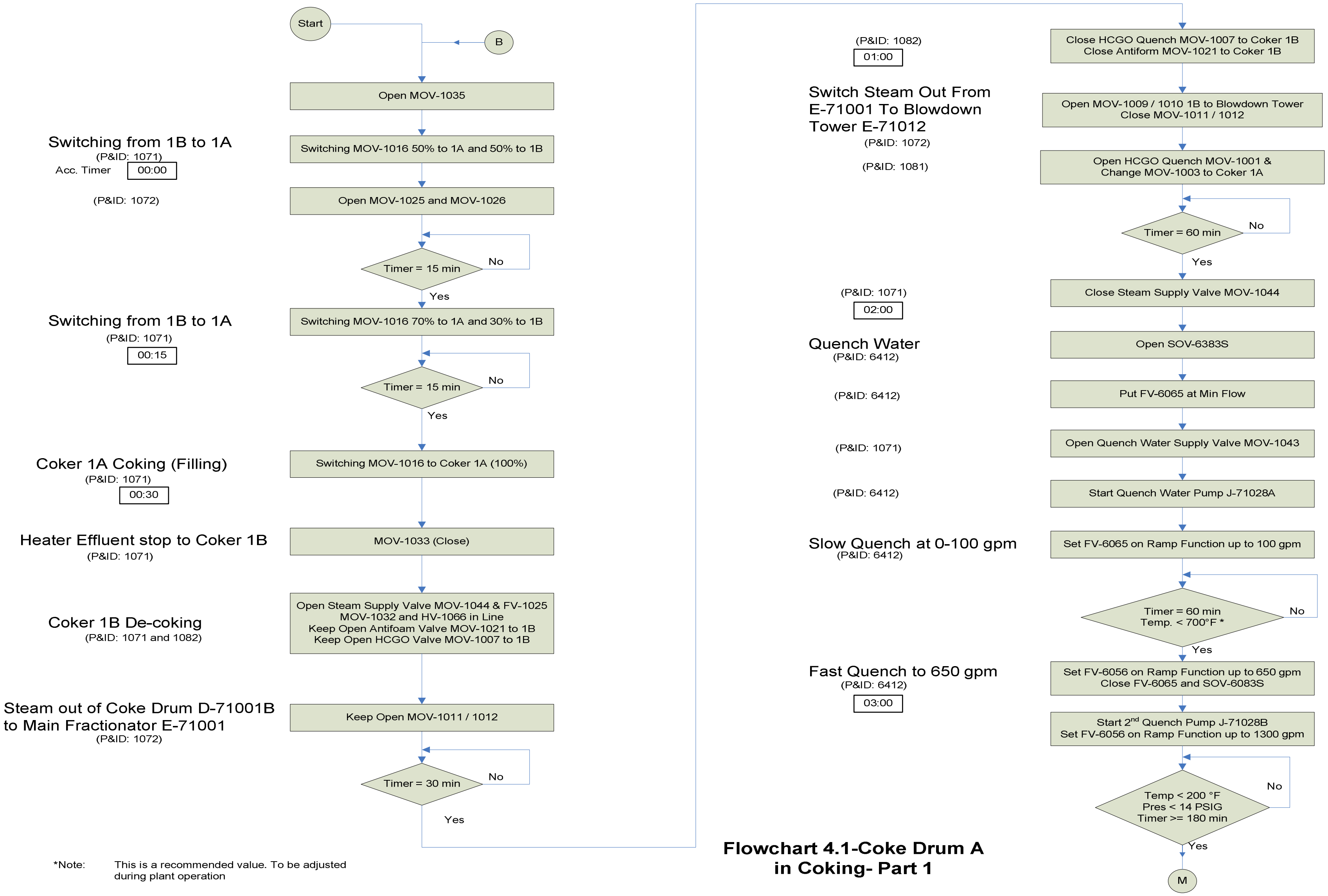


STEP 5:

- D-71001A IS ONLINE
- D-71001B IS OFFLINE
- DURATION: TOTAL 180 MINUTES
- OFFLINE COKE DRUM TEMP: 650 F

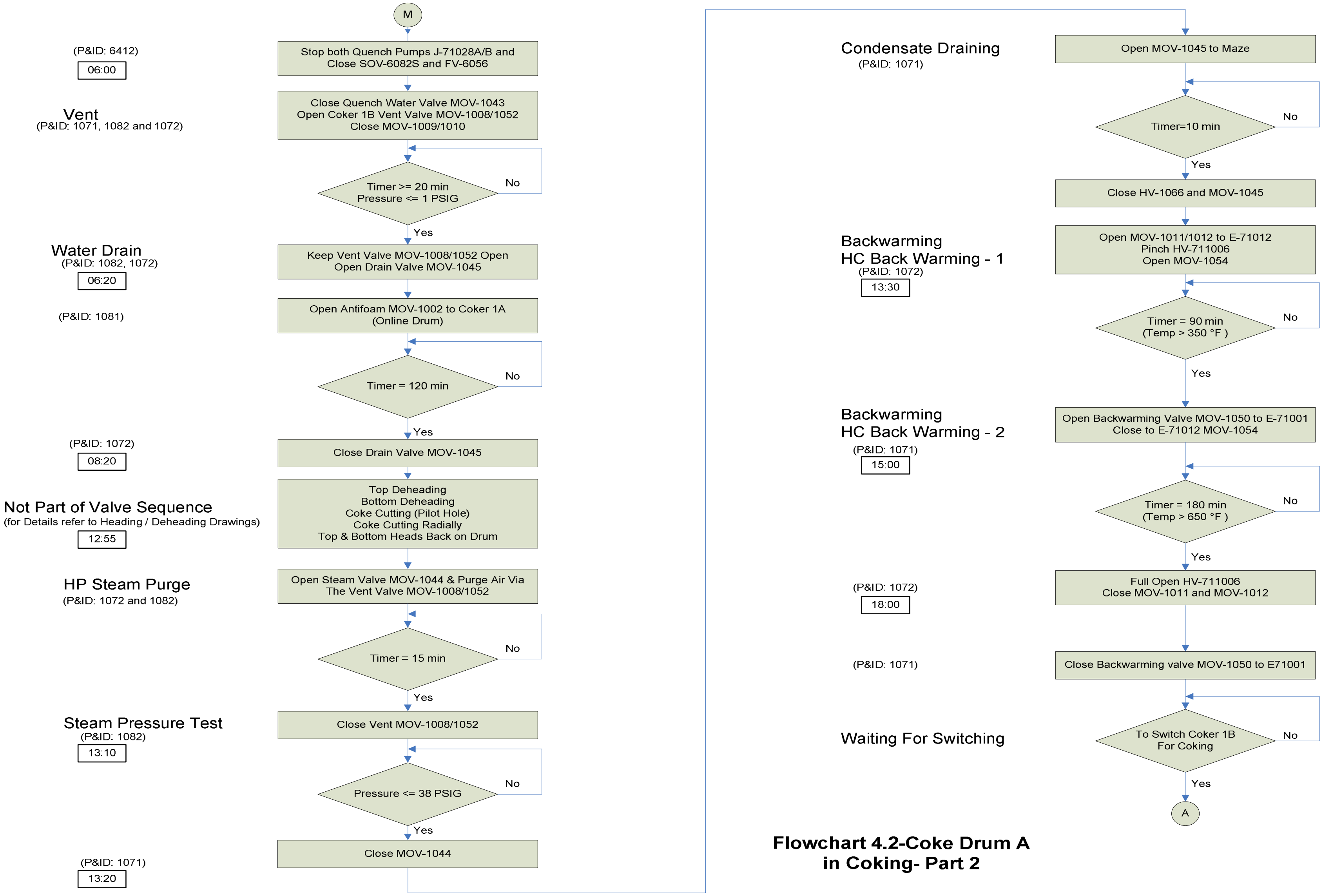
Figure 4.15-HC Backwarming-2

However, in order to proceed to any step shown in the abovementioned a set of permissive must be met. The flow charts 4.1 to 4.4 shown in the following pages are demonstrating the set of permissive to be met for each step before proceeding to the next step during offline mode as well as switching to online mode. These flow charts are the basis for the control engineers to develop the computer programs for each step of cooling/backwarming of offline drum while the online drum is running in its cycle. In order to precede to the next step a set of conditions should be checked and completed successfully. Operators' interventions are minimal under normal operating conditions.

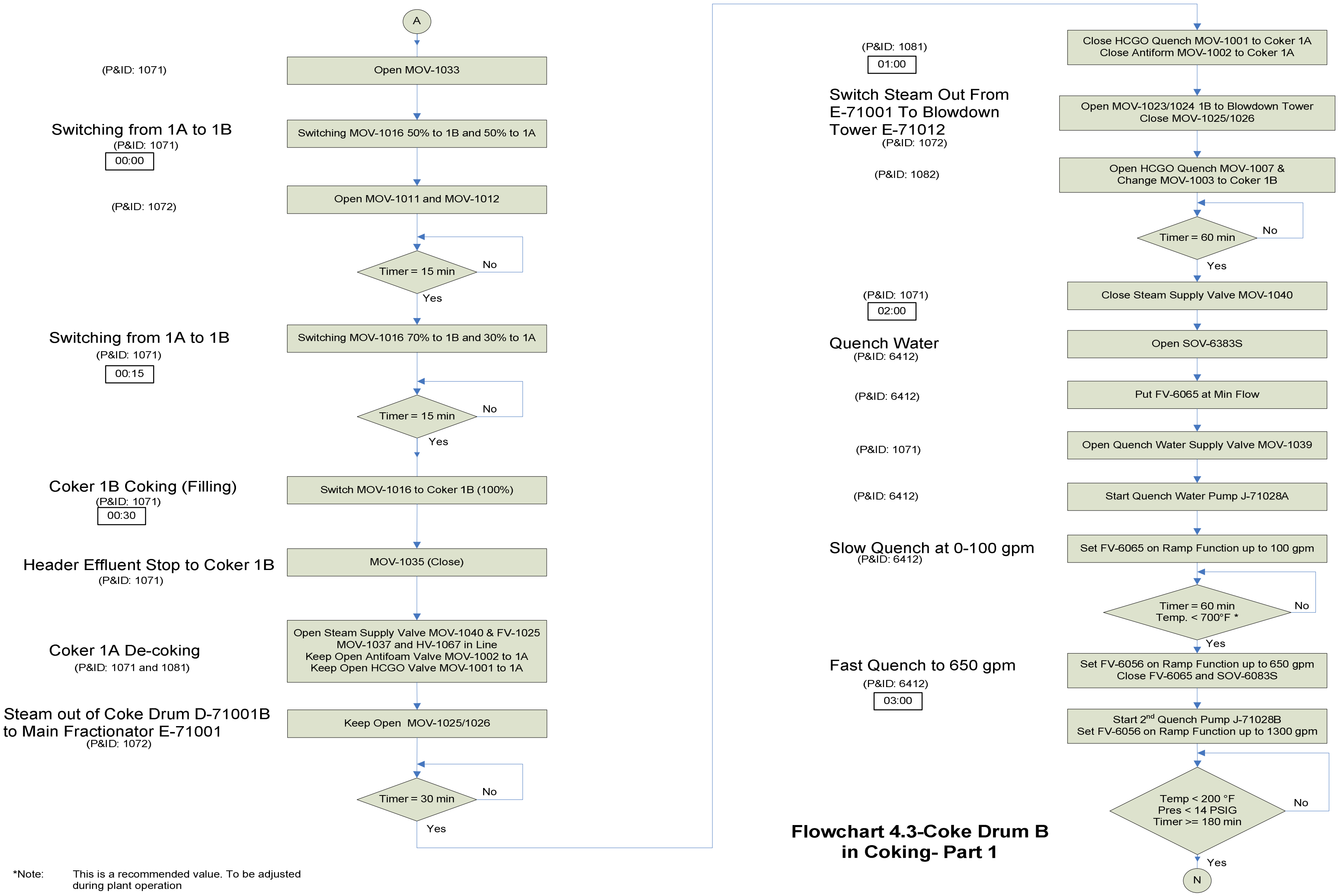


*Note: This is a recommended value. To be adjusted during plant operation

Flowchart 4.1-Coke Drum A in Coking- Part 1

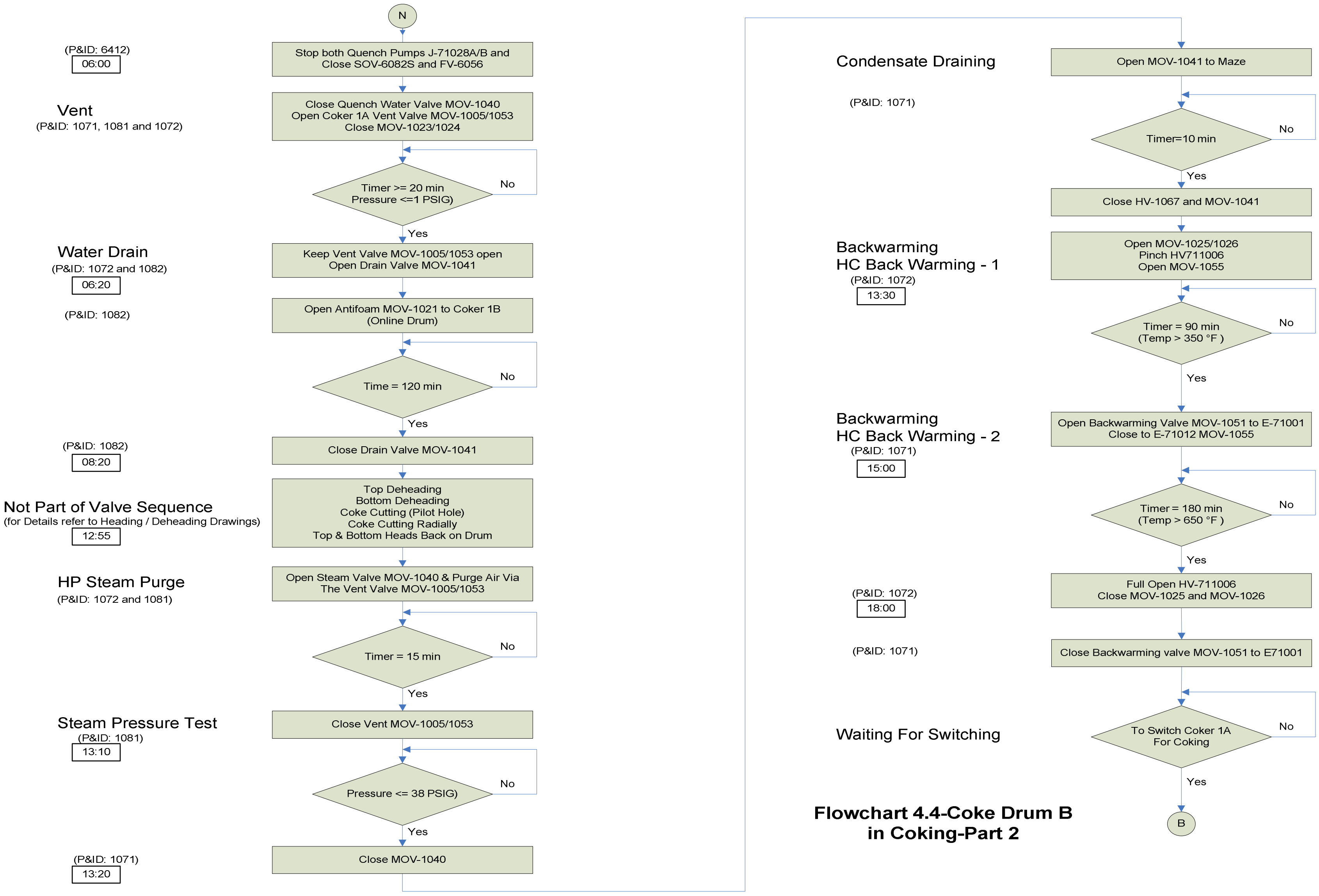


Flowchart 4.2-Coke Drum A in Coking- Part 2

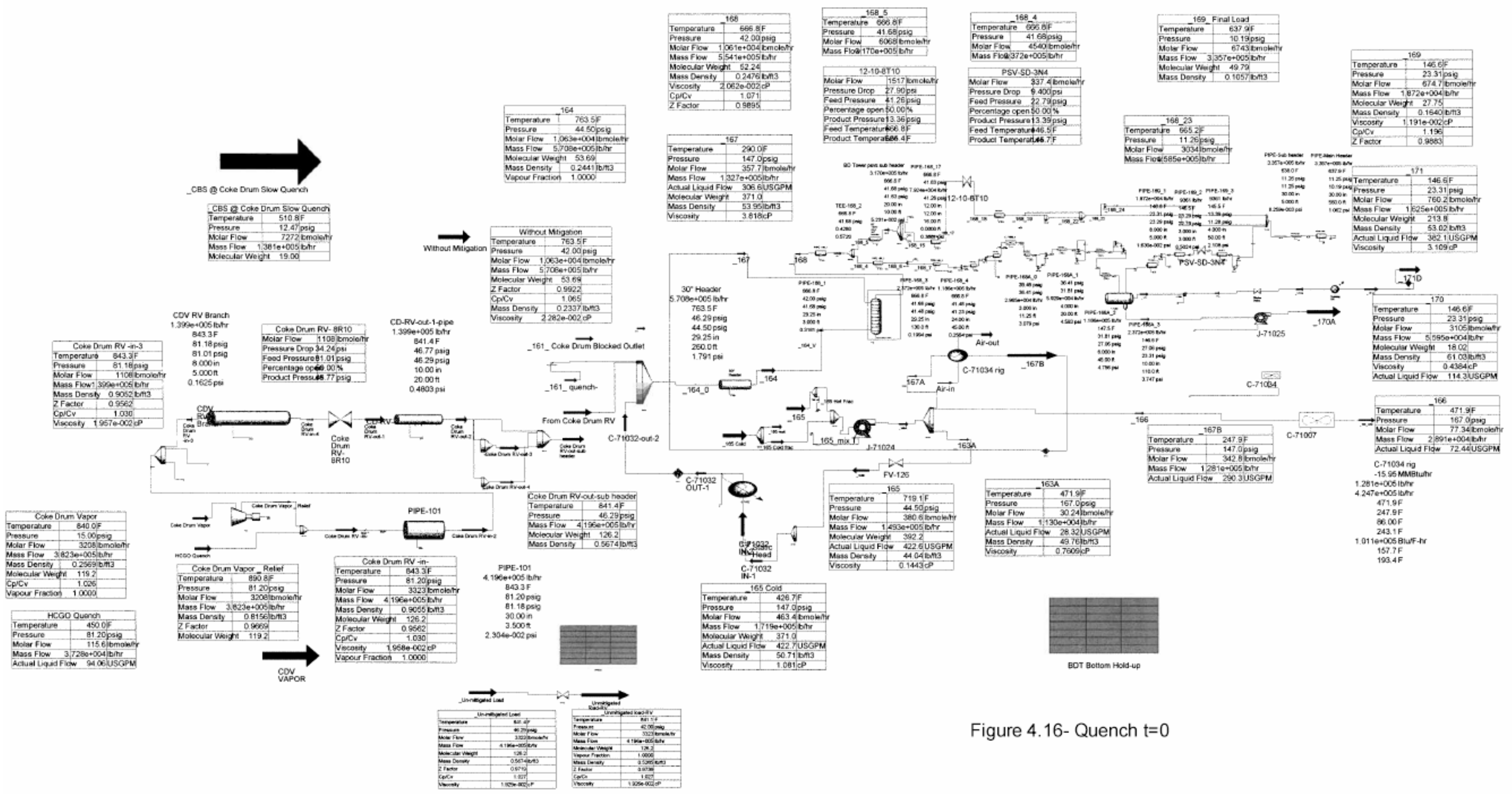


Flowchart 4.3-Coke Drum B in Coking- Part 1

*Note: This is a recommended value. To be adjusted during plant operation



Flowchart 4.4-Coke Drum B in Coking-Part 2



_CBS @ Coke Drum Slow Quench		
Temperature	510.8	F
Pressure	12.47	psig
Molar Flow	7272	lbmole/hr
Mass Flow	1.381e+005	lb/hr
Molecular Weight	19.00	

Coke Drum RV -in-3		
Temperature	843.3	F
Pressure	81.18	psig
Molar Flow	1108	lbmole/hr
Mass Flow	1.399e+005	lb/hr
Mass Density	0.9052	lb/ft3
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.957e-002	cP

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

_164		
Temperature	763.5	F
Pressure	44.50	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.708e+005	lb/hr
Molecular Weight	53.69	
Mass Density	0.2441	lb/ft3
Vapour Fraction	1.0000	

Without Mitigation		
Temperature	763.5	F
Pressure	42.00	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.708e+005	lb/hr
Molecular Weight	53.69	
Z Factor	0.9922	
Cp/Cv	1.065	
Mass Density	0.2337	lb/ft3
Viscosity	2.282e-002	cP

_168		
Temperature	666.8	F
Pressure	42.00	psig
Molar Flow	1.061e+004	lbmole/hr
Mass Flow	5.541e+005	lb/hr
Molecular Weight	52.24	
Mass Density	0.2476	lb/ft3
Viscosity	2.062e-002	cP
Cp/Cv	1.071	
Z Factor	0.9895	

_167		
Temperature	290.0	F
Pressure	147.0	psig
Molar Flow	357.7	lbmole/hr
Mass Flow	1.327e+005	lb/hr
Actual Liquid Flow	306.6	USGPM
Molecular Weight	371.0	
Mass Density	53.95	lb/ft3
Viscosity	3.818	cP

_168_5		
Temperature	666.8	F
Pressure	41.68	psig
Molar Flow	6068	lbmole/hr
Mass Flow	3.170e+005	lb/hr

12-10-8T10		
Molar Flow	1517	lbmole/hr
Pressure Drop	27.90	psi
Feed Pressure	41.26	psig
Percentage open	50.00	%
Product Pressure	13.36	psig
Feed Temperature	666.8	F
Product Temperature	666.4	F

_168_4		
Temperature	666.8	F
Pressure	41.68	psig
Molar Flow	4540	lbmole/hr
Mass Flow	2.372e+005	lb/hr

PSV-SD-3N4		
Molar Flow	337.4	lbmole/hr
Pressure Drop	9.400	psi
Feed Pressure	22.79	psig
Percentage open	50.00	%
Product Pressure	13.39	psig
Feed Temperature	146.5	F
Product Temperature	146.7	F

_169_ Final Load		
Temperature	637.9	F
Pressure	10.19	psig
Molar Flow	6743	lbmole/hr
Mass Flow	3.357e+005	lb/hr
Molecular Weight	49.79	
Mass Density	0.1057	lb/ft3

_168_23		
Temperature	665.2	F
Pressure	11.26	psig
Molar Flow	3034	lbmole/hr
Mass Flow	1.585e+005	lb/hr

_169		
Temperature	146.6	F
Pressure	23.31	psig
Molar Flow	674.7	lbmole/hr
Mass Flow	1.872e+004	lb/hr
Molecular Weight	27.75	
Mass Density	0.1640	lb/ft3
Viscosity	1.191e-002	cP
Cp/Cv	1.196	
Z Factor	0.9883	

_171		
Temperature	146.6	F
Pressure	23.31	psig
Molar Flow	760.2	lbmole/hr
Mass Flow	1.625e+005	lb/hr
Molecular Weight	213.8	
Mass Density	53.02	lb/ft3
Actual Liquid Flow	382.1	USGPM
Viscosity	3.109	cP

_170		
Temperature	146.6	F
Pressure	23.31	psig
Molar Flow	3105	lbmole/hr
Mass Flow	5.595e+004	lb/hr
Molecular Weight	18.02	
Mass Density	61.03	lb/ft3
Viscosity	0.4384	cP
Actual Liquid Flow	114.3	USGPM

_166		
Temperature	471.9	F
Pressure	167.0	psig
Molar Flow	77.34	lbmole/hr
Mass Flow	2.891e+004	lb/hr
Actual Liquid Flow	72.44	USGPM

_167B		
Temperature	247.9	F
Pressure	147.0	psig
Molar Flow	342.8	lbmole/hr
Mass Flow	1.281e+005	lb/hr
Actual Liquid Flow	290.3	USGPM

_163A		
Temperature	471.9	F
Pressure	167.0	psig
Molar Flow	30.24	lbmole/hr
Mass Flow	1.130e+004	lb/hr
Actual Liquid Flow	28.32	USGPM
Mass Density	49.76	lb/ft3
Viscosity	0.7609	cP

_165		
Temperature	719.1	F
Pressure	44.50	psig
Molar Flow	380.6	lbmole/hr
Mass Flow	1.493e+005	lb/hr
Molecular Weight	392.2	
Actual Liquid Flow	422.6	USGPM
Mass Density	44.04	lb/ft3
Viscosity	0.1443	cP

_165 Cold		
Temperature	426.7	F
Pressure	147.0	psig
Molar Flow	463.4	lbmole/hr
Mass Flow	1.719e+005	lb/hr
Molecular Weight	371.0	
Actual Liquid Flow	422.7	USGPM
Mass Density	50.71	lb/ft3
Viscosity	1.081	cP

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

Coke Drum Vapor		
Temperature	840.0	F
Pressure	15.00	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.2569	lb/ft3
Molecular Weight	119.2	
Cp/Cv	1.026	
Vapour Fraction	1.0000	

HCGO Quench		
Temperature	450.0	F
Pressure	81.20	psig
Molar Flow	115.6	lbmole/hr
Mass Flow	3.728e+004	lb/hr
Actual Liquid Flow	94.06	USGPM

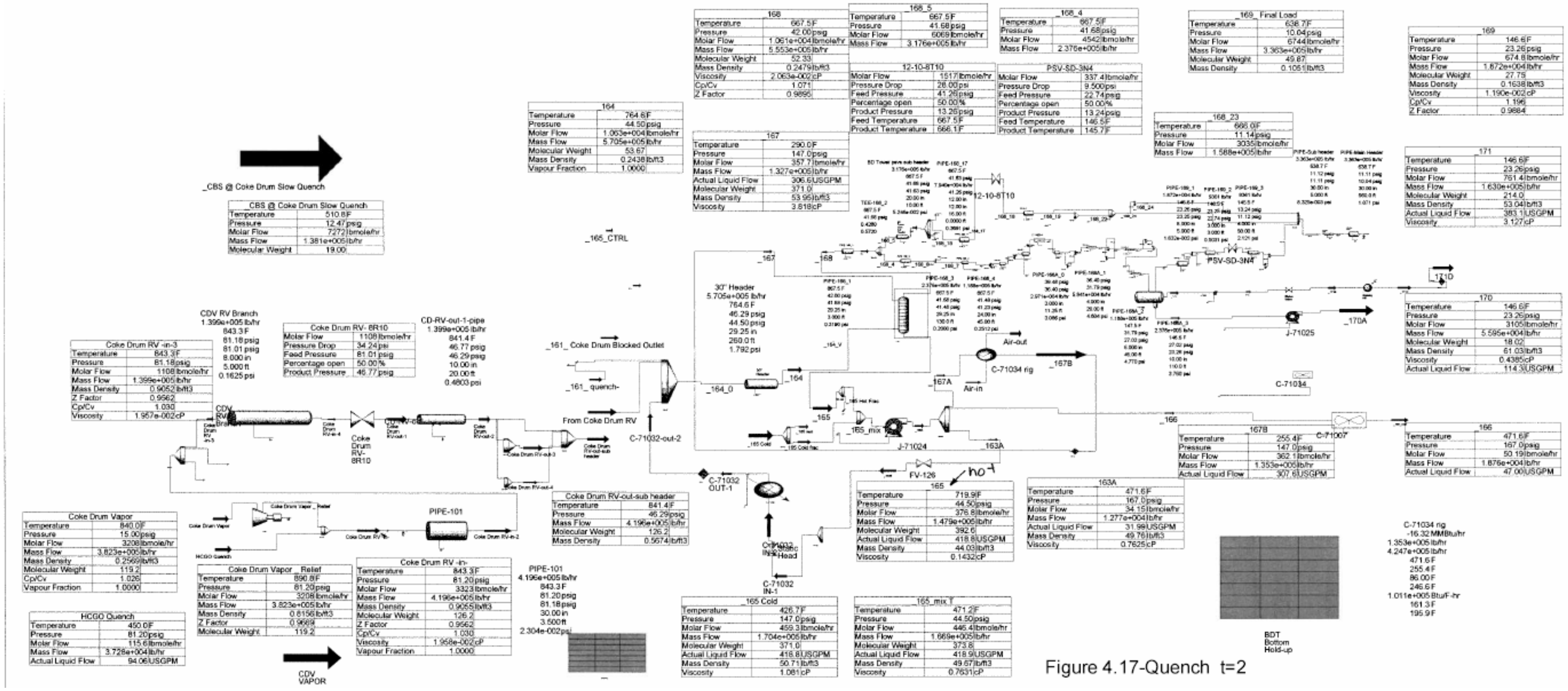
Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9669	
Molecular Weight	119.2	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

_Un-mitigated Load		
Temperature	841.4	F
Pressure	46.29	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3
Z Factor	0.9719	
Cp/Cv	1.027	
Viscosity	1.929e-002	cP

_Unmitigated load-RV		
Temperature	841.1	F
Pressure	42.00	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Vapour Fraction	1.0000	
Mass Density	0.5265	lb/ft3
Z Factor	0.9739	
Cp/Cv	1.027	
Viscosity	1.926e-002	cP

Figure 4.16- Quench t=0



_164		
Temperature	764.6	F
Pressure	44.50	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.705e+005	lb/hr
Molecular Weight	53.67	
Mass Density	0.2438	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	667.5	F
Pressure	42.00	psig
Molar Flow	1.061e+004	lbmole/hr
Mass Flow	5.553e+005	lb/hr
Molecular Weight	52.33	
Mass Density	0.2479	lb/ft3
Viscosity	2.063e-002	cP
Cp/Cv	1.071	
Z Factor	0.9895	

_167		
Temperature	290.0	F
Pressure	147.0	psig
Molar Flow	357.7	lbmole/hr
Mass Flow	1.327e+005	lb/hr
Actual Liquid Flow	306.6	USGPM
Molecular Weight	371.0	
Mass Density	53.95	lb/ft3
Viscosity	3.818	cP

_168_5		
Temperature	667.5	F
Pressure	41.68	psig
Molar Flow	6069	lbmole/hr
Mass Flow	3.176e+005	lb/hr

12-10-8T10		
Molar Flow	1517	lbmole/hr
Pressure Drop	28.00	psi
Feed Pressure	41.26	psig
Percentage open	50.00	%
Product Pressure	13.26	psig
Feed Temperature	667.5	F
Product Temperature	666.1	F

_168_4		
Temperature	667.5	F
Pressure	41.68	psig
Molar Flow	4542	lbmole/hr
Mass Flow	2.376e+005	lb/hr

PSV-SD-3N4		
Molar Flow	337.4	lbmole/hr
Pressure Drop	9.500	psi
Feed Pressure	22.74	psig
Percentage open	50.00	%
Product Pressure	13.24	psig
Feed Temperature	146.5	F
Product Temperature	145.7	F

_169_ Final Load		
Temperature	638.7	F
Pressure	10.04	psig
Molar Flow	6744	lbmole/hr
Mass Flow	3.363e+005	lb/hr
Molecular Weight	49.87	
Mass Density	0.1051	lb/ft3

_168_23		
Temperature	666.0	F
Pressure	11.14	psig
Molar Flow	3035	lbmole/hr
Mass Flow	1.588e+005	lb/hr

_169		
Temperature	146.6	F
Pressure	23.26	psig
Molar Flow	674.8	lbmole/hr
Mass Flow	1.672e+004	lb/hr
Molecular Weight	27.75	
Mass Density	0.1638	lb/ft3
Viscosity	1.190e-002	cP
Cp/Cv	1.196	
Z Factor	0.9684	

_171		
Temperature	146.6	F
Pressure	23.26	psig
Molar Flow	761.4	lbmole/hr
Mass Flow	1.630e+005	lb/hr
Molecular Weight	214.0	
Mass Density	53.04	lb/ft3
Actual Liquid Flow	383.1	USGPM
Viscosity	3.127	cP

_170		
Temperature	146.6	F
Pressure	23.26	psig
Molar Flow	3105	lbmole/hr
Mass Flow	5.595e+004	lb/hr
Molecular Weight	18.02	
Mass Density	61.03	lb/ft3
Viscosity	0.4385	cP
Actual Liquid Flow	114.3	USGPM

_CBS @ Coke Drum Slow Quench		
Temperature	510.8	F
Pressure	12.47	psig
Molar Flow	7272	lbmole/hr
Mass Flow	1.381e+005	lb/hr
Molecular Weight	19.00	

Coke Drum RV -in-3		
Temperature	843.3	F
Pressure	81.18	psig
Molar Flow	1108	lbmole/hr
Mass Flow	1.399e+005	lb/hr
Mass Density	0.9052	lb/ft3
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.957e-002	cP

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

_167B		
Temperature	255.4	F
Pressure	147.0	psig
Molar Flow	362.1	lbmole/hr
Mass Flow	1.353e+005	lb/hr
Actual Liquid Flow	307.6	USGPM

_166		
Temperature	471.6	F
Pressure	167.0	psig
Molar Flow	50.19	lbmole/hr
Mass Flow	1.876e+004	lb/hr
Actual Liquid Flow	47.00	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	719.9	F
Pressure	44.50	psig
Molar Flow	376.8	lbmole/hr
Mass Flow	1.479e+005	lb/hr
Molecular Weight	392.6	
Actual Liquid Flow	418.8	USGPM
Mass Density	44.03	lb/ft3
Viscosity	0.1432	cP

_163A		
Temperature	471.6	F
Pressure	167.0	psig
Molar Flow	34.15	lbmole/hr
Mass Flow	1.277e+004	lb/hr
Actual Liquid Flow	31.99	USGPM
Mass Density	49.76	lb/ft3
Viscosity	0.7625	cP

Coke Drum Vapor		
Temperature	840.0	F
Pressure	15.00	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.2569	lb/ft3
Molecular Weight	119.2	
Cp/Cv	1.026	
Vapour Fraction	1.0000	

HCGO Quench		
Temperature	450.0	F
Pressure	81.20	psig
Molar Flow	115.6	lbmole/hr
Mass Flow	3.728e+004	lb/hr
Actual Liquid Flow	94.06	USGPM

Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9689	
Molecular Weight	119.2	

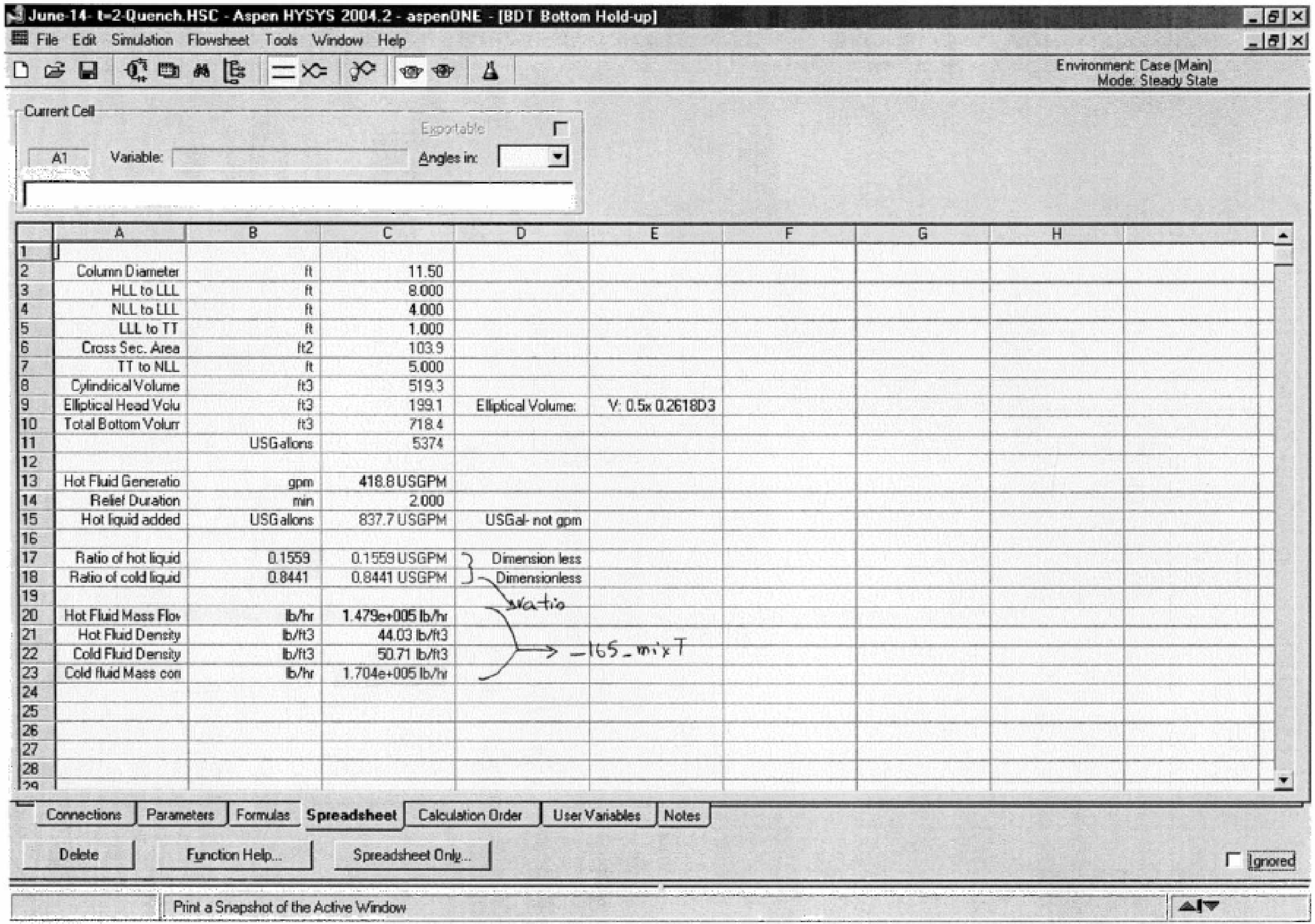
Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

_165 Cold		
Temperature	426.7	F
Pressure	147.0	psig
Molar Flow	459.3	lbmole/hr
Mass Flow	1.704e+005	lb/hr
Molecular Weight	371.0	
Actual Liquid Flow	418.8	USGPM
Mass Density	50.71	lb/ft3
Viscosity	1.081	cP

_165_mix T		
Temperature	471.2	F
Pressure	44.50	psig
Molar Flow	446.4	lbmole/hr
Mass Flow	1.669e+005	lb/hr
Molecular Weight	373.8	
Actual Liquid Flow	418.9	USGPM
Mass Density	49.67	lb/ft3
Viscosity	0.7631	cP

Figure 4.17-Quench t=2

BDT Bottom Hold-up

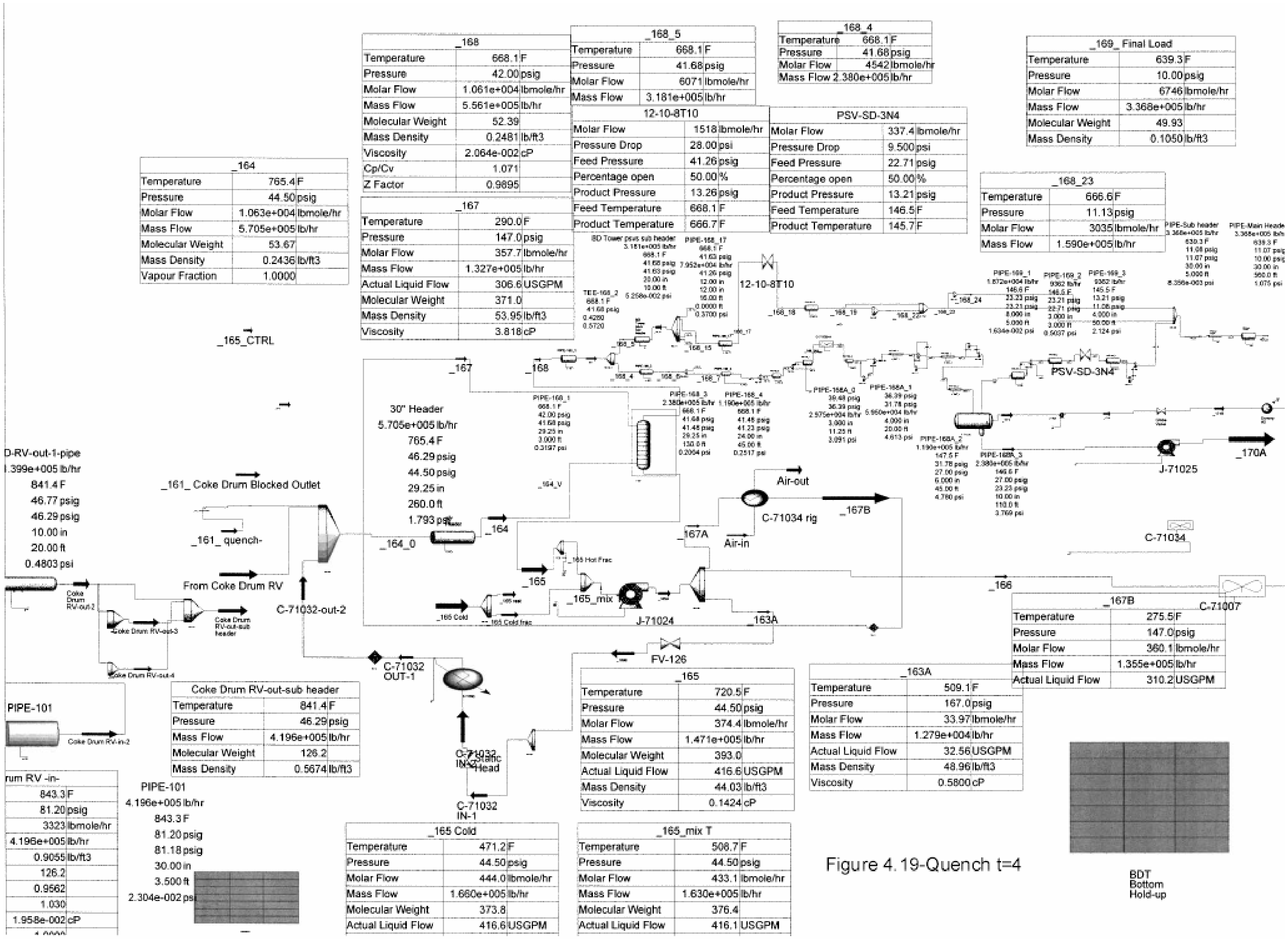


	A	B	C	D	E	F	G	H
1								
2	Column Diameter	ft	11.50					
3	HLL to LLL	ft	8.000					
4	NLL to LLL	ft	4.000					
5	LLL to TT	ft	1.000					
6	Cross Sec. Area	ft2	103.9					
7	TT to NLL	ft	5.000					
8	Cylindrical Volume	ft3	519.3					
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3			
10	Total Bottom Volun	ft3	718.4					
11		USGallons	5374					
12								
13	Hot Fluid Generatio	gpm	418.8 USGPM					
14	Relief Duration	min	2.000					
15	Hot liquid added	USGallons	837.7 USGPM	USGal- not gpm				
16								
17	Ratio of hot liquid	0.1559	0.1559 USGPM	Dimension less				
18	Ratio of cold liquid	0.8441	0.8441 USGPM	Dimensionless				
19								
20	Hot Fluid Mass Flov	lb/hr	1.479e+005 lb/hr					
21	Hot Fluid Density	lb/ft3	44.03 lb/ft3					
22	Cold Fluid Density	lb/ft3	50.71 lb/ft3					
23	Cold fluid Mass con	lb/hr	1.704e+005 lb/hr					
24								
25								
26								
27								
28								

ratio

→ —165_mixT

Figure 4.18- Quench Ratio at t=2



D-RV-out-1-pipe
1.399e+005 lb/hr
841.4 F
46.77 psig
46.29 psig
10.00 in
20.00 ft
0.4803 psi

30" Header
5.705e+005 lb/hr
765.4 F
46.29 psig
44.50 psig
29.25 in
260.0 ft
1.793 psi

PIPE-101
4.196e+005 lb/hr
843.3 F
81.20 psig
81.18 psig
30.00 in
3.500 ft
2.304e-002 psi

_164		
Temperature	765.4	F
Pressure	44.50	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.705e+005	lb/hr
Molecular Weight	53.67	
Mass Density	0.2436	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	668.1	F
Pressure	42.00	psig
Molar Flow	1.061e+004	lbmole/hr
Mass Flow	5.561e+005	lb/hr
Molecular Weight	52.39	
Mass Density	0.2481	lb/ft3
Viscosity	2.064e-002	cP
Cp/Cv	1.071	
Z Factor	0.9895	

_167		
Temperature	290.0	F
Pressure	147.0	psig
Molar Flow	357.7	lbmole/hr
Mass Flow	1.327e+005	lb/hr
Actual Liquid Flow	306.6	USGPM
Molecular Weight	371.0	
Mass Density	53.95	lb/ft3
Viscosity	3.818	cP

_168_5		
Temperature	668.1	F
Pressure	41.68	psig
Molar Flow	6071	lbmole/hr
Mass Flow	3.181e+005	lb/hr

12-10-8T10		
Molar Flow	1518	lbmole/hr
Pressure Drop	28.00	psi
Feed Pressure	41.26	psig
Percentage open	50.00	%
Product Pressure	13.26	psig
Feed Temperature	668.1	F
Product Temperature	666.7	F

_168_4		
Temperature	668.1	F
Pressure	41.68	psig
Molar Flow	4542	lbmole/hr
Mass Flow	2.380e+005	lb/hr

PSV-SD-3N4		
Molar Flow	337.4	lbmole/hr
Pressure Drop	9.500	psi
Feed Pressure	22.71	psig
Percentage open	50.00	%
Product Pressure	13.21	psig
Feed Temperature	146.5	F
Product Temperature	145.7	F

_169_ Final Load		
Temperature	639.3	F
Pressure	10.00	psig
Molar Flow	6746	lbmole/hr
Mass Flow	3.368e+005	lb/hr
Molecular Weight	49.93	
Mass Density	0.1050	lb/ft3

_168_23		
Temperature	666.6	F
Pressure	11.13	psig
Molar Flow	3035	lbmole/hr
Mass Flow	1.590e+005	lb/hr

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

rum RV -in-	
843.3	F
81.20	psig
3323	lbmole/hr
4.196e+005	lb/hr
0.9055	lb/ft3
126.2	
0.9562	
1.030	
1.958e-002	cP

_165		
Temperature	720.5	F
Pressure	44.50	psig
Molar Flow	374.4	lbmole/hr
Mass Flow	1.471e+005	lb/hr
Molecular Weight	393.0	
Actual Liquid Flow	416.6	USGPM
Mass Density	44.03	lb/ft3
Viscosity	0.1424	cP

_165 Cold		
Temperature	471.2	F
Pressure	44.50	psig
Molar Flow	444.0	lbmole/hr
Mass Flow	1.660e+005	lb/hr
Molecular Weight	373.8	
Actual Liquid Flow	416.6	USGPM

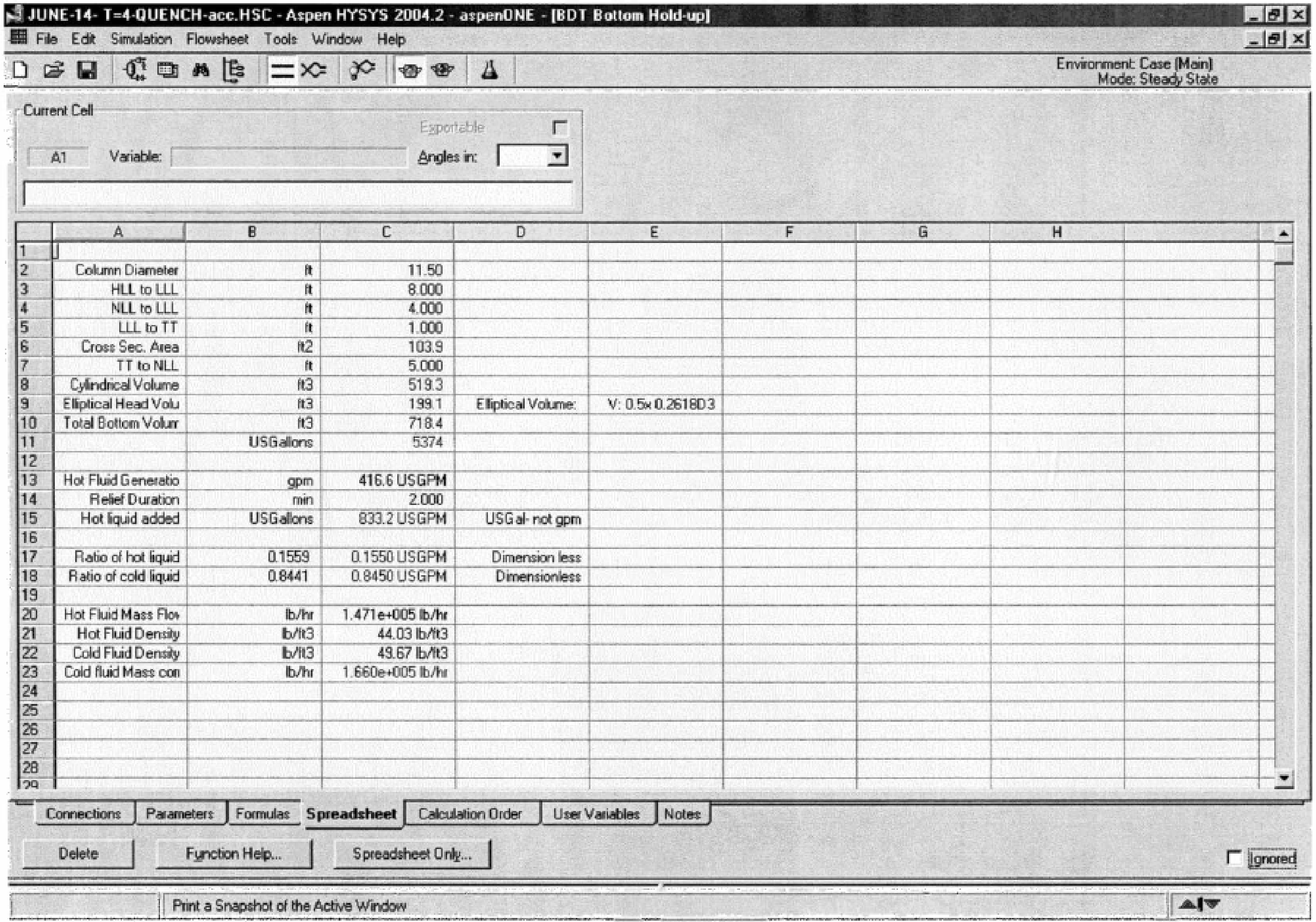
_165_mix T		
Temperature	506.7	F
Pressure	44.50	psig
Molar Flow	433.1	lbmole/hr
Mass Flow	1.630e+005	lb/hr
Molecular Weight	376.4	
Actual Liquid Flow	416.1	USGPM

_163A		
Temperature	509.1	F
Pressure	167.0	psig
Molar Flow	33.97	lbmole/hr
Mass Flow	1.279e+004	lb/hr
Actual Liquid Flow	32.56	USGPM
Mass Density	48.96	lb/ft3
Viscosity	0.5800	cP

_167B		
Temperature	275.5	F
Pressure	147.0	psig
Molar Flow	360.1	lbmole/hr
Mass Flow	1.355e+005	lb/hr
Actual Liquid Flow	310.2	USGPM

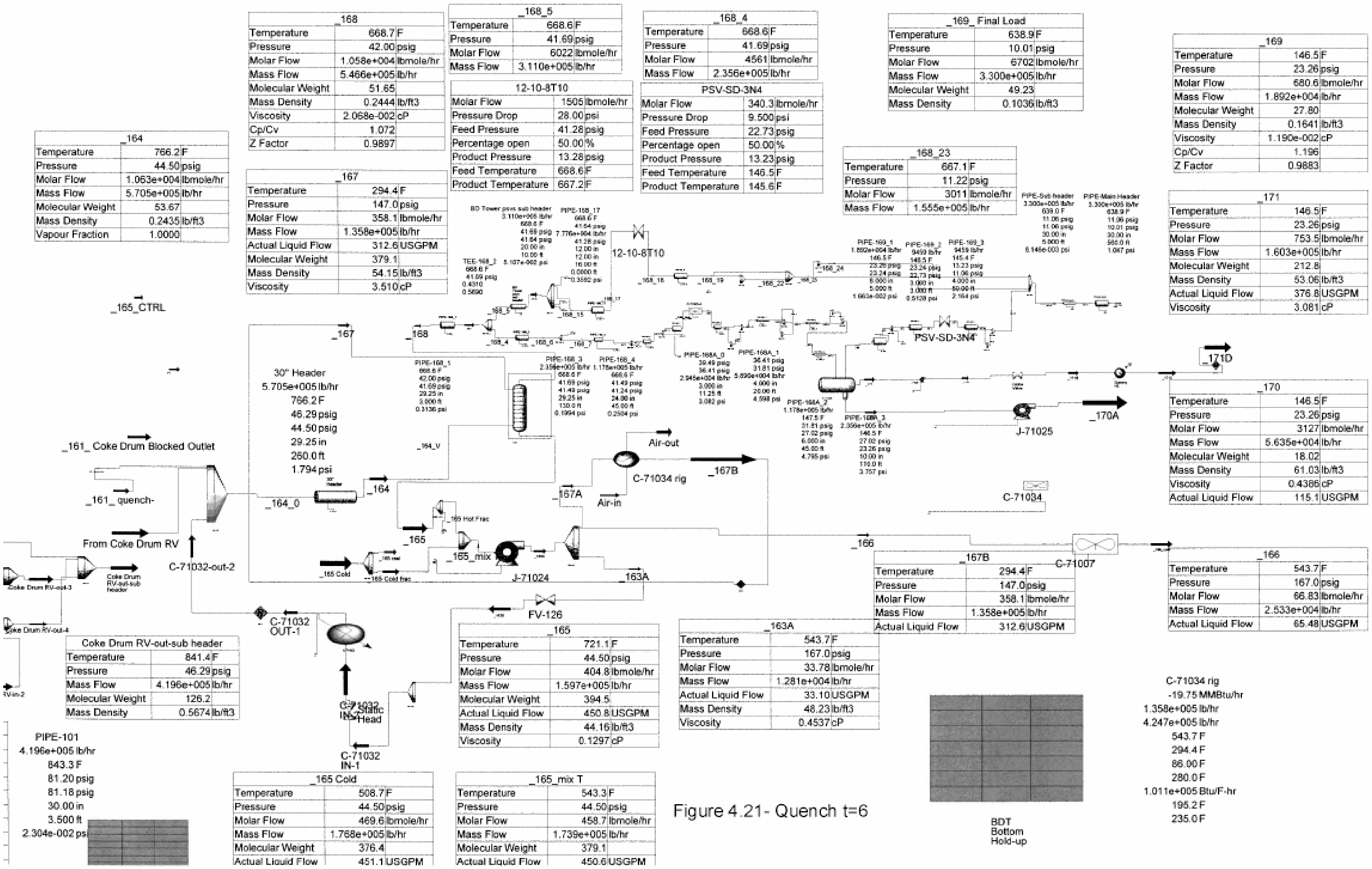
Figure 4.19-Quench t=4

BDT Bottom Hold-up



	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volur	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	416.6 USGPM		
14	Relief Duration	min	2.000		
15	Hot liquid added	USGallons	833.2 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.1559	0.1550 USGPM	Dimension less	
18	Ratio of cold liquid	0.8441	0.8450 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flov	lb/hr	1.471e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	44.03 lb/ft3		
22	Cold Fluid Density	lb/ft3	49.67 lb/ft3		
23	Cold fluid Mass con	lb/hr	1.660e+005 lb/hr		

Figure 4.20- Quench, Ratio at t=4



_164		
Temperature	766.2	F
Pressure	44.50	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.705e+005	lb/hr
Molecular Weight	53.67	
Mass Density	0.2435	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	668.7	F
Pressure	42.00	psig
Molar Flow	1.058e+004	lbmole/hr
Mass Flow	5.466e+005	lb/hr
Molecular Weight	51.65	
Mass Density	0.2444	lb/ft3
Viscosity	2.068e-002	cP
Cp/Cv	1.072	
Z Factor	0.9897	

_167		
Temperature	294.4	F
Pressure	147.0	psig
Molar Flow	358.1	lbmole/hr
Mass Flow	1.358e+005	lb/hr
Actual Liquid Flow	312.6	USGPM
Molecular Weight	379.1	
Mass Density	54.15	lb/ft3
Viscosity	3.510	cP

_168_5		
Temperature	668.6	F
Pressure	41.69	psig
Molar Flow	6022	lbmole/hr
Mass Flow	3.110e+005	lb/hr

12-10-8T10		
Molar Flow	1505	lbmole/hr
Pressure Drop	28.00	psi
Feed Pressure	41.28	psig
Percentage open	50.00	%
Product Pressure	13.28	psig
Feed Temperature	668.6	F
Product Temperature	667.2	F

_168_4		
Temperature	668.6	F
Pressure	41.69	psig
Molar Flow	4561	lbmole/hr
Mass Flow	2.356e+005	lb/hr

PSV-SD-3N4		
Molar Flow	340.3	lbmole/hr
Pressure Drop	9.500	psi
Feed Pressure	22.73	psig
Percentage open	50.00	%
Product Pressure	13.23	psig
Feed Temperature	146.5	F
Product Temperature	145.6	F

_169_ Final Load		
Temperature	638.9	F
Pressure	10.01	psig
Molar Flow	6702	lbmole/hr
Mass Flow	3.300e+005	lb/hr
Molecular Weight	49.23	
Mass Density	0.1036	lb/ft3

_168_23		
Temperature	667.1	F
Pressure	11.22	psig
Molar Flow	3011	lbmole/hr
Mass Flow	1.555e+005	lb/hr

_169		
Temperature	146.5	F
Pressure	23.26	psig
Molar Flow	680.6	lbmole/hr
Mass Flow	1.892e+004	lb/hr
Molecular Weight	27.80	
Mass Density	0.1641	lb/ft3
Viscosity	1.190e-002	cP
Cp/Cv	1.196	
Z Factor	0.9883	

_171		
Temperature	146.5	F
Pressure	23.26	psig
Molar Flow	753.5	lbmole/hr
Mass Flow	1.603e+005	lb/hr
Molecular Weight	212.8	
Mass Density	53.06	lb/ft3
Actual Liquid Flow	376.8	USGPM
Viscosity	3.081	cP

_170		
Temperature	146.5	F
Pressure	23.26	psig
Molar Flow	3127	lbmole/hr
Mass Flow	5.635e+004	lb/hr
Molecular Weight	18.02	
Mass Density	61.03	lb/ft3
Viscosity	0.4386	cP
Actual Liquid Flow	115.1	USGPM

_167B		
Temperature	294.4	F
Pressure	147.0	psig
Molar Flow	358.1	lbmole/hr
Mass Flow	1.358e+005	lb/hr
Actual Liquid Flow	312.6	USGPM

_166		
Temperature	543.7	F
Pressure	167.0	psig
Molar Flow	66.83	lbmole/hr
Mass Flow	2.533e+004	lb/hr
Actual Liquid Flow	65.48	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	721.1	F
Pressure	44.50	psig
Molar Flow	404.8	lbmole/hr
Mass Flow	1.597e+005	lb/hr
Molecular Weight	394.5	
Actual Liquid Flow	450.8	USGPM
Mass Density	44.16	lb/ft3
Viscosity	0.1297	cP

_163A		
Temperature	543.7	F
Pressure	167.0	psig
Molar Flow	33.78	lbmole/hr
Mass Flow	1.281e+004	lb/hr
Actual Liquid Flow	33.10	USGPM
Mass Density	48.23	lb/ft3
Viscosity	0.4537	cP

PIPE-101
4.196e+005 lb/hr
843.3 F
81.20 psig
81.18 psig
30.00 in
3.500 ft
2.304e-002 psi

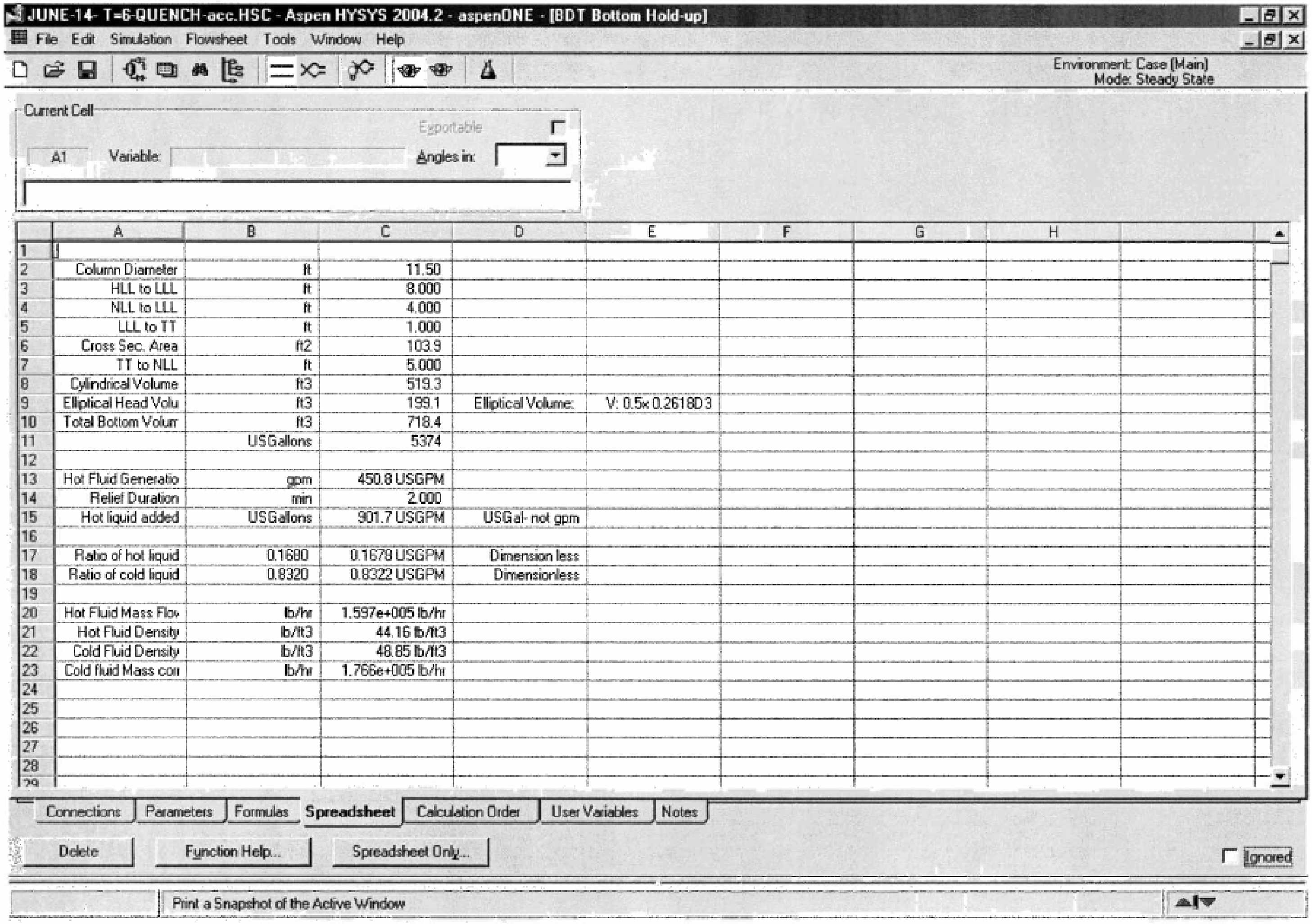
_165 Cold		
Temperature	508.7	F
Pressure	44.50	psig
Molar Flow	469.6	lbmole/hr
Mass Flow	1.768e+005	lb/hr
Molecular Weight	376.4	
Actual Liquid Flow	451.1	USGPM

_165_mix T		
Temperature	543.3	F
Pressure	44.50	psig
Molar Flow	458.7	lbmole/hr
Mass Flow	1.739e+005	lb/hr
Molecular Weight	379.1	
Actual Liquid Flow	450.6	USGPM

C-71034 rig
-19.75 MMBtu/hr
1.358e+005 lb/hr
4.247e+005 lb/hr
543.7 F
294.4 F
86.00 F
280.0 F
1.011e+005 Btu/F-hr
195.2 F
235.0 F

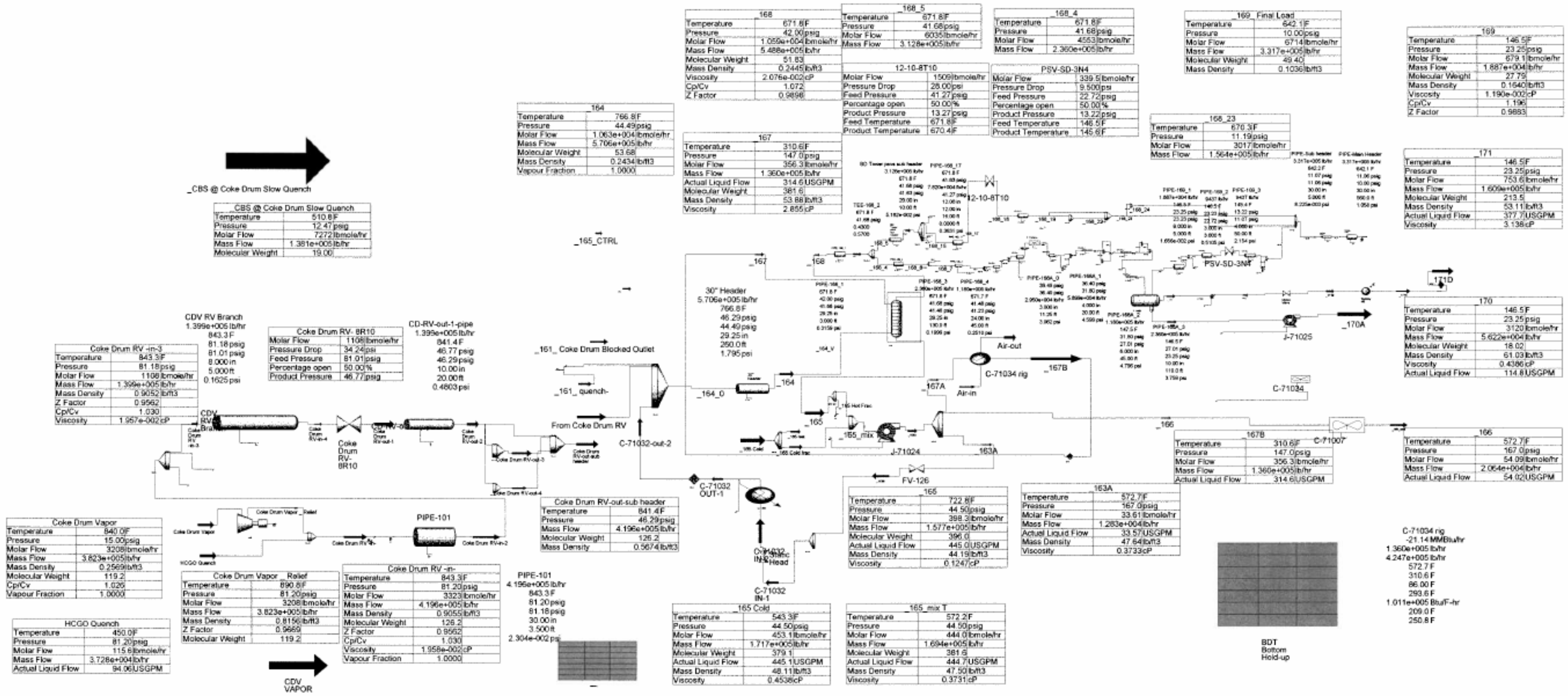
Figure 4.21- Quench t=6

BDT Bottom Hold-up



	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volur	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	450.8 USGPM		
14	Relief Duration	min	2.000		
15	Hot liquid added	USGallons	901.7 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.1680	0.1678 USGPM	Dimension less	
18	Ratio of cold liquid	0.8320	0.8322 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flov	lb/hr	1.597e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	44.16 lb/ft3		
22	Cold Fluid Density	lb/ft3	48.85 lb/ft3		
23	Cold fluid Mass con	lb/hr	1.766e+005 lb/hr		

Figure 4.22-Quench, Ratio at t=6



_168		
Temperature	671.8	F
Pressure	42.00	psig
Molar Flow	1.059e+004	lbmole/hr
Mass Flow	5.488e+005	lb/hr
Molecular Weight	51.83	
Mass Density	0.2445	lb/ft3
Viscosity	2.076e-002	cP
Cp/Cv	1.072	
Z Factor	0.9898	

_168_5		
Temperature	671.8	F
Pressure	41.68	psig
Molar Flow	6035	lbmole/hr
Mass Flow	3.128e+005	lb/hr

_168_4		
Temperature	671.8	F
Pressure	41.68	psig
Molar Flow	4553	lbmole/hr
Mass Flow	2.360e+005	lb/hr

_169_ Final Load		
Temperature	642.1	F
Pressure	10.00	psig
Molar Flow	6714	lbmole/hr
Mass Flow	3.317e+005	lb/hr
Molecular Weight	49.40	
Mass Density	0.1036	lb/ft3

_169		
Temperature	146.5	F
Pressure	23.25	psig
Molar Flow	679.1	lbmole/hr
Mass Flow	1.887e+004	lb/hr
Molecular Weight	27.79	
Mass Density	0.1640	lb/ft3
Viscosity	1.190e-002	cP
Cp/Cv	1.196	
Z Factor	0.9883	

12-10-8T10		
Molar Flow	1509	lbmole/hr
Pressure Drop	28.00	psi
Feed Pressure	41.27	psig
Percentage open	50.00	%
Product Pressure	13.27	psig
Feed Temperature	671.8	F
Product Temperature	670.4	F

PSV-SD-3N4		
Molar Flow	339.5	lbmole/hr
Pressure Drop	9.500	psi
Feed Pressure	22.72	psig
Percentage open	50.00	%
Product Pressure	13.22	psig
Feed Temperature	146.5	F
Product Temperature	145.6	F

_164		
Temperature	766.8	F
Pressure	44.49	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.706e+005	lb/hr
Molecular Weight	53.68	
Mass Density	0.2434	lb/ft3
Vapour Fraction	1.0000	

_167		
Temperature	310.6	F
Pressure	147.0	psig
Molar Flow	356.3	lbmole/hr
Mass Flow	1.360e+005	lb/hr
Actual Liquid Flow	314.6	USGPM
Molecular Weight	381.6	
Mass Density	53.88	lb/ft3
Viscosity	2.855	cP

_168_23		
Temperature	670.3	F
Pressure	11.19	psig
Molar Flow	3017	lbmole/hr
Mass Flow	1.564e+005	lb/hr

_171		
Temperature	146.5	F
Pressure	23.25	psig
Molar Flow	753.6	lbmole/hr
Mass Flow	1.609e+005	lb/hr
Molecular Weight	213.5	
Mass Density	53.11	lb/ft3
Actual Liquid Flow	377.7	USGPM
Viscosity	3.138	cP

_CBS @ Coke Drum Slow Quench		
Temperature	510.8	F
Pressure	12.47	psig
Molar Flow	7272	lbmole/hr
Mass Flow	1.381e+005	lb/hr
Molecular Weight	19.00	

Coke Drum RV -in-3		
Temperature	843.3	F
Pressure	81.18	psig
Molar Flow	1108	lbmole/hr
Mass Flow	1.399e+005	lb/hr
Mass Density	0.9052	lb/ft3
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.957e-002	cP

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

_170		
Temperature	146.5	F
Pressure	23.25	psig
Molar Flow	3120	lbmole/hr
Mass Flow	5.622e+004	lb/hr
Molecular Weight	18.02	
Mass Density	61.03	lb/ft3
Viscosity	0.4386	cP
Actual Liquid Flow	114.8	USGPM

_167B		
Temperature	310.6	F
Pressure	147.0	psig
Molar Flow	356.3	lbmole/hr
Mass Flow	1.360e+005	lb/hr
Actual Liquid Flow	314.6	USGPM

_166		
Temperature	572.7	F
Pressure	167.0	psig
Molar Flow	54.09	lbmole/hr
Mass Flow	2.064e+004	lb/hr
Actual Liquid Flow	54.02	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	722.8	F
Pressure	44.50	psig
Molar Flow	398.3	lbmole/hr
Mass Flow	1.577e+005	lb/hr
Molecular Weight	396.0	
Actual Liquid Flow	445.0	USGPM
Mass Density	44.19	lb/ft3
Viscosity	0.1247	cP

_163A		
Temperature	572.7	F
Pressure	167.0	psig
Molar Flow	33.61	lbmole/hr
Mass Flow	1.283e+004	lb/hr
Actual Liquid Flow	33.57	USGPM
Mass Density	47.64	lb/ft3
Viscosity	0.3733	cP

Coke Drum Vapor		
Temperature	840.0	F
Pressure	15.00	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.2569	lb/ft3
Molecular Weight	119.2	
Cp/Cv	1.026	
Vapour Fraction	1.0000	

Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9669	
Molecular Weight	119.2	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

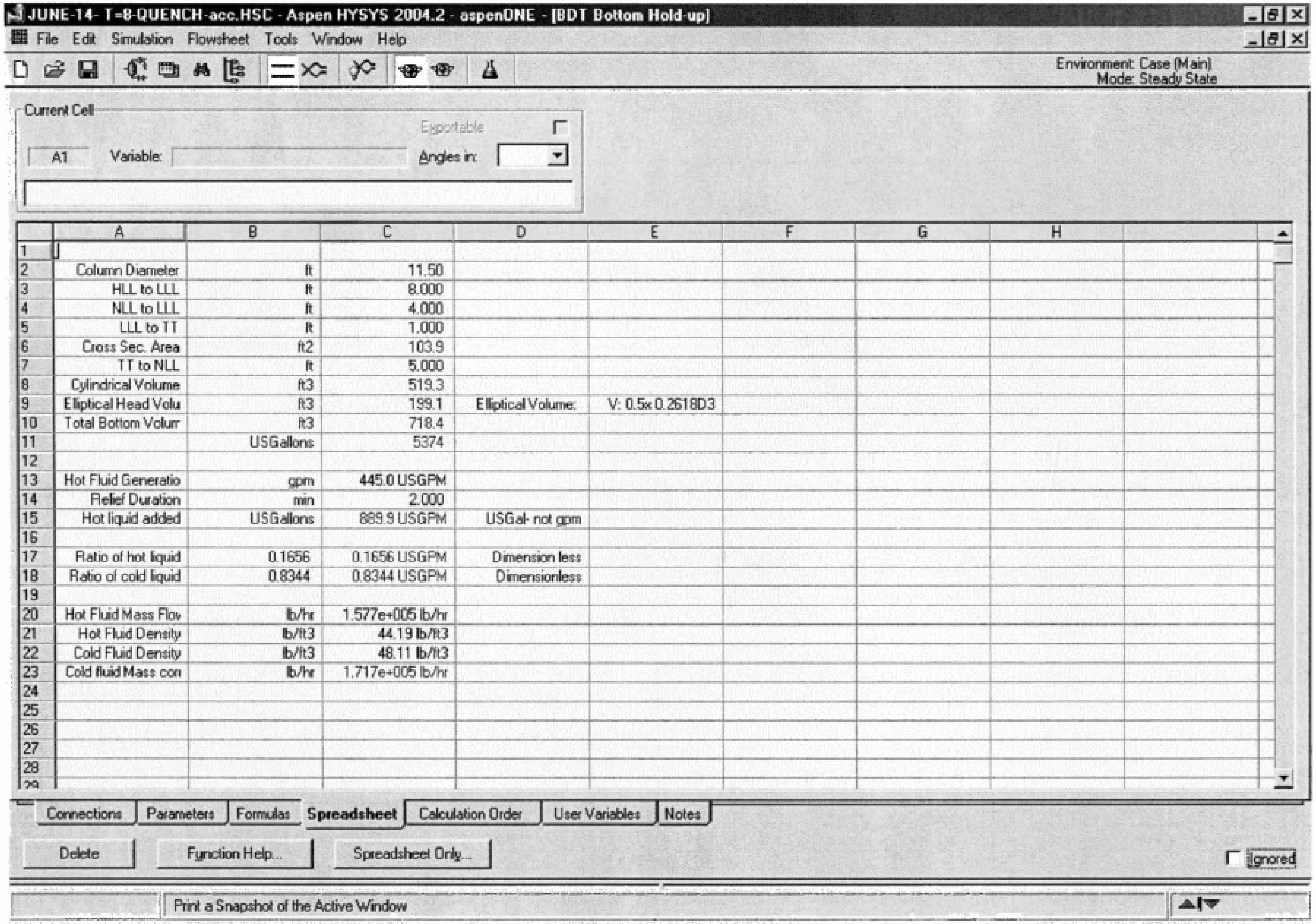
HCGO Quench		
Temperature	450.0	F
Pressure	81.20	psig
Molar Flow	115.6	lbmole/hr
Mass Flow	3.728e+004	lb/hr
Actual Liquid Flow	94.06	USGPM

_165 Cold		
Temperature	543.3	F
Pressure	44.50	psig
Molar Flow	453.1	lbmole/hr
Mass Flow	1.717e+005	lb/hr
Molecular Weight	379.1	
Actual Liquid Flow	445.1	USGPM
Mass Density	48.11	lb/ft3
Viscosity	0.4538	cP

_165_mix T		
Temperature	572.2	F
Pressure	44.50	psig
Molar Flow	444.0	lbmole/hr
Mass Flow	1.694e+005	lb/hr
Molecular Weight	381.6	
Actual Liquid Flow	444.7	USGPM
Mass Density	47.50	lb/ft3
Viscosity	0.3731	cP

Figure 4.23-Quench t=8

BDT Bottom Hold-up

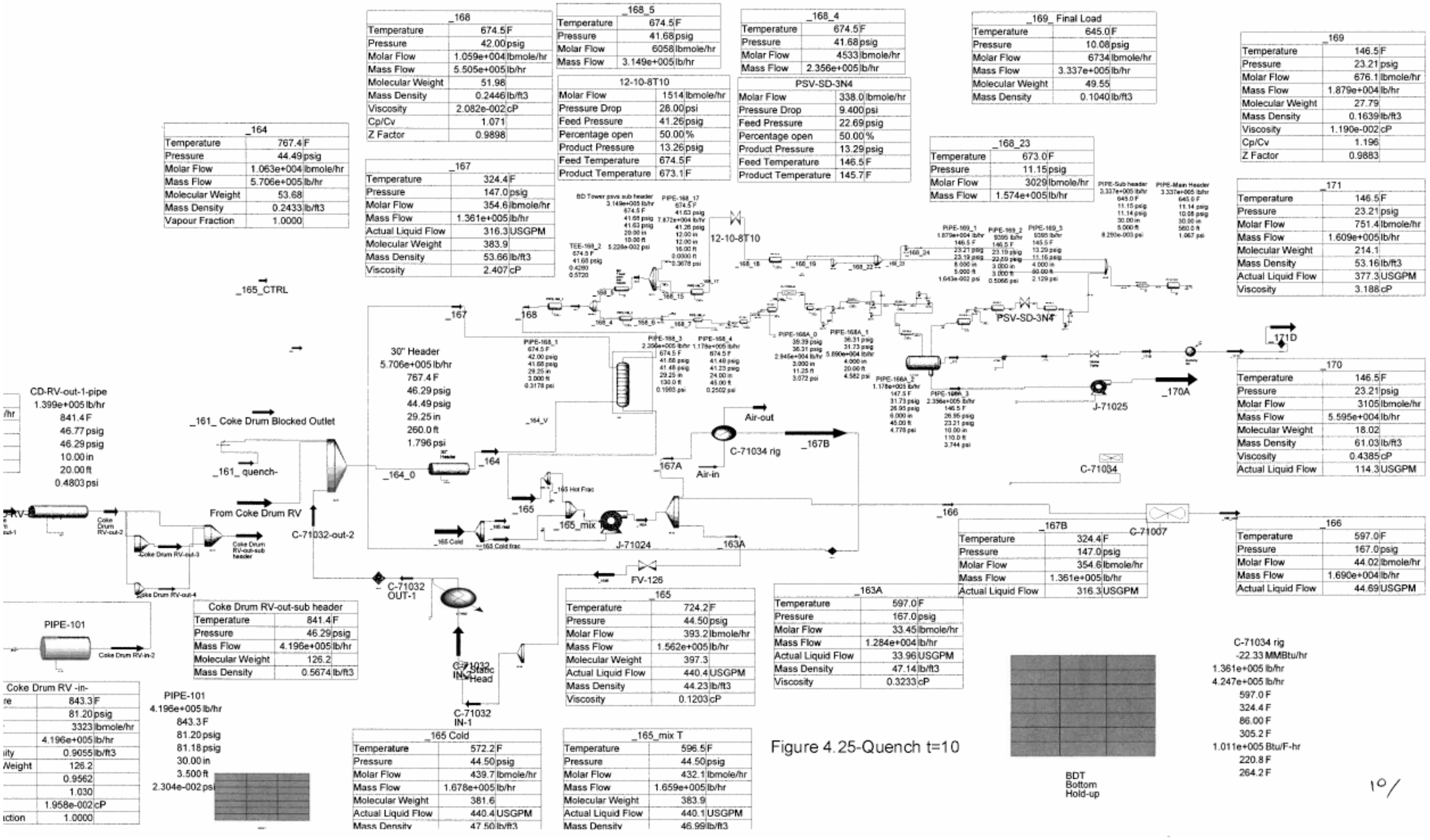


Environment: Case (Main)
Mode: Steady State

Current Cell: A1 Variable:

	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volum	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	445.0 USGPM		
14	Relief Duration	min	2.000		
15	Hot liquid added	USGallons	889.9 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.1656	0.1656 USGPM	Dimension less	
18	Ratio of cold liquid	0.8344	0.8344 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flov	lb/hr	1.577e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	44.19 lb/ft3		
22	Cold Fluid Density	lb/ft3	48.11 lb/ft3		
23	Cold fluid Mass con	lb/hr	1.717e+005 lb/hr		

Figure 4.24-Quench, Ratio at t=8



_164		
Temperature	767.4	F
Pressure	44.49	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.706e+005	lb/hr
Molecular Weight	53.68	
Mass Density	0.2433	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	674.5	F
Pressure	42.00	psig
Molar Flow	1.059e+004	lbmole/hr
Mass Flow	5.505e+005	lb/hr
Molecular Weight	51.98	
Mass Density	0.2446	lb/ft3
Viscosity	2.082e-002	cP
Cp/Cv	1.071	
Z Factor	0.9898	

_167		
Temperature	324.4	F
Pressure	147.0	psig
Molar Flow	354.6	lbmole/hr
Mass Flow	1.361e+005	lb/hr
Actual Liquid Flow	316.3	USGPM
Molecular Weight	383.9	
Mass Density	53.66	lb/ft3
Viscosity	2.407	cP

_168_5		
Temperature	674.5	F
Pressure	41.68	psig
Molar Flow	6058	lbmole/hr
Mass Flow	3.149e+005	lb/hr

12-10-8T10		
Molar Flow	1514	lbmole/hr
Pressure Drop	28.00	psi
Feed Pressure	41.26	psig
Percentage open	50.00	%
Product Pressure	13.26	psig
Feed Temperature	674.5	F
Product Temperature	673.1	F

_168_4		
Temperature	674.5	F
Pressure	41.68	psig
Molar Flow	4533	lbmole/hr
Mass Flow	2.356e+005	lb/hr

PSV-SD-3N4		
Molar Flow	338.0	lbmole/hr
Pressure Drop	9.400	psi
Feed Pressure	22.69	psig
Percentage open	50.00	%
Product Pressure	13.29	psig
Feed Temperature	146.5	F
Product Temperature	145.7	F

_169_ Final Load		
Temperature	645.0	F
Pressure	10.08	psig
Molar Flow	6734	lbmole/hr
Mass Flow	3.337e+005	lb/hr
Molecular Weight	49.55	
Mass Density	0.1040	lb/ft3

_168_23		
Temperature	673.0	F
Pressure	11.15	psig
Molar Flow	3029	lbmole/hr
Mass Flow	1.574e+005	lb/hr

_169		
Temperature	146.5	F
Pressure	23.21	psig
Molar Flow	676.1	lbmole/hr
Mass Flow	1.879e+004	lb/hr
Molecular Weight	27.79	
Mass Density	0.1639	lb/ft3
Viscosity	1.190e-002	cP
Cp/Cv	1.196	
Z Factor	0.9883	

_171		
Temperature	146.5	F
Pressure	23.21	psig
Molar Flow	751.4	lbmole/hr
Mass Flow	1.609e+005	lb/hr
Molecular Weight	214.1	
Mass Density	53.16	lb/ft3
Actual Liquid Flow	377.3	USGPM
Viscosity	3.188	cP

_170		
Temperature	146.5	F
Pressure	23.21	psig
Molar Flow	3105	lbmole/hr
Mass Flow	5.595e+004	lb/hr
Molecular Weight	18.02	
Mass Density	61.03	lb/ft3
Viscosity	0.4385	cP
Actual Liquid Flow	114.3	USGPM

_167B		
Temperature	324.4	F
Pressure	147.0	psig
Molar Flow	354.6	lbmole/hr
Mass Flow	1.361e+005	lb/hr
Actual Liquid Flow	316.3	USGPM

_166		
Temperature	597.0	F
Pressure	167.0	psig
Molar Flow	44.02	lbmole/hr
Mass Flow	1.690e+004	lb/hr
Actual Liquid Flow	44.69	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	724.2	F
Pressure	44.50	psig
Molar Flow	393.2	lbmole/hr
Mass Flow	1.562e+005	lb/hr
Molecular Weight	397.3	
Actual Liquid Flow	440.4	USGPM
Mass Density	44.23	lb/ft3
Viscosity	0.1203	cP

_163A		
Temperature	597.0	F
Pressure	167.0	psig
Molar Flow	33.45	lbmole/hr
Mass Flow	1.284e+004	lb/hr
Actual Liquid Flow	33.96	USGPM
Mass Density	47.14	lb/ft3
Viscosity	0.3233	cP

Coke Drum RV -in-		
re	843.3	F
	81.20	psig
	3323	lbmole/hr
	4.196e+005	lb/hr
ity	0.9055	lb/ft3
Weight	126.2	
	0.9562	
	1.030	
	1.958e-002	cP
ction	1.0000	

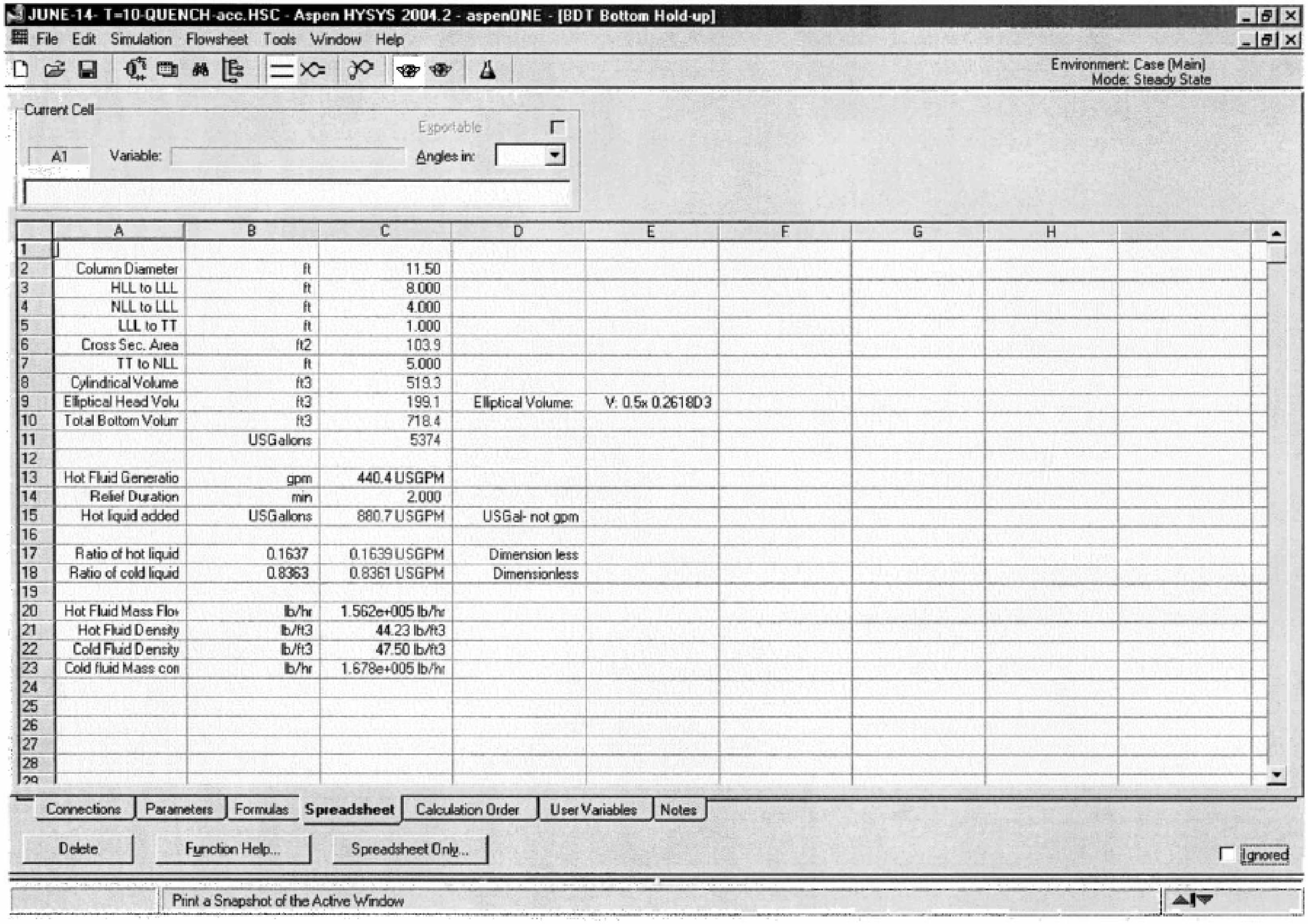
_165 Cold		
Temperature	572.2	F
Pressure	44.50	psig
Molar Flow	439.7	lbmole/hr
Mass Flow	1.678e+005	lb/hr
Molecular Weight	381.6	
Actual Liquid Flow	440.4	USGPM
Mass Density	47.50	lb/ft3

_165_mix T		
Temperature	596.5	F
Pressure	44.50	psig
Molar Flow	432.1	lbmole/hr
Mass Flow	1.659e+005	lb/hr
Molecular Weight	383.9	
Actual Liquid Flow	440.1	USGPM
Mass Density	46.99	lb/ft3

Figure 4.25-Quench t=10

10/

BDT Bottom Hold-up



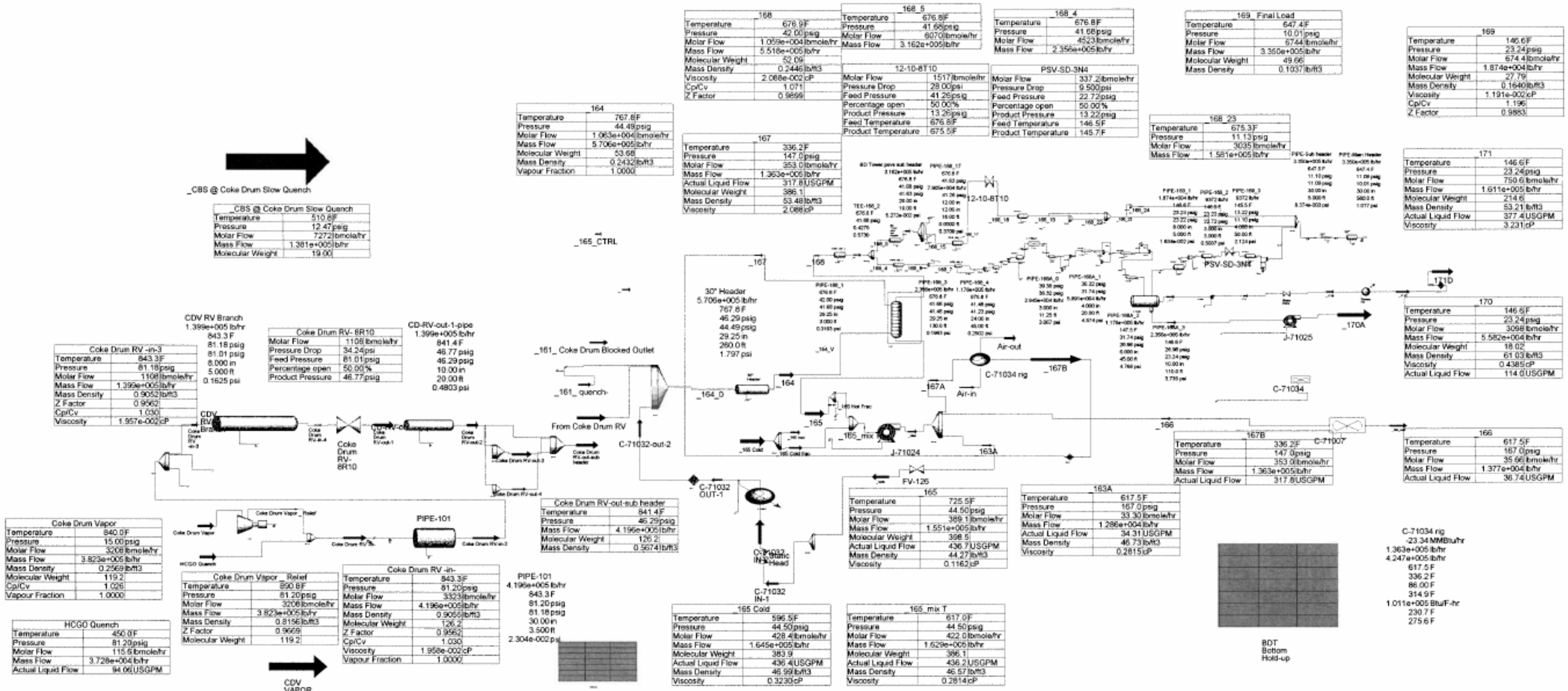
Environment: Case (Main)
Mode: Steady State

A1 Variable:
Angles in:

	A	B	C	D	E	F	G	H
1								
2	Column Diameter	ft	11.50					
3	HLL to LLL	ft	8.000					
4	NLL to LLL	ft	4.000					
5	LLL to TT	ft	1.000					
6	Cross Sec. Area	ft2	103.9					
7	TT to NLL	ft	5.000					
8	Cylindrical Volume	ft3	519.3					
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3			
10	Total Bottom Volur	ft3	718.4					
11		USGallons	5374					
12								
13	Hot Fluid Generatio	gpm	440.4 USGPM					
14	Relief Duration	min	2.000					
15	Hot liquid added	USGallons	880.7 USGPM	USGal- not gpm				
16								
17	Ratio of hot liquid	0.1637	0.1639 USGPM	Dimension less				
18	Ratio of cold liquid	0.8363	0.8361 USGPM	Dimensionless				
19								
20	Hot Fluid Mass Flo	lb/hr	1.562e+005 lb/hr					
21	Hot Fluid Density	lb/ft3	44.23 lb/ft3					
22	Cold Fluid Density	lb/ft3	47.50 lb/ft3					
23	Cold fluid Mass con	lb/hr	1.678e+005 lb/hr					
24								
25								
26								
27								
28								

Print a Snapshot of the Active Window

Figure 4.26-Quench, Ratio at t=10



_CBS @ Coke Drum Slow Quench		
Temperature	510.8	F
Pressure	12.47	psig
Molar Flow	7272	lbmole/hr
Mass Flow	1.381e+005	lb/hr
Molecular Weight	19.00	

164		
Temperature	767.8	F
Pressure	44.49	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.706e+005	lb/hr
Molecular Weight	53.68	
Mass Density	0.2432	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	676.9	F
Pressure	42.00	psig
Molar Flow	1.059e+004	lbmole/hr
Mass Flow	5.518e+005	lb/hr
Molecular Weight	52.09	
Mass Density	0.2446	lb/ft3
Viscosity	2.088e-002	cP
Cp/Cv	1.071	
Z Factor	0.9899	

_167		
Temperature	336.2	F
Pressure	147.0	psig
Molar Flow	353.0	lbmole/hr
Mass Flow	1.363e+005	lb/hr
Actual Liquid Flow	317.8	USGPM
Molecular Weight	386.1	
Mass Density	53.48	lb/ft3
Viscosity	2.088	cP

_168_5		
Temperature	676.8	F
Pressure	41.68	psig
Molar Flow	6070	lbmole/hr
Mass Flow	3.162e+005	lb/hr

12-10-8T10		
Molar Flow	1517	lbmole/hr
Pressure Drop	28.00	psi
Feed Pressure	41.26	psig
Percentage open	50.00	%
Product Pressure	13.26	psig
Feed Temperature	676.8	F
Product Temperature	675.5	F

_168_4		
Temperature	676.8	F
Pressure	41.68	psig
Molar Flow	4523	lbmole/hr
Mass Flow	2.356e+005	lb/hr

PSV-SD-3N4		
Molar Flow	337.2	lbmole/hr
Pressure Drop	9.500	psi
Feed Pressure	22.72	psig
Percentage open	50.00	%
Product Pressure	13.22	psig
Feed Temperature	146.5	F
Product Temperature	145.7	F

_169_ Final Load		
Temperature	647.4	F
Pressure	10.01	psig
Molar Flow	6744	lbmole/hr
Mass Flow	3.350e+005	lb/hr
Molecular Weight	49.66	
Mass Density	0.1037	lb/ft3

_168_23		
Temperature	675.3	F
Pressure	11.13	psig
Molar Flow	3035	lbmole/hr
Mass Flow	1.581e+005	lb/hr

_169		
Temperature	146.6	F
Pressure	23.24	psig
Molar Flow	674.4	lbmole/hr
Mass Flow	1.874e+004	lb/hr
Molecular Weight	27.79	
Mass Density	0.1640	lb/ft3
Viscosity	1.191e-002	cP
Cp/Cv	1.196	
Z Factor	0.9883	

_171		
Temperature	146.6	F
Pressure	23.24	psig
Molar Flow	750.6	lbmole/hr
Mass Flow	1.611e+005	lb/hr
Molecular Weight	214.6	
Mass Density	53.21	lb/ft3
Actual Liquid Flow	377.4	USGPM
Viscosity	3.231	cP

_170		
Temperature	146.6	F
Pressure	23.24	psig
Molar Flow	3098	lbmole/hr
Mass Flow	5.582e+004	lb/hr
Molecular Weight	18.02	
Mass Density	61.03	lb/ft3
Viscosity	0.4385	cP
Actual Liquid Flow	114.0	USGPM

Coke Drum RV -in-3		
Temperature	843.3	F
Pressure	81.18	psig
Molar Flow	1108	lbmole/hr
Mass Flow	1.399e+005	lb/hr
Mass Density	0.9052	lb/ft3
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.957e-002	cP

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

_167B		
Temperature	336.2	F
Pressure	147.0	psig
Molar Flow	353.0	lbmole/hr
Mass Flow	1.363e+005	lb/hr
Actual Liquid Flow	317.8	USGPM

_166		
Temperature	617.5	F
Pressure	167.0	psig
Molar Flow	35.66	lbmole/hr
Mass Flow	1.377e+004	lb/hr
Actual Liquid Flow	36.74	USGPM

Coke Drum Vapor		
Temperature	840.0	F
Pressure	15.00	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.2569	lb/ft3
Molecular Weight	119.2	
Cp/Cv	1.026	
Vapour Fraction	1.0000	

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	725.5	F
Pressure	44.50	psig
Molar Flow	389.1	lbmole/hr
Mass Flow	1.551e+005	lb/hr
Molecular Weight	398.5	
Actual Liquid Flow	436.7	USGPM
Mass Density	44.27	lb/ft3
Viscosity	0.1162	cP

163A		
Temperature	617.5	F
Pressure	167.0	psig
Molar Flow	33.30	lbmole/hr
Mass Flow	1.286e+004	lb/hr
Actual Liquid Flow	34.31	USGPM
Mass Density	46.73	lb/ft3
Viscosity	0.2815	cP

Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9669	
Molecular Weight	119.2	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

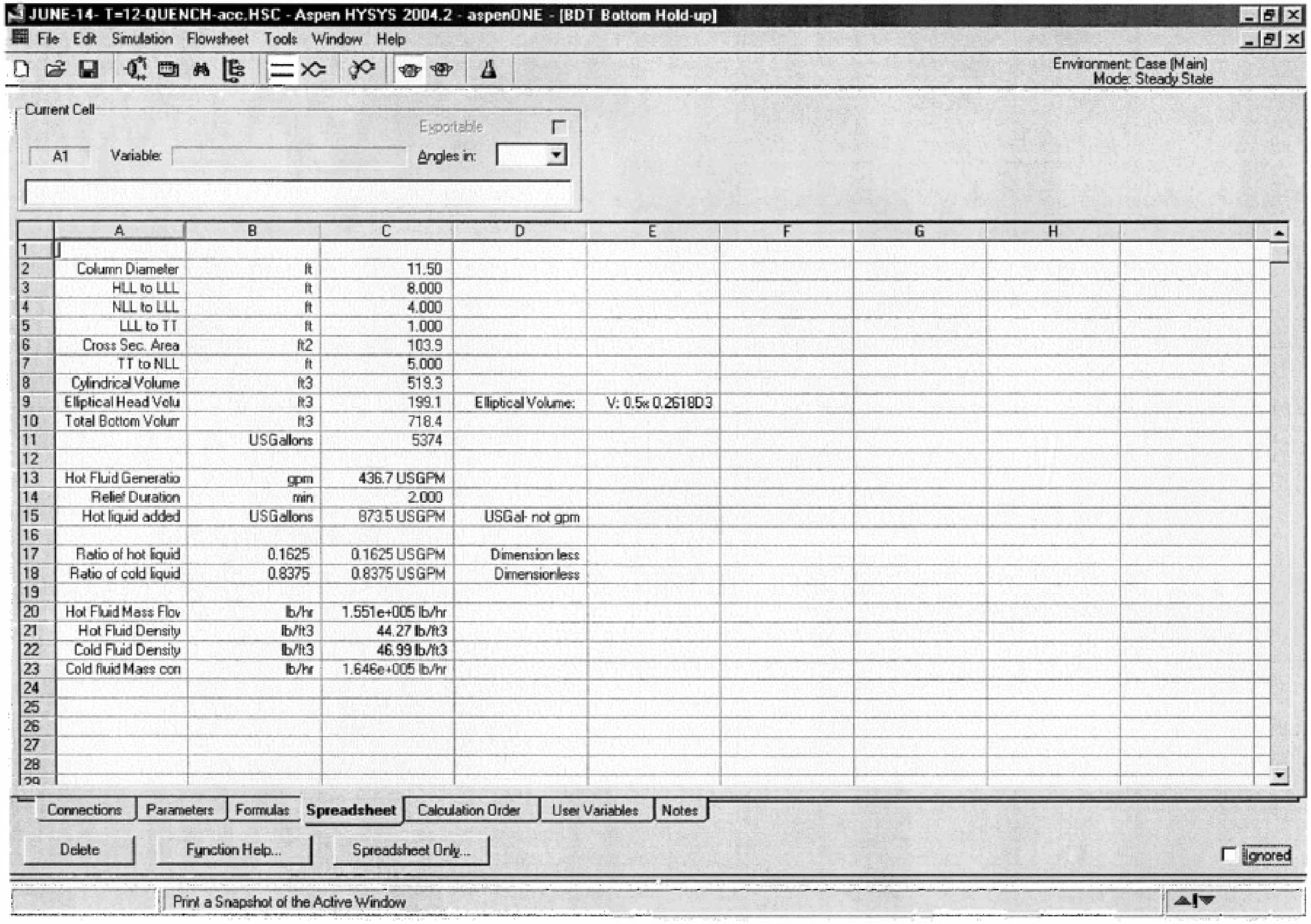
HCGO Quench		
Temperature	450.0	F
Pressure	81.20	psig
Molar Flow	115.6	lbmole/hr
Mass Flow	3.728e+004	lb/hr
Actual Liquid Flow	94.06	USGPM

_165 Cold		
Temperature	596.5	F
Pressure	44.50	psig
Molar Flow	428.4	lbmole/hr
Mass Flow	1.645e+005	lb/hr
Molecular Weight	383.9	
Actual Liquid Flow	436.4	USGPM
Mass Density	46.99	lb/ft3
Viscosity	0.3230	cP

_165_mix T		
Temperature	617.0	F
Pressure	44.50	psig
Molar Flow	422.0	lbmole/hr
Mass Flow	1.629e+005	lb/hr
Molecular Weight	386.1	
Actual Liquid Flow	436.2	USGPM
Mass Density	46.57	lb/ft3
Viscosity	0.2814	cP

Figure 4.27- Quench t=12

BDT Bottom Hold-up



	A	B	C	D	E	F	G	H
1								
2	Column Diameter	ft	11.50					
3	HLL to LLL	ft	8.000					
4	NLL to LLL	ft	4.000					
5	LLL to TT	ft	1.000					
6	Cross Sec. Area	ft2	103.9					
7	TT to NLL	ft	5.000					
8	Cylindrical Volume	ft3	519.3					
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3			
10	Total Bottom Volur	ft3	718.4					
11		USGallons	5374					
12								
13	Hot Fluid Generatio	gpm	436.7 USGPM					
14	Relief Duration	min	2.000					
15	Hot liquid added	USGallons	873.5 USGPM	USGal- not gpm				
16								
17	Ratio of hot liquid	0.1625	0.1625 USGPM	Dimension less				
18	Ratio of cold liquid	0.8375	0.8375 USGPM	Dimensionless				
19								
20	Hot Fluid Mass Flov	lb/hr	1.551e+005 lb/hr					
21	Hot Fluid Density	lb/ft3	44.27 lb/ft3					
22	Cold Fluid Density	lb/ft3	46.99 lb/ft3					
23	Cold fluid Mass con	lb/hr	1.646e+005 lb/hr					
24								
25								
26								
27								
28								

Figure 4.28-Quench, Ratio at t=12

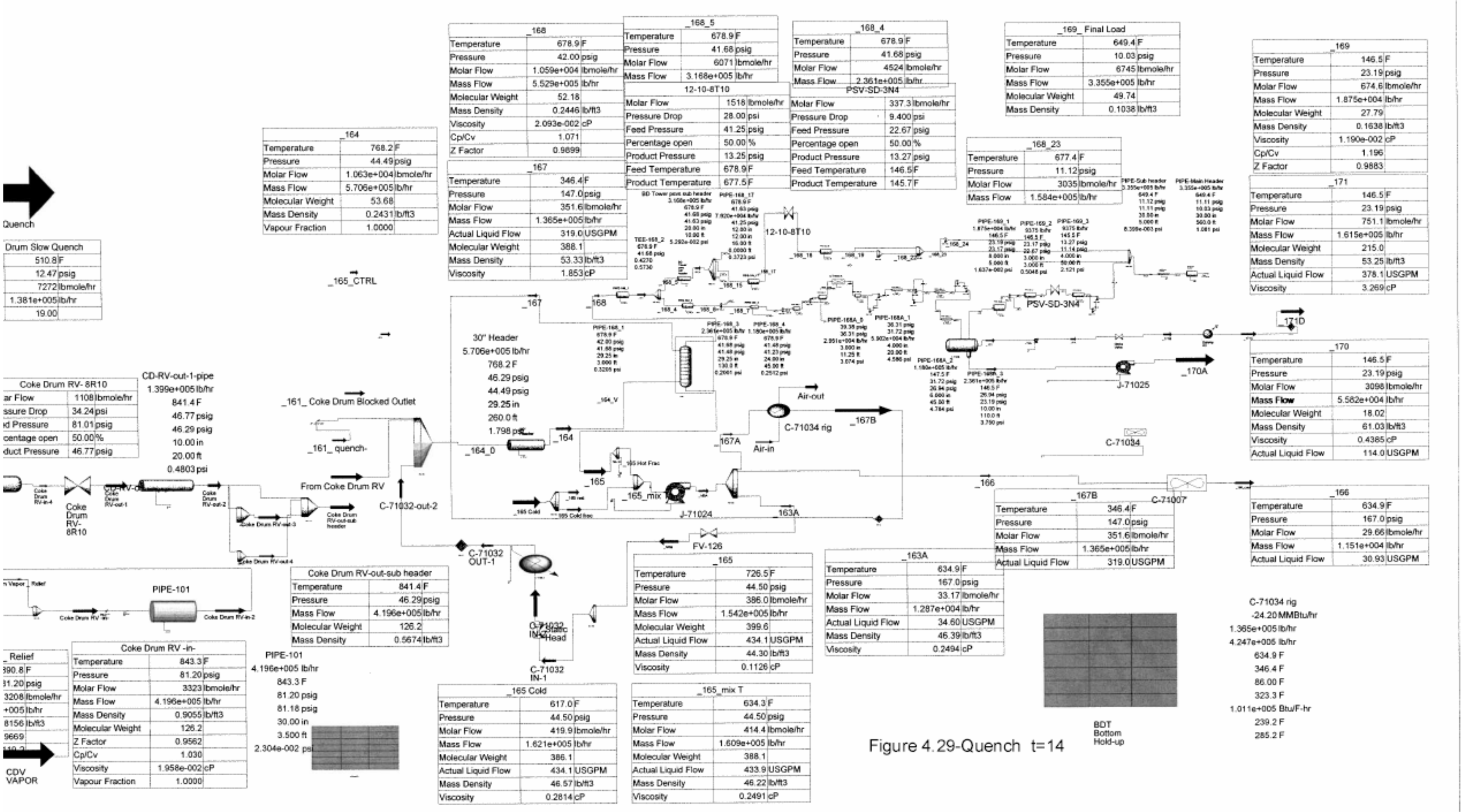


Figure 4.29-Quench t=14

_168		
Temperature	678.9	F
Pressure	42.00	psig
Molar Flow	1.059e+004	lbmole/hr
Mass Flow	5.529e+005	lb/hr
Molecular Weight	52.18	
Mass Density	0.2446	lb/ft3
Viscosity	2.093e-002	cP
Cp/Cv	1.071	
Z Factor	0.9899	

_168_5		
Temperature	678.9	F
Pressure	41.68	psig
Molar Flow	6071	lbmole/hr
Mass Flow	3.168e+005	lb/hr

_168_4		
Temperature	678.9	F
Pressure	41.68	psig
Molar Flow	4524	lbmole/hr
Mass Flow	2.361e+005	lb/hr

12-10-8T10		
Molar Flow	1518	lbmole/hr
Pressure Drop	28.00	psi
Feed Pressure	41.25	psig
Percentage open	50.00	%
Product Pressure	13.25	psig
Feed Temperature	678.9	F
Product Temperature	677.5	F

PSV-SD-3N4		
Molar Flow	337.3	lbmole/hr
Pressure Drop	9.400	psi
Feed Pressure	22.67	psig
Percentage open	50.00	%
Product Pressure	13.27	psig
Feed Temperature	146.5	F
Product Temperature	145.7	F

_169_ Final Load		
Temperature	649.4	F
Pressure	10.03	psig
Molar Flow	6745	lbmole/hr
Mass Flow	3.355e+005	lb/hr
Molecular Weight	49.74	
Mass Density	0.1038	lb/ft3

_169		
Temperature	146.5	F
Pressure	23.19	psig
Molar Flow	674.6	lbmole/hr
Mass Flow	1.875e+004	lb/hr
Molecular Weight	27.79	
Mass Density	0.1638	lb/ft3
Viscosity	1.190e-002	cP
Cp/Cv	1.196	
Z Factor	0.9883	

_164		
Temperature	768.2	F
Pressure	44.49	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.706e+005	lb/hr
Molecular Weight	53.68	
Mass Density	0.2431	lb/ft3
Vapour Fraction	1.0000	

_167		
Temperature	346.4	F
Pressure	147.0	psig
Molar Flow	351.6	lbmole/hr
Mass Flow	1.365e+005	lb/hr
Actual Liquid Flow	319.0	USGPM
Molecular Weight	388.1	
Mass Density	53.33	lb/ft3
Viscosity	1.853	cP

_168_23		
Temperature	677.4	F
Pressure	11.12	psig
Molar Flow	3035	lbmole/hr
Mass Flow	1.584e+005	lb/hr

_171		
Temperature	146.5	F
Pressure	23.19	psig
Molar Flow	751.1	lbmole/hr
Mass Flow	1.615e+005	lb/hr
Molecular Weight	215.0	
Mass Density	53.25	lb/ft3
Actual Liquid Flow	378.1	USGPM
Viscosity	3.269	cP

Drum Slow Quench	
510.8	F
12.47	psig
7272	lbmole/hr
1.381e+005	lb/hr
19.00	

Coke Drum RV- 8R10		
ar Flow	1108	lbmole/hr
ssure Drop	34.24	psi
d Pressure	81.01	psig
centage open	50.00	%
duct Pressure	46.77	psig

_170		
Temperature	146.5	F
Pressure	23.19	psig
Molar Flow	3098	lbmole/hr
Mass Flow	5.582e+004	lb/hr
Molecular Weight	18.02	
Mass Density	61.03	lb/ft3
Viscosity	0.4385	cP
Actual Liquid Flow	114.0	USGPM

_167B		
Temperature	346.4	F
Pressure	147.0	psig
Molar Flow	351.6	lbmole/hr
Mass Flow	1.365e+005	lb/hr
Actual Liquid Flow	319.0	USGPM

_166		
Temperature	634.9	F
Pressure	167.0	psig
Molar Flow	29.66	lbmole/hr
Mass Flow	1.151e+004	lb/hr
Actual Liquid Flow	30.93	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	726.5	F
Pressure	44.50	psig
Molar Flow	386.0	lbmole/hr
Mass Flow	1.542e+005	lb/hr
Molecular Weight	399.6	
Actual Liquid Flow	434.1	USGPM
Mass Density	44.30	lb/ft3
Viscosity	0.1126	cP

_163A		
Temperature	634.9	F
Pressure	167.0	psig
Molar Flow	33.17	lbmole/hr
Mass Flow	1.287e+004	lb/hr
Actual Liquid Flow	34.60	USGPM
Mass Density	46.39	lb/ft3
Viscosity	0.2494	cP

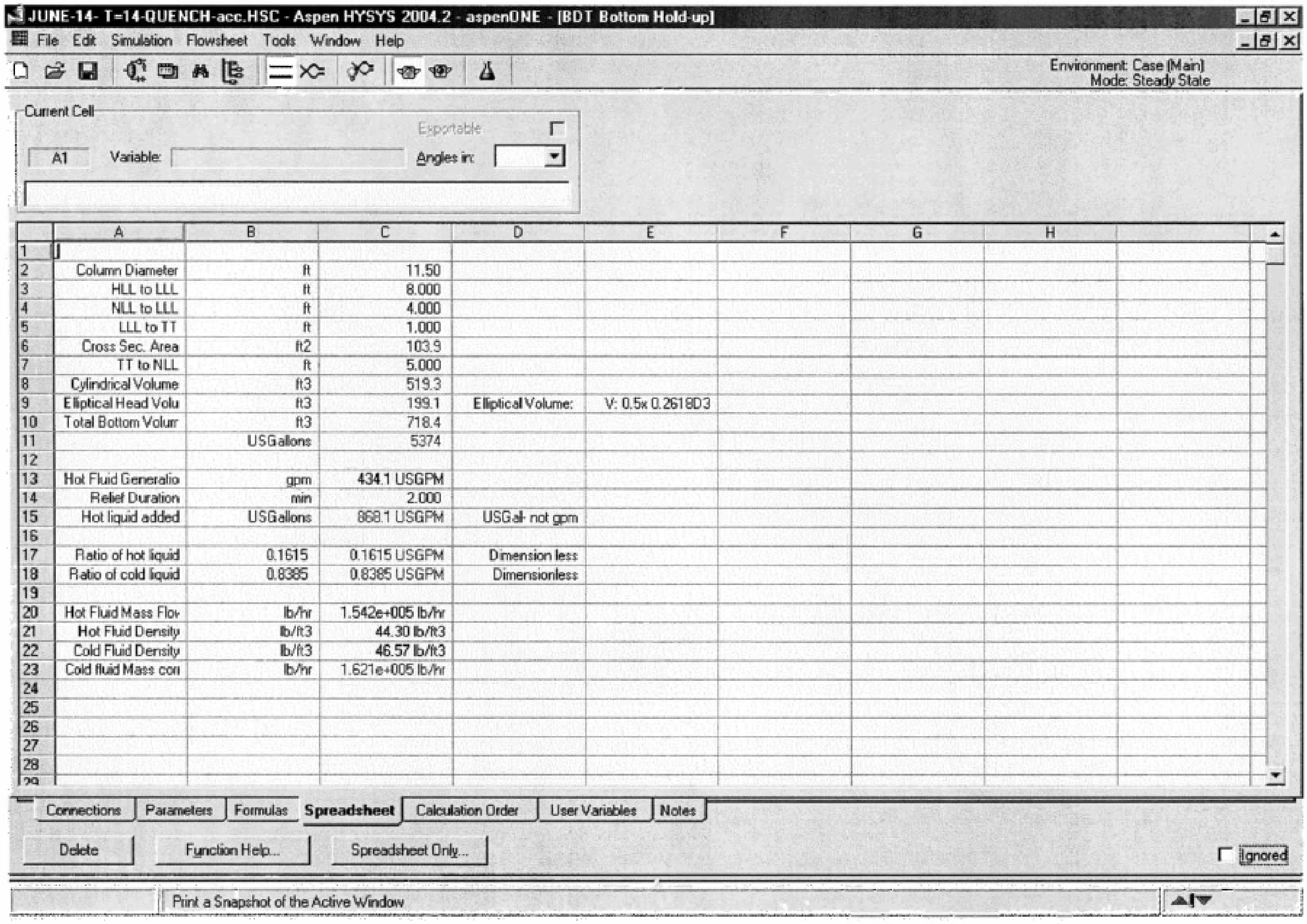
_ Relief	
390.8	F
1.20	psig
3208	lbmole/hr
+005	lb/hr
8156	lb/ft3
9669	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

_165 Cold		
Temperature	617.0	F
Pressure	44.50	psig
Molar Flow	419.9	lbmole/hr
Mass Flow	1.621e+005	lb/hr
Molecular Weight	386.1	
Actual Liquid Flow	434.1	USGPM
Mass Density	46.57	lb/ft3
Viscosity	0.2814	cP

_165_mix T		
Temperature	634.3	F
Pressure	44.50	psig
Molar Flow	414.4	lbmole/hr
Mass Flow	1.609e+005	lb/hr
Molecular Weight	388.1	
Actual Liquid Flow	433.9	USGPM
Mass Density	46.22	lb/ft3
Viscosity	0.2491	cP

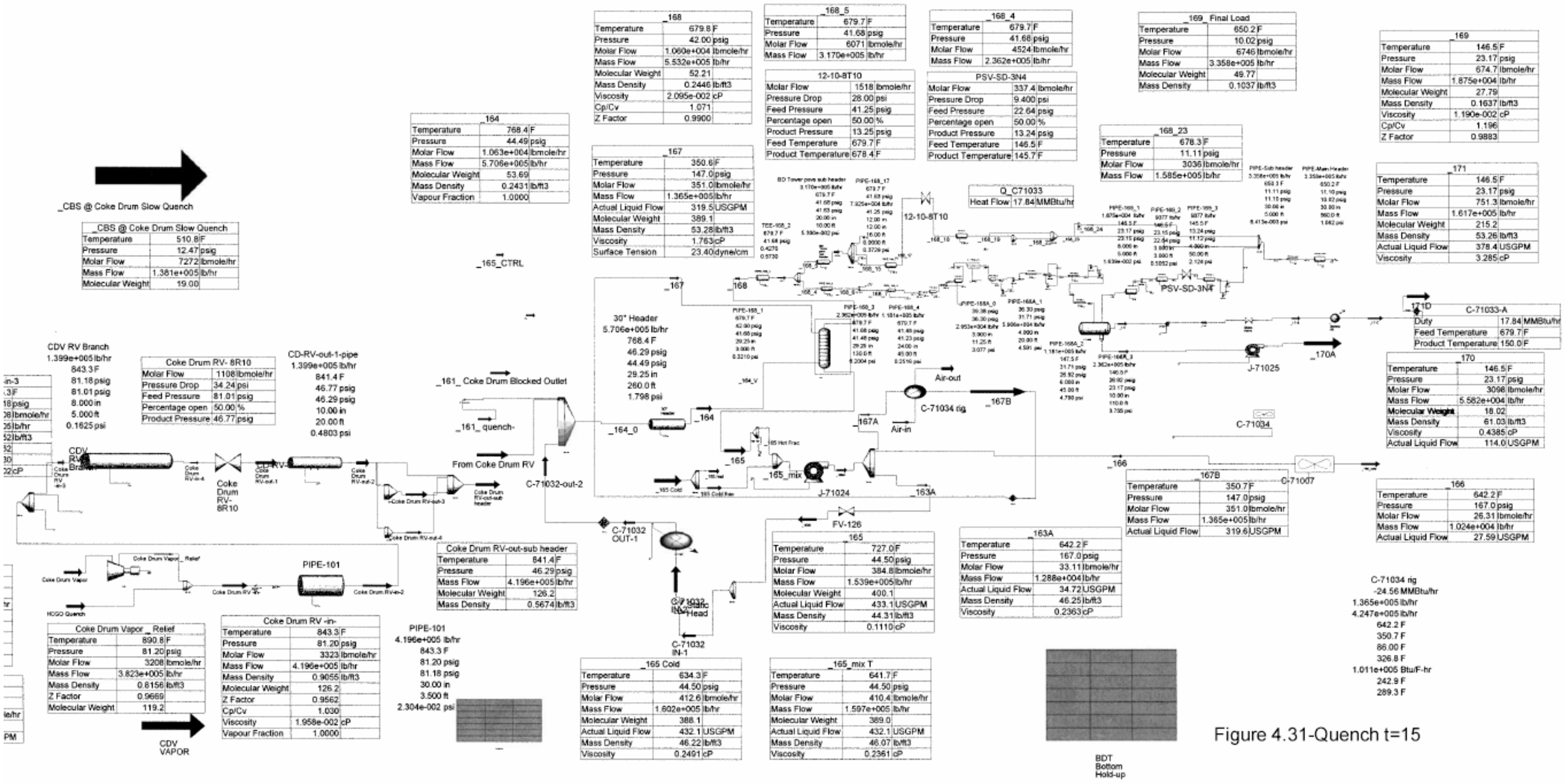
BDT Bottom Hold-up



	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volur	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	434.1 USGPM		
14	Relief Duration	min	2.000		
15	Hot liquid added	USGallons	868.1 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.1615	0.1615 USGPM	Dimension less	
18	Ratio of cold liquid	0.8385	0.8385 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flov	lb/hr	1.542e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	44.30 lb/ft3		
22	Cold Fluid Density	lb/ft3	46.57 lb/ft3		
23	Cold fluid Mass con	lb/hr	1.621e+005 lb/hr		

Print a Snapshot of the Active Window

Figure 4.30-Quench, Ratio at t=14



_CBS @ Coke Drum Slow Quench		
Temperature	510.8	F
Pressure	12.47	psig
Molar Flow	7272	lbmole/hr
Mass Flow	1.381e+005	lb/hr
Molecular Weight	19.00	

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

_164		
Temperature	768.4	F
Pressure	44.49	psig
Molar Flow	1.063e+004	lbmole/hr
Mass Flow	5.706e+005	lb/hr
Molecular Weight	53.69	
Mass Density	0.2431	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	679.8	F
Pressure	42.00	psig
Molar Flow	1.060e+004	lbmole/hr
Mass Flow	5.532e+005	lb/hr
Molecular Weight	52.21	
Mass Density	0.2446	lb/ft3
Viscosity	2.095e-002	cP
Cp/Cv	1.071	
Z Factor	0.9900	

_167		
Temperature	350.6	F
Pressure	147.0	psig
Molar Flow	351.0	lbmole/hr
Mass Flow	1.365e+005	lb/hr
Actual Liquid Flow	319.5	USGPM
Molecular Weight	389.1	
Mass Density	53.28	lb/ft3
Viscosity	1.763	cP
Surface Tension	23.40	dyne/cm

_168_5		
Temperature	679.7	F
Pressure	41.68	psig
Molar Flow	6071	lbmole/hr
Mass Flow	3.170e+005	lb/hr

12-10-8T10		
Molar Flow	1518	lbmole/hr
Pressure Drop	28.00	psi
Feed Pressure	41.25	psig
Percentage open	50.00	%
Product Pressure	13.25	psig
Feed Temperature	679.7	F
Product Temperature	678.4	F

_168_4		
Temperature	679.7	F
Pressure	41.68	psig
Molar Flow	4524	lbmole/hr
Mass Flow	2.362e+005	lb/hr

PSV-SD-3N4		
Molar Flow	337.4	lbmole/hr
Pressure Drop	9.400	psi
Feed Pressure	22.64	psig
Percentage open	50.00	%
Product Pressure	13.24	psig
Feed Temperature	146.5	F
Product Temperature	145.7	F

Q_C71033		
Heat Flow	17.84	MMBtu/hr

_169_ Final Load		
Temperature	650.2	F
Pressure	10.02	psig
Molar Flow	6746	lbmole/hr
Mass Flow	3.358e+005	lb/hr
Molecular Weight	49.77	
Mass Density	0.1037	lb/ft3

_168_23		
Temperature	678.3	F
Pressure	11.11	psig
Molar Flow	3036	lbmole/hr
Mass Flow	1.585e+005	lb/hr

_169		
Temperature	146.5	F
Pressure	23.17	psig
Molar Flow	674.7	lbmole/hr
Mass Flow	1.875e+004	lb/hr
Molecular Weight	27.79	
Mass Density	0.1637	lb/ft3
Viscosity	1.190e-002	cP
Cp/Cv	1.196	
Z Factor	0.9883	

_171		
Temperature	146.5	F
Pressure	23.17	psig
Molar Flow	751.3	lbmole/hr
Mass Flow	1.617e+005	lb/hr
Molecular Weight	215.2	
Mass Density	53.26	lb/ft3
Actual Liquid Flow	378.4	USGPM
Viscosity	3.285	cP

C-71033-A		
Duty	17.84	MMBtu/hr
Feed Temperature	679.7	F
Product Temperature	150.0	F

_170		
Temperature	146.5	F
Pressure	23.17	psig
Molar Flow	3098	lbmole/hr
Mass Flow	5.582e+004	lb/hr
Molecular Weight	18.02	
Mass Density	61.03	lb/ft3
Viscosity	0.4385	cP
Actual Liquid Flow	114.0	USGPM

_167B		
Temperature	350.7	F
Pressure	147.0	psig
Molar Flow	351.0	lbmole/hr
Mass Flow	1.365e+005	lb/hr
Actual Liquid Flow	319.6	USGPM

_166		
Temperature	642.2	F
Pressure	167.0	psig
Molar Flow	26.31	lbmole/hr
Mass Flow	1.024e+004	lb/hr
Actual Liquid Flow	27.59	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	727.0	F
Pressure	44.50	psig
Molar Flow	384.8	lbmole/hr
Mass Flow	1.539e+005	lb/hr
Molecular Weight	400.1	
Actual Liquid Flow	433.1	USGPM
Mass Density	44.31	lb/ft3
Viscosity	0.1110	cP

_163A		
Temperature	642.2	F
Pressure	167.0	psig
Molar Flow	33.11	lbmole/hr
Mass Flow	1.288e+004	lb/hr
Actual Liquid Flow	34.72	USGPM
Mass Density	46.25	lb/ft3
Viscosity	0.2363	cP

Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9669	
Molecular Weight	119.2	

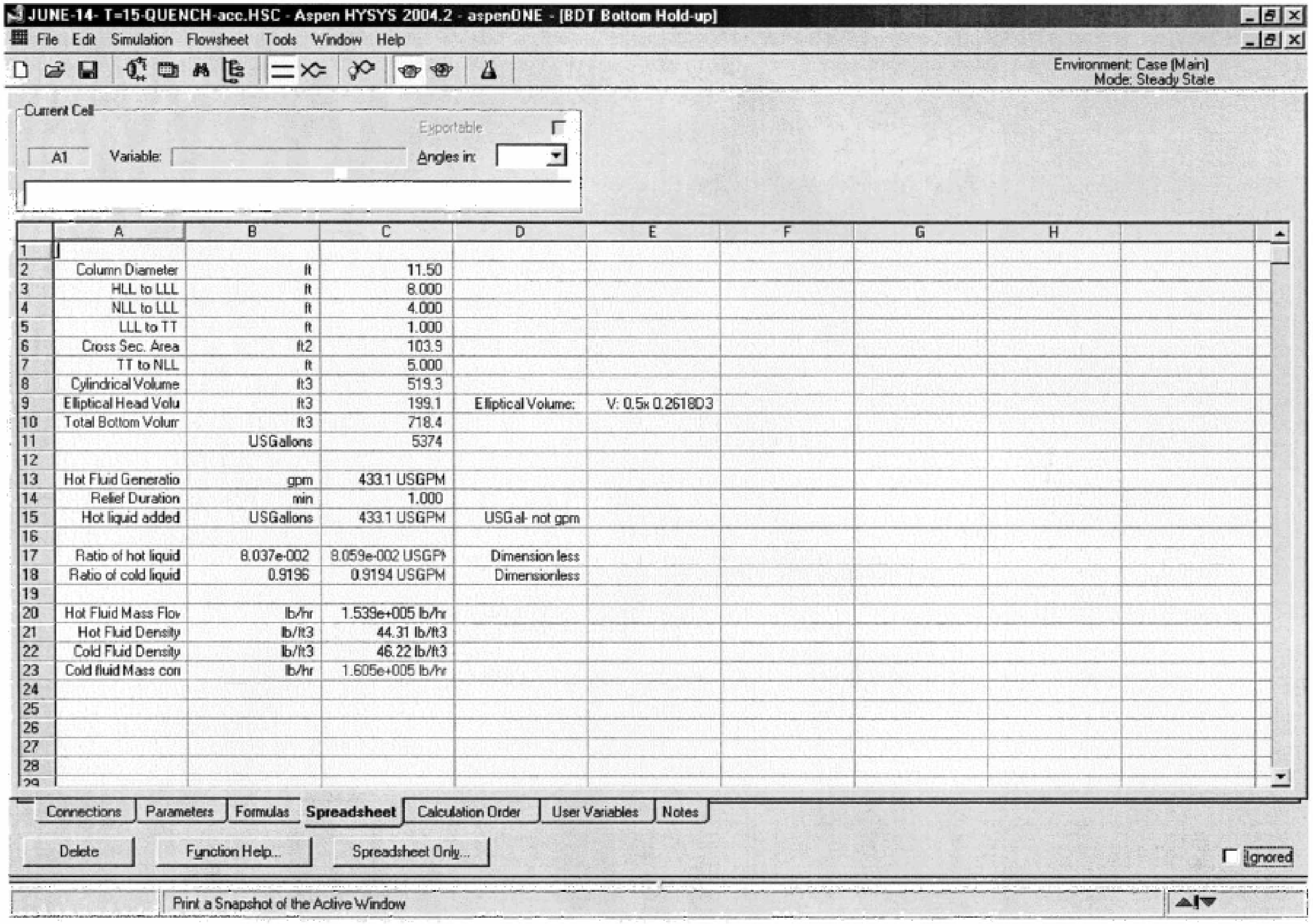
Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

_165 Cold		
Temperature	634.3	F
Pressure	44.50	psig
Molar Flow	412.6	lbmole/hr
Mass Flow	1.602e+005	lb/hr
Molecular Weight	388.1	
Actual Liquid Flow	432.1	USGPM
Mass Density	46.22	lb/ft3
Viscosity	0.2491	cP

_165_mix T		
Temperature	641.7	F
Pressure	44.50	psig
Molar Flow	410.4	lbmole/hr
Mass Flow	1.597e+005	lb/hr
Molecular Weight	389.0	
Actual Liquid Flow	432.1	USGPM
Mass Density	46.07	lb/ft3
Viscosity	0.2361	cP

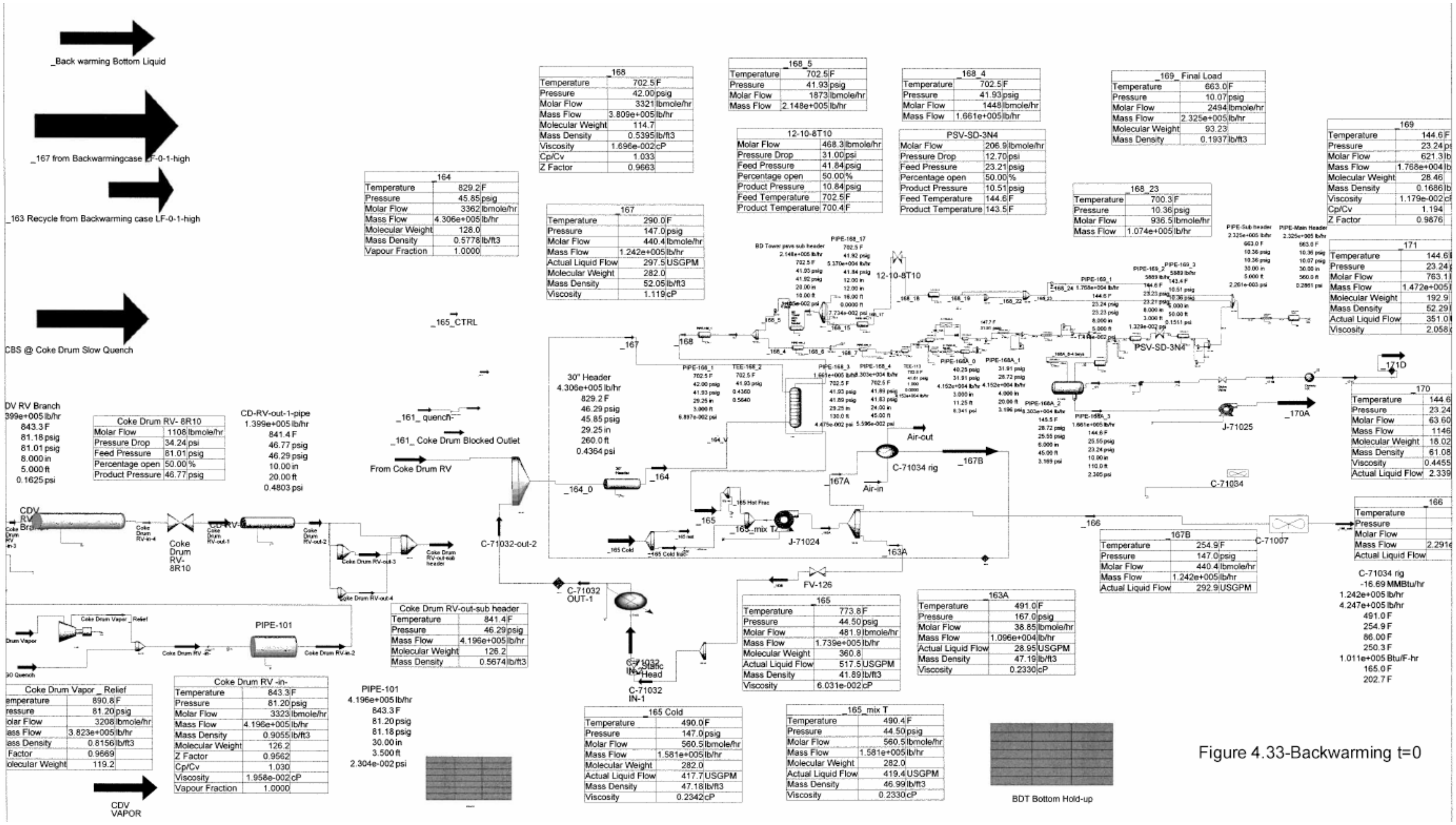
Figure 4.31-Quench t=15

BDT Bottom Hold-up



	A	B	C	D	E	F	G	H
1								
2	Column Diameter	ft	11.50					
3	HLL to LLL	ft	8.000					
4	NLL to LLL	ft	4.000					
5	LLL to TT	ft	1.000					
6	Cross Sec. Area	ft2	103.9					
7	TT to NLL	ft	5.000					
8	Cylindrical Volume	ft3	519.3					
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3			
10	Total Bottom Volur	ft3	718.4					
11		USGallons	5374					
12								
13	Hot Fluid Generatio	gpm	433.1 USGPM					
14	Relief Duration	min	1.000					
15	Hot liquid added	USGallons	433.1 USGPM	USGal- not gpm				
16								
17	Ratio of hot liquid	8.037e-002	8.059e-002 USGPI	Dimension less				
18	Ratio of cold liquid	0.9196	0.9194 USGPM	Dimensionless				
19								
20	Hot Fluid Mass Flov	lb/hr	1.539e+005 lb/hr					
21	Hot Fluid Density	lb/ft3	44.31 lb/ft3					
22	Cold Fluid Density	lb/ft3	46.22 lb/ft3					
23	Cold fluid Mass con	lb/hr	1.605e+005 lb/hr					
24								
25								
26								
27								
28								

Figure 4.32-Quench, Ratio at t=15



_168		
Temperature	702.5	F
Pressure	42.00	psig
Molar Flow	3321	lbmole/hr
Mass Flow	3.809e+005	lb/hr
Molecular Weight	114.7	
Mass Density	0.5395	lb/ft3
Viscosity	1.696e-002	cP
Cp/Cv	1.033	
Z Factor	0.9663	

_168_5		
Temperature	702.5	F
Pressure	41.93	psig
Molar Flow	1873	lbmole/hr
Mass Flow	2.148e+005	lb/hr

_168_4		
Temperature	702.5	F
Pressure	41.93	psig
Molar Flow	1448	lbmole/hr
Mass Flow	1.661e+005	lb/hr

_169_ Final Load		
Temperature	663.0	F
Pressure	10.07	psig
Molar Flow	2494	lbmole/hr
Mass Flow	2.325e+005	lb/hr
Molecular Weight	93.23	
Mass Density	0.1937	lb/ft3

_169		
Temperature	144.6	F
Pressure	23.24	ps
Molar Flow	621.3	lb
Mass Flow	1.768e+004	lb
Molecular Weight	28.46	
Mass Density	0.1686	lb
Viscosity	1.179e-002	cl
Cp/Cv	1.194	
Z Factor	0.9876	

12-10-8T10		
Molar Flow	468.3	lbmole/hr
Pressure Drop	31.00	psi
Feed Pressure	41.84	psig
Percentage open	50.00	%
Product Pressure	10.84	psig
Feed Temperature	702.5	F
Product Temperature	700.4	F

PSV-SD-3N4		
Molar Flow	206.9	lbmole/hr
Pressure Drop	12.70	psi
Feed Pressure	23.21	psig
Percentage open	50.00	%
Product Pressure	10.51	psig
Feed Temperature	144.6	F
Product Temperature	143.5	F

_164		
Temperature	829.2	F
Pressure	45.85	psig
Molar Flow	3362	lbmole/hr
Mass Flow	4.306e+005	lb/hr
Molecular Weight	128.0	
Mass Density	0.5778	lb/ft3
Vapour Fraction	1.0000	

_167		
Temperature	290.0	F
Pressure	147.0	psig
Molar Flow	440.4	lbmole/hr
Mass Flow	1.242e+005	lb/hr
Actual Liquid Flow	297.5	USGPM
Molecular Weight	282.0	
Mass Density	52.05	lb/ft3
Viscosity	1.119	cP

_168_23		
Temperature	700.3	F
Pressure	10.36	psig
Molar Flow	936.5	lbmole/hr
Mass Flow	1.074e+005	lb/hr

_171	
Temperature	144.6
Pressure	23.24
Molar Flow	763.1
Mass Flow	1.472e+005
Molecular Weight	192.9
Mass Density	52.29
Actual Liquid Flow	351.0
Viscosity	2.058

_170	
Temperature	144.6
Pressure	23.24
Molar Flow	63.60
Mass Flow	1146
Molecular Weight	18.02
Mass Density	61.08
Viscosity	0.4455
Actual Liquid Flow	2.339

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

_166	
Temperature	
Pressure	
Molar Flow	
Mass Flow	2.291e
Actual Liquid Flow	

_167B		
Temperature	254.9	F
Pressure	147.0	psig
Molar Flow	440.4	lbmole/hr
Mass Flow	1.242e+005	lb/hr
Actual Liquid Flow	292.9	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	773.8	F
Pressure	44.50	psig
Molar Flow	481.9	lbmole/hr
Mass Flow	1.739e+005	lb/hr
Molecular Weight	360.8	
Actual Liquid Flow	517.5	USGPM
Mass Density	41.89	lb/ft3
Viscosity	6.031e-002	cP

_163A		
Temperature	491.0	F
Pressure	167.0	psig
Molar Flow	38.85	lbmole/hr
Mass Flow	1.096e+004	lb/hr
Actual Liquid Flow	28.95	USGPM
Mass Density	47.19	lb/ft3
Viscosity	0.2330	cP

Coke Drum Vapor _ Relief		
emperature	890.8	F
ressure	81.20	psig
olar Flow	3208	lbmole/hr
ass Flow	3.823e+005	lb/hr
ass Density	0.8156	lb/ft3
Factor	0.9669	
olecular Weight	119.2	

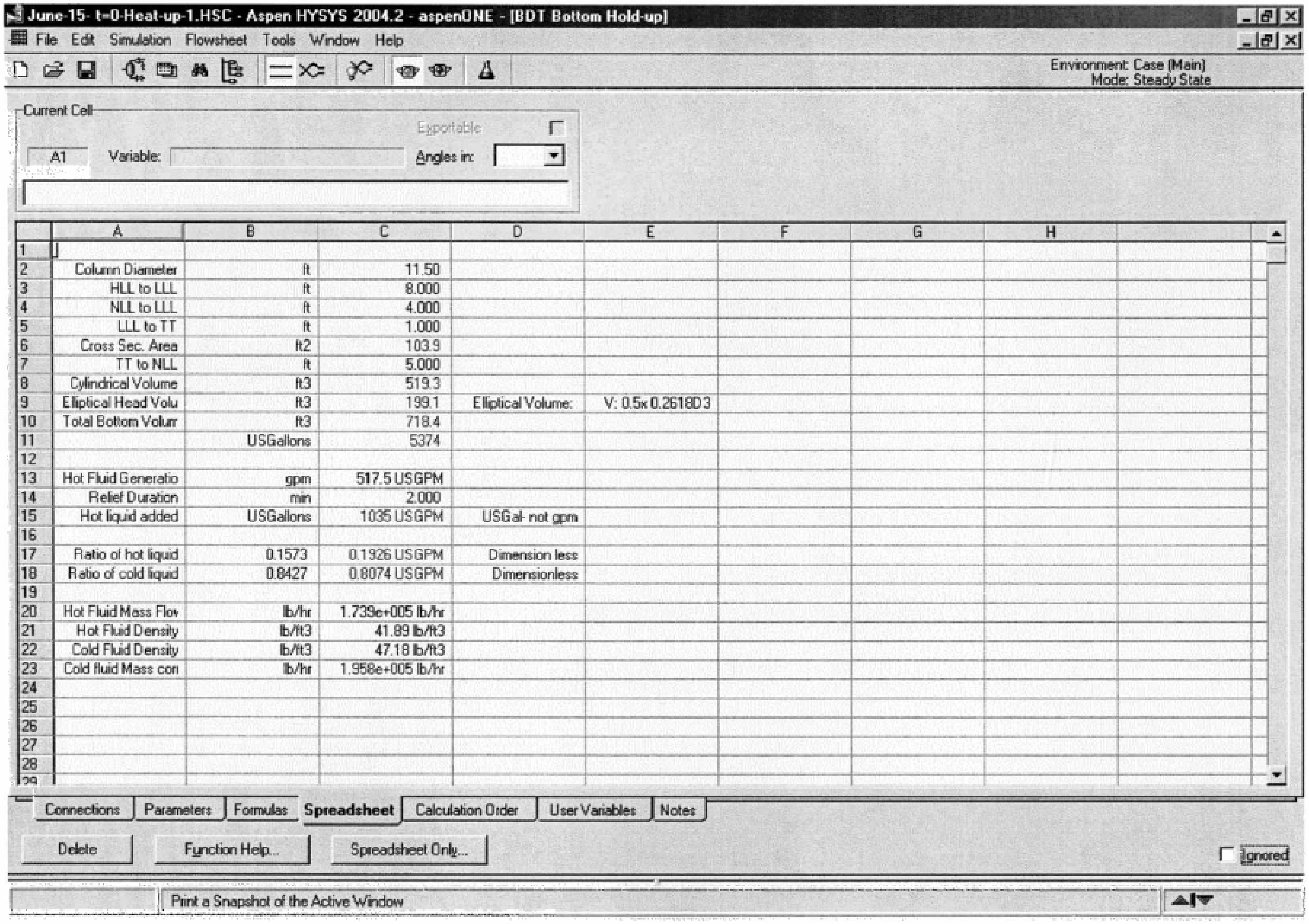
Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

_165 Cold		
Temperature	490.0	F
Pressure	147.0	psig
Molar Flow	560.5	lbmole/hr
Mass Flow	1.581e+005	lb/hr
Molecular Weight	282.0	
Actual Liquid Flow	417.7	USGPM
Mass Density	47.18	lb/ft3
Viscosity	0.2342	cP

_165_mix T		
Temperature	490.4	F
Pressure	44.50	psig
Molar Flow	560.5	lbmole/hr
Mass Flow	1.581e+005	lb/hr
Molecular Weight	282.0	
Actual Liquid Flow	419.4	USGPM
Mass Density	46.99	lb/ft3
Viscosity	0.2330	cP

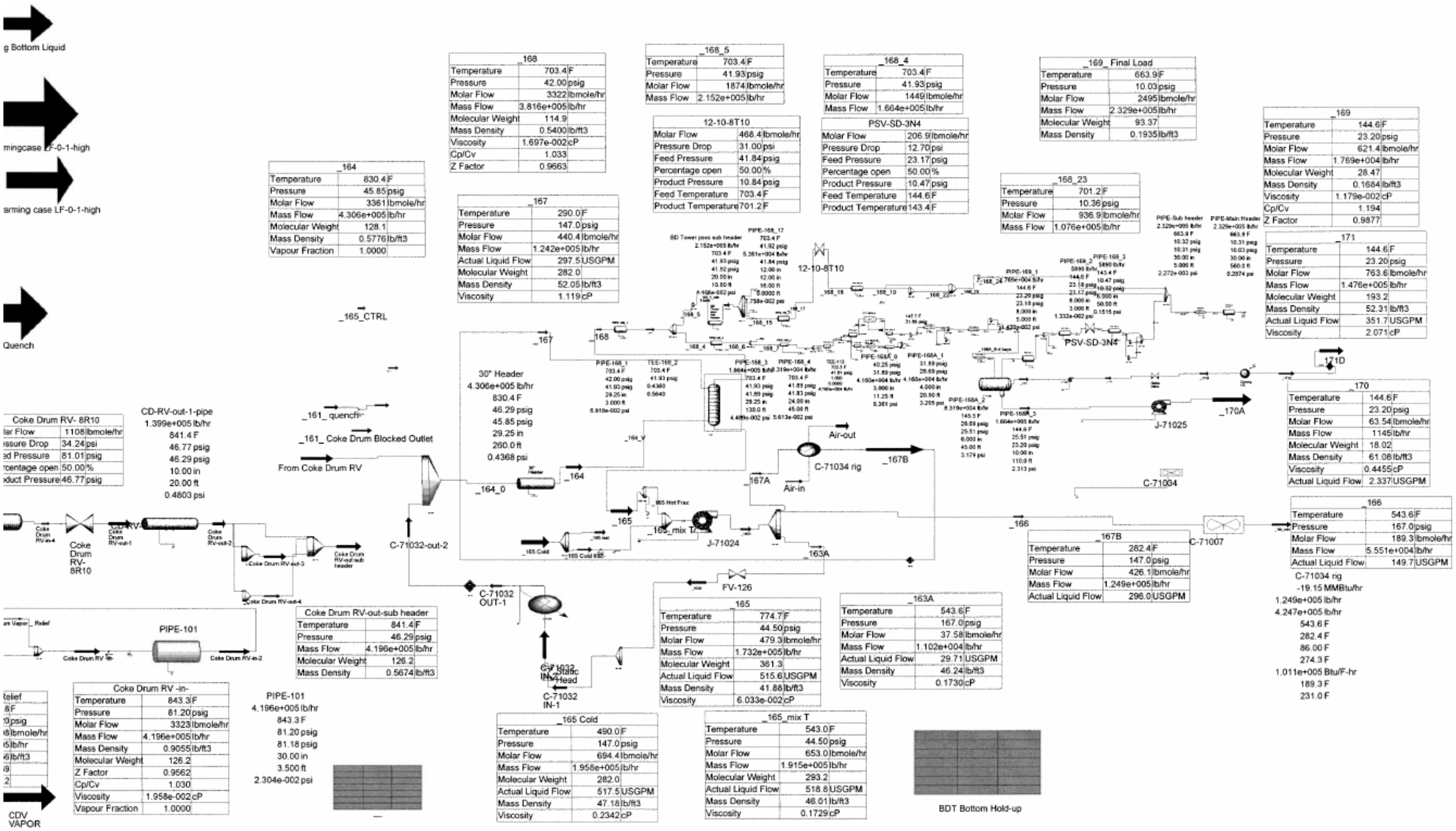
Figure 4.33-Backwarming t=0

BDT Bottom Hold-up



	A	B	C	D	E	F	G	H
1								
2	Column Diameter	ft	11.50					
3	HLL to LLL	ft	8.000					
4	NLL to LLL	ft	4.000					
5	LLL to TT	ft	1.000					
6	Cross Sec. Area	ft2	103.9					
7	TT to NLL	ft	5.000					
8	Cylindrical Volume	ft3	519.3					
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3			
10	Total Bottom Volum	ft3	718.4					
11		USGallons	5374					
12								
13	Hot Fluid Generatio	gpm	517.5 USGPM					
14	Relief Duration	min	2.000					
15	Hot liquid added	USGallons	1035 USGPM	USGal- not gpm				
16								
17	Ratio of hot liquid	0.1573	0.1926 USGPM	Dimension less				
18	Ratio of cold liquid	0.8427	0.8074 USGPM	Dimensionless				
19								
20	Hot Fluid Mass Flov	lb/hr	1.739e+005 lb/hr					
21	Hot Fluid Density	lb/ft3	41.89 lb/ft3					
22	Cold Fluid Density	lb/ft3	47.18 lb/ft3					
23	Cold fluid Mass con	lb/hr	1.958e+005 lb/hr					
24								
25								
26								
27								
28								

Figure 4.34-Backwarming, Ratio at t=0



_168		
Temperature	703.4	F
Pressure	42.00	psig
Molar Flow	3322	lbmole/hr
Mass Flow	3.816e+005	lb/hr
Molecular Weight	114.9	
Mass Density	0.5400	lb/ft3
Viscosity	1.697e-002	cP
Cp/Cv	1.033	
Z Factor	0.9663	

_164		
Temperature	830.4	F
Pressure	45.85	psig
Molar Flow	3361	lbmole/hr
Mass Flow	4.306e+005	lb/hr
Molecular Weight	128.1	
Mass Density	0.5776	lb/ft3
Vapour Fraction	1.0000	

_167		
Temperature	290.0	F
Pressure	147.0	psig
Molar Flow	440.4	lbmole/hr
Mass Flow	1.242e+005	lb/hr
Actual Liquid Flow	297.5	USGPM
Molecular Weight	282.0	
Mass Density	52.05	lb/ft3
Viscosity	1.119	cP

_168_5		
Temperature	703.4	F
Pressure	41.93	psig
Molar Flow	1874	lbmole/hr
Mass Flow	2.152e+005	lb/hr

12-10-8T10		
Molar Flow	468.4	lbmole/hr
Pressure Drop	31.00	psi
Feed Pressure	41.84	psig
Percentage open	50.00	%
Product Pressure	10.84	psig
Feed Temperature	703.4	F
Product Temperature	701.2	F

_168_4		
Temperature	703.4	F
Pressure	41.93	psig
Molar Flow	1449	lbmole/hr
Mass Flow	1.664e+005	lb/hr

PSV-SD-3N4		
Molar Flow	206.9	lbmole/hr
Pressure Drop	12.70	psi
Feed Pressure	23.17	psig
Percentage open	50.00	%
Product Pressure	10.47	psig
Feed Temperature	144.6	F
Product Temperature	143.4	F

_169_ Final Load		
Temperature	663.9	F
Pressure	10.03	psig
Molar Flow	2495	lbmole/hr
Mass Flow	2.329e+005	lb/hr
Molecular Weight	93.37	
Mass Density	0.1935	lb/ft3

_168_23		
Temperature	701.2	F
Pressure	10.36	psig
Molar Flow	936.9	lbmole/hr
Mass Flow	1.076e+005	lb/hr

_169		
Temperature	144.6	F
Pressure	23.20	psig
Molar Flow	621.4	lbmole/hr
Mass Flow	1.769e+004	lb/hr
Molecular Weight	28.47	
Mass Density	0.1684	lb/ft3
Viscosity	1.179e-002	cP
Cp/Cv	1.194	
Z Factor	0.9877	

_171		
Temperature	144.6	F
Pressure	23.20	psig
Molar Flow	763.6	lbmole/hr
Mass Flow	1.476e+005	lb/hr
Molecular Weight	193.2	
Mass Density	52.31	lb/ft3
Actual Liquid Flow	351.7	USGPM
Viscosity	2.071	cP

PIPE-Sub header
2.329e+005 lb/hr
663.9 F
10.32 psig
10.31 psig
30.00 in
5.000 ft
2.272e-003 psi

PIPE-Main Header
2.329e+005 lb/hr
663.9 F
10.31 psig
10.03 psig
30.00 in
560.0 ft
0.2874 psi

BD Tower pass sub header
2.152e+005 lb/hr
703.4 F
41.93 psig
41.92 psig
20.00 in
10.00 ft
4.108e-002 psi

PIPE-168_17
703.4 F
41.92 psig
5.381e+004 lb/hr
41.84 psig
12.00 in
12.00 in
16.00 ft
5.0000 ft
7.758e-002 psi

PIPE-169_1
1.769e+004 lb/hr
144.6 F
23.20 psig
23.18 psig
8.000 in
5.000 ft
1.420e-002 psi

PIPE-169_2
5890 lb/hr
144.6 F
23.18 psig
23.17 psig
8.000 in
3.000 ft
1.332e-002 psi

PIPE-169_3
5890 lb/hr
143.4 F
10.47 psig
10.32 psig
6.000 in
50.00 ft
0.1515 psi

PIPE-168_1
703.4 F
42.00 psig
41.93 psig
29.25 in
3.000 ft
6.916e-002 psi

TEE-168_2
703.4 F
41.93 psig
0.4360
0.5640

PIPE-168_3
1.664e+005 lb/hr
703.4 F
41.93 psig
41.89 psig
29.25 in
130.0 ft
4.489e-002 psi

PIPE-168_4
5.319e+004 lb/hr
703.4 F
41.89 psig
41.83 psig
24.00 in
45.00 ft
5.613e-002 psi

PIPE-168A_0
40.25 psig
31.89 psig
4.160e+004 lb/hr
3.000 in
11.25 ft
8.361 psi

PIPE-168A_1
31.89 psig
28.69 psig
4.160e+004 lb/hr
4.000 in
20.00 ft
3.205 psi

PIPE-168A_2
8.319e+004 lb/hr
145.5 F
28.69 psig
25.51 psig
6.000 in
45.00 ft
3.179 psi

PIPE-168A_3
1.664e+005 lb/hr
144.6 F
25.51 psig
23.20 psig
10.00 in
110.0 ft
2.313 psi

_170		
Temperature	144.6	F
Pressure	23.20	psig
Molar Flow	63.54	lbmole/hr
Mass Flow	1145	lb/hr
Molecular Weight	18.02	
Mass Density	61.08	lb/ft3
Viscosity	0.4455	cP
Actual Liquid Flow	2.337	USGPM

30" Header
4.306e+005 lb/hr
830.4 F
46.29 psig
45.85 psig
29.25 in
260.0 ft
0.4368 psi

Coke Drum RV- 8R10		
lar Flow	1108	lbmole/hr
ssure Drop	34.24	psi
ed Pressure	81.01	psig
rcentage open	50.00	%
duct Pressure	46.77	psig

CD-RV-out-1-pipe
1.399e+005 lb/hr
841.4 F
46.77 psig
46.29 psig
10.00 in
20.00 ft
0.4803 psi

_166		
Temperature	543.6	F
Pressure	167.0	psig
Molar Flow	189.3	lbmole/hr
Mass Flow	5.551e+004	lb/hr
Actual Liquid Flow	149.7	USGPM

_167B		
Temperature	282.4	F
Pressure	147.0	psig
Molar Flow	426.1	lbmole/hr
Mass Flow	1.249e+005	lb/hr
Actual Liquid Flow	296.0	USGPM

C-71034 rig
-19.15 MMBtu/hr
1.249e+005 lb/hr
4.247e+005 lb/hr
543.6 F
282.4 F
86.00 F
274.3 F
1.011e+005 Btu/F-hr
189.3 F
231.0 F

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	774.7	F
Pressure	44.50	psig
Molar Flow	479.3	lbmole/hr
Mass Flow	1.732e+005	lb/hr
Molecular Weight	361.3	
Actual Liquid Flow	515.6	USGPM
Mass Density	41.88	lb/ft3
Viscosity	6.033e-002	cP

_163A		
Temperature	543.6	F
Pressure	167.0	psig
Molar Flow	37.58	lbmole/hr
Mass Flow	1.102e+004	lb/hr
Actual Liquid Flow	29.71	USGPM
Mass Density	46.24	lb/ft3
Viscosity	0.1730	cP

Relief	
8	F
0	psig
8	lbmole/hr
5	lb/hr
6	lb/ft3
9	
2	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

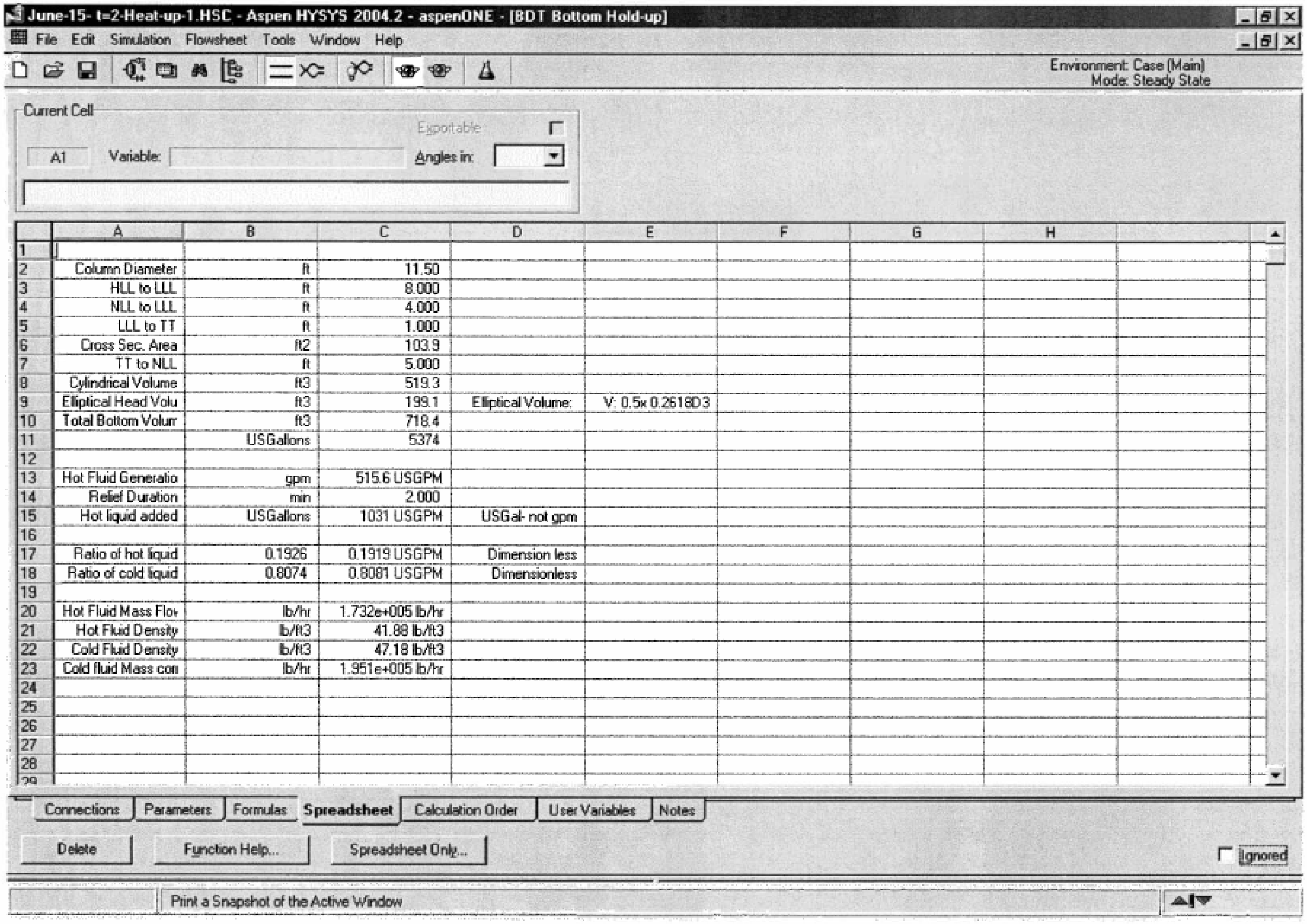
PIPE-101
4.196e+005 lb/hr
843.3 F
81.20 psig
81.18 psig
30.00 in
3.500 ft
2.304e-002 psi

_165 Cold		
Temperature	490.0	F
Pressure	147.0	psig
Molar Flow	694.4	lbmole/hr
Mass Flow	1.958e+005	lb/hr
Molecular Weight	282.0	
Actual Liquid Flow	517.5	USGPM
Mass Density	47.18	lb/ft3
Viscosity	0.2342	cP

_165_mix T		
Temperature	543.0	F
Pressure	44.50	psig
Molar Flow	653.0	lbmole/hr
Mass Flow	1.915e+005	lb/hr
Molecular Weight	293.2	
Actual Liquid Flow	518.8	USGPM
Mass Density	46.01	lb/ft3
Viscosity	0.1729	cP

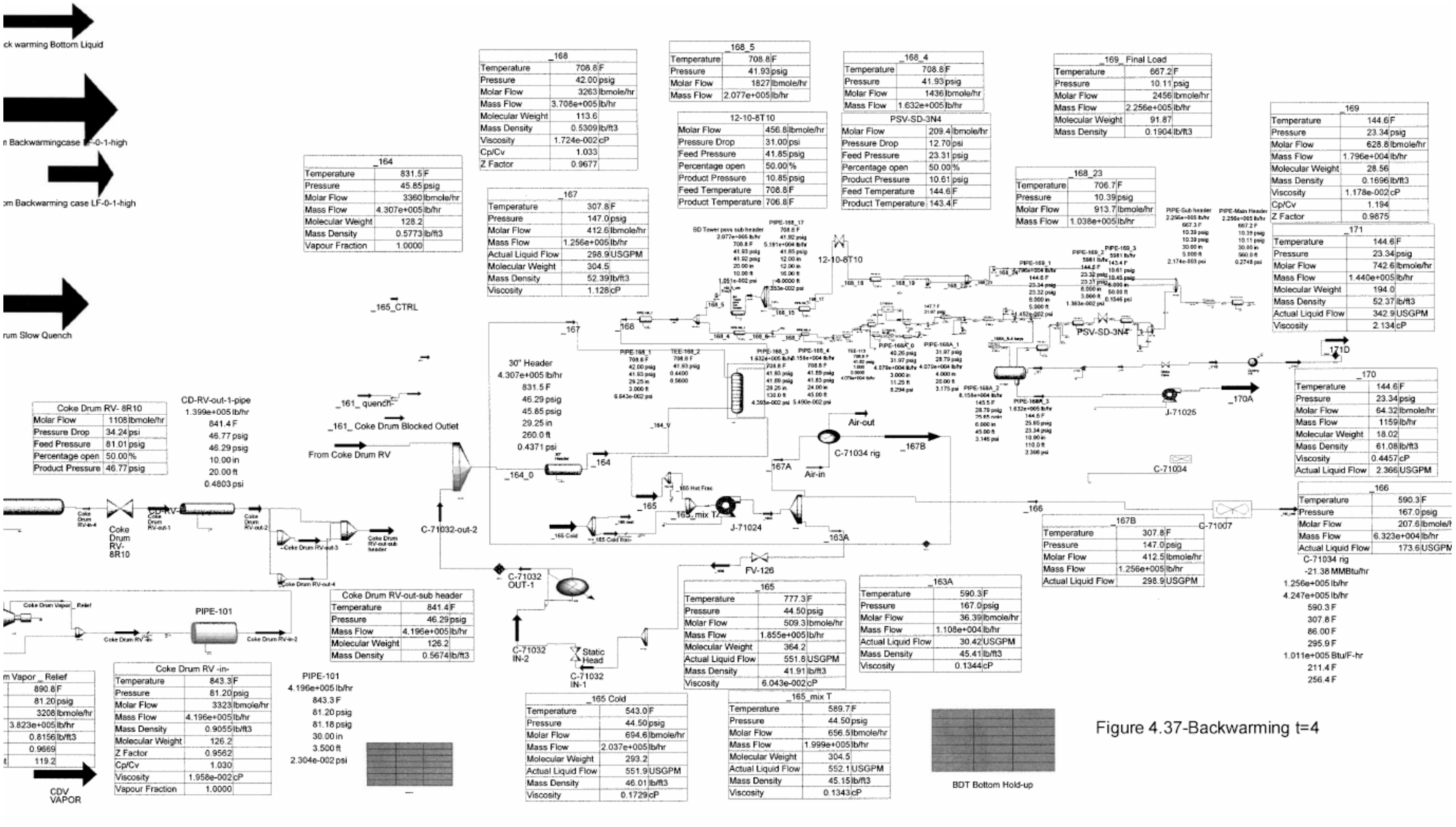
Figure 4.35-Backwarming t=2

BDT Bottom Hold-up



	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volum	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	515.6 USGPM		
14	Relief Duration	min	2.000		
15	Hot liquid added	USGallons	1031 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.1926	0.1919 USGPM	Dimension less	
18	Ratio of cold liquid	0.8074	0.8081 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flo	lb/hr	1.732e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	41.88 lb/ft3		
22	Cold Fluid Density	lb/ft3	47.18 lb/ft3		
23	Cold fluid Mass con	lb/hr	1.951e+005 lb/hr		

Figure 4.36-Backwarming, Ratio at t=2



_168		
Temperature	708.8	F
Pressure	42.00	psig
Molar Flow	3263	lbmole/hr
Mass Flow	3.708e+005	lb/hr
Molecular Weight	113.6	
Mass Density	0.5309	lb/ft3
Viscosity	1.724e-002	cP
Cp/Cv	1.033	
Z Factor	0.9677	

_168_5		
Temperature	708.8	F
Pressure	41.93	psig
Molar Flow	1827	lbmole/hr
Mass Flow	2.077e+005	lb/hr

_168_4		
Temperature	708.8	F
Pressure	41.93	psig
Molar Flow	1436	lbmole/hr
Mass Flow	1.632e+005	lb/hr

_169_ Final Load		
Temperature	667.2	F
Pressure	10.11	psig
Molar Flow	2456	lbmole/hr
Mass Flow	2.256e+005	lb/hr
Molecular Weight	91.87	
Mass Density	0.1904	lb/ft3

12-10-8T10		
Molar Flow	456.8	lbmole/hr
Pressure Drop	31.00	psi
Feed Pressure	41.85	psig
Percentage open	50.00	%
Product Pressure	10.85	psig
Feed Temperature	708.8	F
Product Temperature	706.8	F

PSV-SD-3N4		
Molar Flow	209.4	lbmole/hr
Pressure Drop	12.70	psi
Feed Pressure	23.31	psig
Percentage open	50.00	%
Product Pressure	10.61	psig
Feed Temperature	144.6	F
Product Temperature	143.4	F

_169		
Temperature	144.6	F
Pressure	23.34	psig
Molar Flow	628.8	lbmole/hr
Mass Flow	1.796e+004	lb/hr
Molecular Weight	28.56	
Mass Density	0.1696	lb/ft3
Viscosity	1.178e-002	cP
Cp/Cv	1.194	
Z Factor	0.9875	

_164		
Temperature	831.5	F
Pressure	45.85	psig
Molar Flow	3360	lbmole/hr
Mass Flow	4.307e+005	lb/hr
Molecular Weight	128.2	
Mass Density	0.5773	lb/ft3
Vapour Fraction	1.0000	

_167		
Temperature	307.8	F
Pressure	147.0	psig
Molar Flow	412.6	lbmole/hr
Mass Flow	1.256e+005	lb/hr
Actual Liquid Flow	298.9	USGPM
Molecular Weight	304.5	
Mass Density	52.39	lb/ft3
Viscosity	1.128	cP

_168_23		
Temperature	706.7	F
Pressure	10.39	psig
Molar Flow	913.7	lbmole/hr
Mass Flow	1.038e+005	lb/hr

_171		
Temperature	144.6	F
Pressure	23.34	psig
Molar Flow	742.6	lbmole/hr
Mass Flow	1.440e+005	lb/hr
Molecular Weight	194.0	
Mass Density	52.37	lb/ft3
Actual Liquid Flow	342.9	USGPM
Viscosity	2.134	cP

_170		
Temperature	144.6	F
Pressure	23.34	psig
Molar Flow	64.32	lbmole/hr
Mass Flow	1159	lb/hr
Molecular Weight	18.02	
Mass Density	61.08	lb/ft3
Viscosity	0.4457	cP
Actual Liquid Flow	2.366	USGPM

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

_166		
Temperature	590.3	F
Pressure	167.0	psig
Molar Flow	207.6	lbmole/
Mass Flow	6.323e+004	lb/hr
Actual Liquid Flow	173.6	USGPM

_167B		
Temperature	307.8	F
Pressure	147.0	psig
Molar Flow	412.5	lbmole/hr
Mass Flow	1.256e+005	lb/hr
Actual Liquid Flow	298.9	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	777.3	F
Pressure	44.50	psig
Molar Flow	509.3	lbmole/hr
Mass Flow	1.855e+005	lb/hr
Molecular Weight	364.2	
Actual Liquid Flow	551.8	USGPM
Mass Density	41.91	lb/ft3
Viscosity	6.043e-002	cP

_163A		
Temperature	590.3	F
Pressure	167.0	psig
Molar Flow	36.39	lbmole/hr
Mass Flow	1.108e+004	lb/hr
Actual Liquid Flow	30.42	USGPM
Mass Density	45.41	lb/ft3
Viscosity	0.1344	cP

m Vapor _ Relief		
	890.8	F
	81.20	psig
	3208	lbmole/hr
	3.823e+005	lb/hr
	0.8156	lb/ft3
	0.9669	
t	119.2	

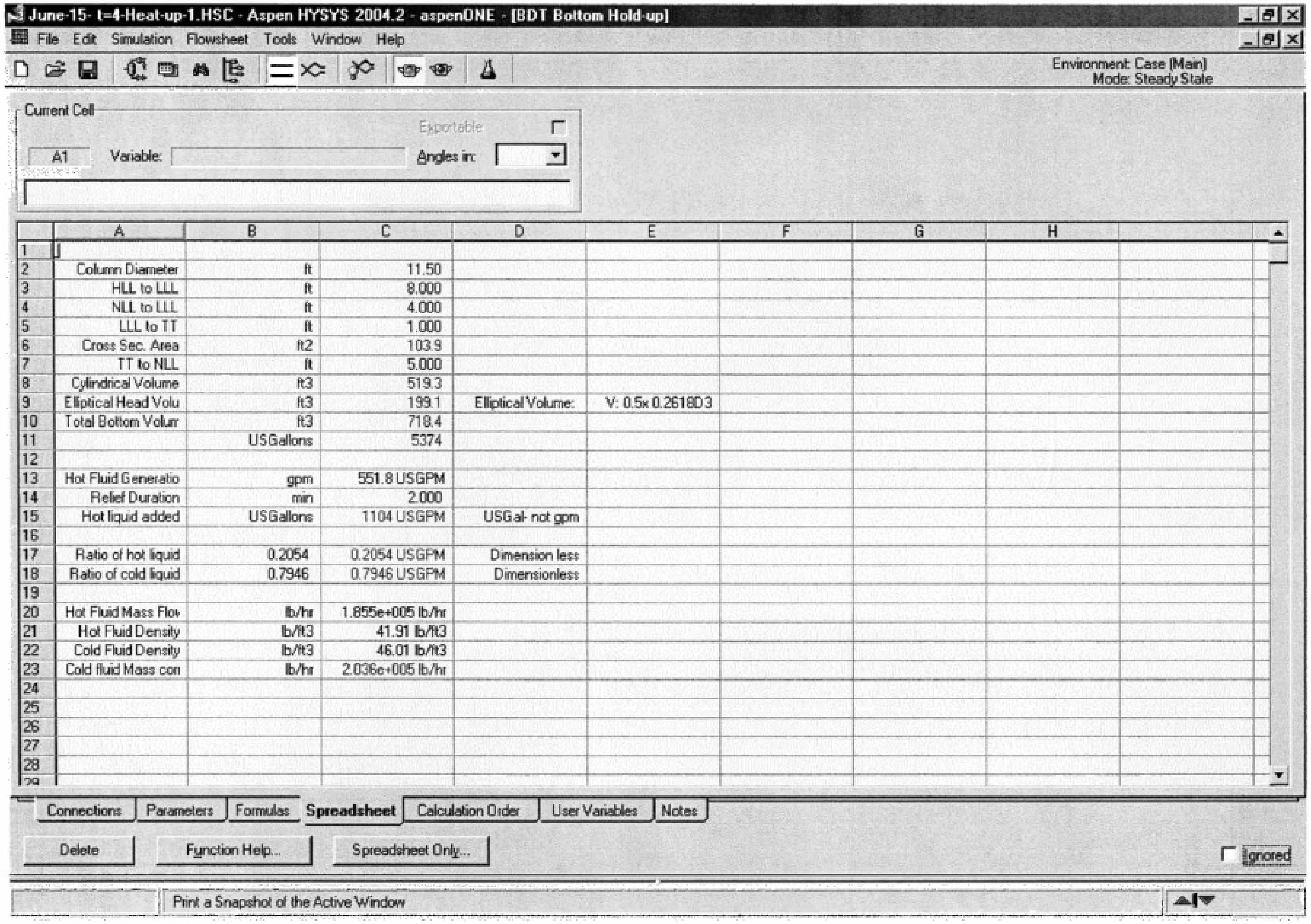
Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

_165 Cold		
Temperature	543.0	F
Pressure	44.50	psig
Molar Flow	694.6	lbmole/hr
Mass Flow	2.037e+005	lb/hr
Molecular Weight	293.2	
Actual Liquid Flow	551.9	USGPM
Mass Density	46.01	lb/ft3
Viscosity	0.1729	cP

_165_mix T		
Temperature	589.7	F
Pressure	44.50	psig
Molar Flow	656.5	lbmole/hr
Mass Flow	1.999e+005	lb/hr
Molecular Weight	304.5	
Actual Liquid Flow	552.1	USGPM
Mass Density	45.15	lb/ft3
Viscosity	0.1343	cP

Figure 4.37-Backwarming t=4

BDT Bottom Hold-up



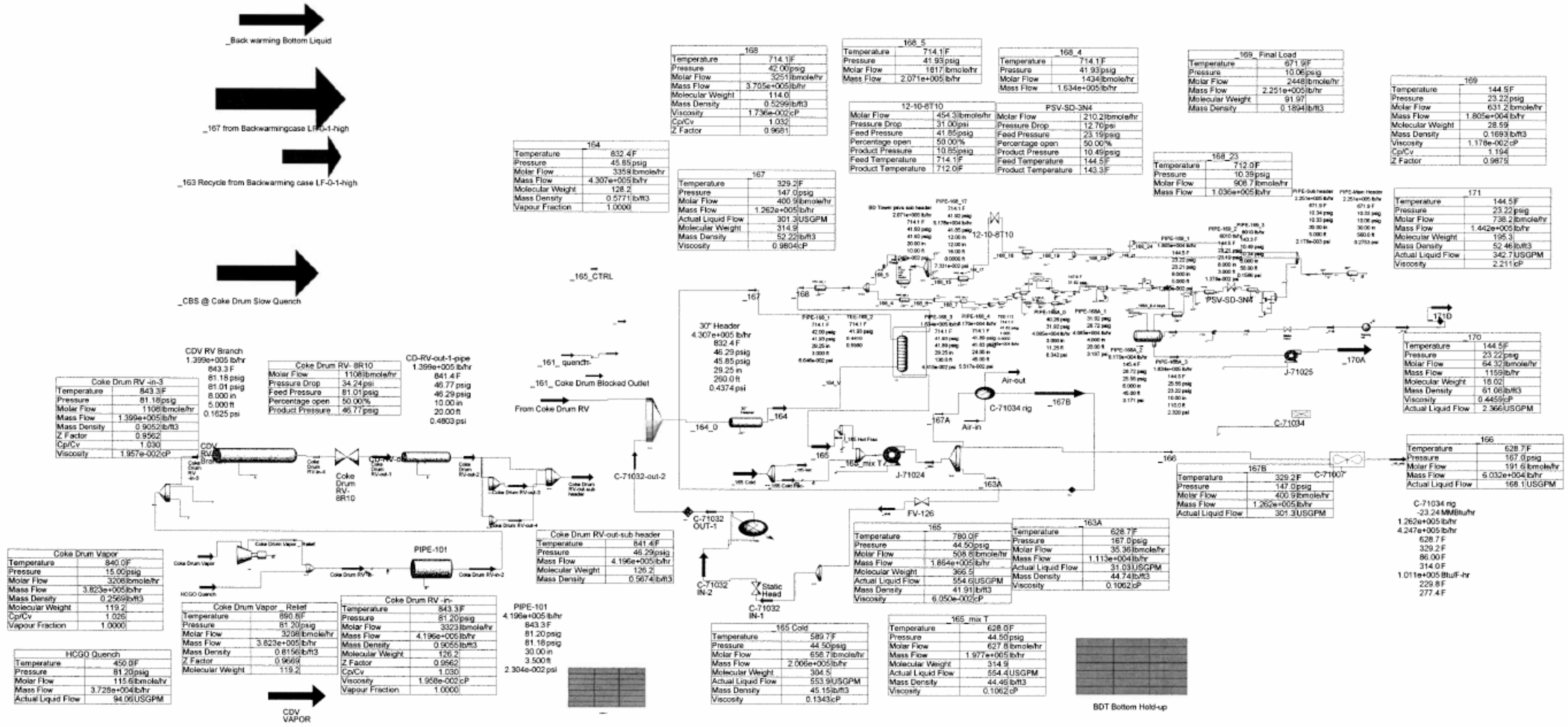
Environment: Case (Main)
Mode: Steady State

A1 Variable: Angles in:

	A	B	C	D	E	F	G	H
1								
2	Column Diameter	ft	11.50					
3	HLL to LLL	ft	8.000					
4	NLL to LLL	ft	4.000					
5	LLL to TT	ft	1.000					
6	Cross Sec. Area	ft2	103.9					
7	TT to NLL	ft	5.000					
8	Cylindrical Volume	ft3	519.3					
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3			
10	Total Bottom Volum	ft3	718.4					
11		USGallons	5374					
12								
13	Hot Fluid Generatio	gpm	551.8 USGPM					
14	Relief Duration	min	2.000					
15	Hot liquid added	USGallons	1104 USGPM	USGal- not gpm				
16								
17	Ratio of hot liquid	0.2054	0.2054 USGPM	Dimension less				
18	Ratio of cold liquid	0.7946	0.7946 USGPM	Dimensionless				
19								
20	Hot Fluid Mass Flov	lb/hr	1.855e+005 lb/hr					
21	Hot Fluid Density	lb/ft3	41.91 lb/ft3					
22	Cold Fluid Density	lb/ft3	46.01 lb/ft3					
23	Cold fluid Mass con	lb/hr	2.036e+005 lb/hr					
24								
25								
26								
27								
28								

Print a Snapshot of the Active Window

Figure 4.38-Backwarming, ratio at t=4



Coke Drum RV -in-3		
Temperature	843.3	F
Pressure	81.18	psig
Molar Flow	1108	lbmole/hr
Mass Flow	1.399e+005	lb/hr
Mass Density	0.9052	lb/ft3
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.957e-002	cP

CDV RV Branch
1.399e+005 lb/hr
843.3 F
81.18 psig
81.01 psig
8.000 in
5.000 ft
0.1625 psi

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

CD-RV-out-1-pipe
1.399e+005 lb/hr
841.4 F
46.77 psig
46.29 psig
10.00 in
20.00 ft
0.4803 psi

_164		
Temperature	832.4	F
Pressure	45.85	psig
Molar Flow	3358	lbmole/hr
Mass Flow	4.307e+005	lb/hr
Molecular Weight	128.2	
Mass Density	0.5771	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	714.1	F
Pressure	42.00	psig
Molar Flow	3251	lbmole/hr
Mass Flow	3.705e+005	lb/hr
Molecular Weight	114.0	
Mass Density	0.5299	lb/ft3
Viscosity	1.736e-002	cP
Cp/Cv	1.032	
Z Factor	0.9681	

_167		
Temperature	329.2	F
Pressure	147.0	psig
Molar Flow	400.9	lbmole/hr
Mass Flow	1.262e+005	lb/hr
Actual Liquid Flow	301.3	USGPM
Molecular Weight	314.9	
Mass Density	52.22	lb/ft3
Viscosity	0.9804	cP

_168_5		
Temperature	714.1	F
Pressure	41.93	psig
Molar Flow	1817	lbmole/hr
Mass Flow	2.071e+005	lb/hr

_168_4		
Temperature	714.1	F
Pressure	41.93	psig
Molar Flow	1434	lbmole/hr
Mass Flow	1.634e+005	lb/hr

12-10-8T10		
Molar Flow	454.3	lbmole/hr
Pressure Drop	31.00	psi
Feed Pressure	41.85	psig
Percentage open	50.00	%
Product Pressure	10.85	psig
Feed Temperature	714.1	F
Product Temperature	712.0	F

PSV-SD-3N4		
Molar Flow	210.2	lbmole/hr
Pressure Drop	12.70	psi
Feed Pressure	23.19	psig
Percentage open	50.00	%
Product Pressure	10.49	psig
Feed Temperature	144.5	F
Product Temperature	143.3	F

_169_ Final Load		
Temperature	671.9	F
Pressure	10.06	psig
Molar Flow	2448	lbmole/hr
Mass Flow	2.251e+005	lb/hr
Molecular Weight	91.97	
Mass Density	0.1894	lb/ft3

_168_23		
Temperature	712.0	F
Pressure	10.39	psig
Molar Flow	908.7	lbmole/hr
Mass Flow	1.036e+005	lb/hr

_169		
Temperature	144.5	F
Pressure	23.22	psig
Molar Flow	631.2	lbmole/hr
Mass Flow	1.805e+004	lb/hr
Molecular Weight	28.59	
Mass Density	0.1693	lb/ft3
Viscosity	1.178e-002	cP
Cp/Cv	1.194	
Z Factor	0.9875	

_171		
Temperature	144.5	F
Pressure	23.22	psig
Molar Flow	738.2	lbmole/hr
Mass Flow	1.442e+005	lb/hr
Molecular Weight	195.3	
Mass Density	52.46	lb/ft3
Actual Liquid Flow	342.7	USGPM
Viscosity	2.211	cP

30" Header
4.307e+005 lb/hr
832.4 F
46.29 psig
45.85 psig
29.25 in
260.0 ft
0.4374 psi

_170		
Temperature	144.5	F
Pressure	23.22	psig
Molar Flow	64.32	lbmole/hr
Mass Flow	1159	lb/hr
Molecular Weight	18.02	
Mass Density	61.06	lb/ft3
Viscosity	0.4459	cP
Actual Liquid Flow	2.366	USGPM

_166		
Temperature	628.7	F
Pressure	167.0	psig
Molar Flow	191.6	lbmole/hr
Mass Flow	6.032e+004	lb/hr
Actual Liquid Flow	168.1	USGPM

_167B		
Temperature	329.2	F
Pressure	147.0	psig
Molar Flow	400.9	lbmole/hr
Mass Flow	1.262e+005	lb/hr
Actual Liquid Flow	301.3	USGPM

C-71034 rig
-23.24 MMBtu/hr
1.262e+005 lb/hr
4.247e+005 lb/hr
628.7 F
329.2 F
86.00 F
314.0 F
1.011e+005 Btu/F-hr
229.8 F
277.4 F

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	780.0	F
Pressure	44.50	psig
Molar Flow	508.8	lbmole/hr
Mass Flow	1.864e+005	lb/hr
Molecular Weight	366.5	
Actual Liquid Flow	554.6	USGPM
Mass Density	41.91	lb/ft3
Viscosity	6.050e-002	cP

_163A		
Temperature	628.7	F
Pressure	167.0	psig
Molar Flow	35.36	lbmole/hr
Mass Flow	1.113e+004	lb/hr
Actual Liquid Flow	31.03	USGPM
Mass Density	44.74	lb/ft3
Viscosity	0.1062	cP

Coke Drum Vapor		
Temperature	840.0	F
Pressure	15.00	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.2569	lb/ft3
Molecular Weight	119.2	
Cp/Cv	1.026	
Vapour Fraction	1.0000	

HCGO Quench		
Temperature	450.0	F
Pressure	81.20	psig
Molar Flow	115.6	lbmole/hr
Mass Flow	3.728e+004	lb/hr
Actual Liquid Flow	94.06	USGPM

Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9669	
Molecular Weight	119.2	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

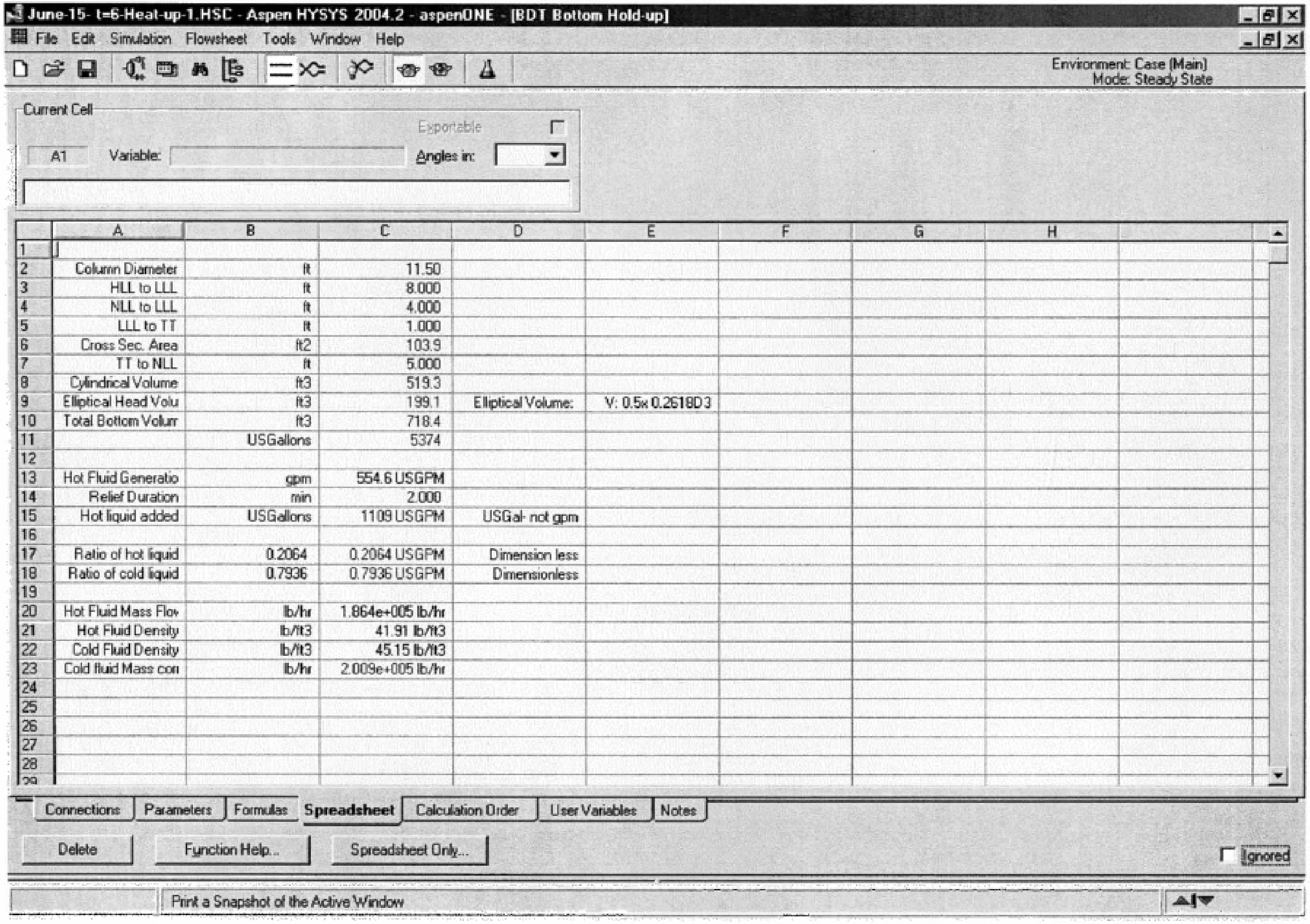
PIPE-101
4.196e+005 lb/hr
843.3 F
81.20 psig
81.18 psig
30.00 in
3.500 ft
2.304e-002 psi

_165 Cold		
Temperature	589.7	F
Pressure	44.50	psig
Molar Flow	658.7	lbmole/hr
Mass Flow	2.006e+005	lb/hr
Molecular Weight	304.5	
Actual Liquid Flow	553.9	USGPM
Mass Density	45.15	lb/ft3
Viscosity	0.1343	cP

_165_mix T		
Temperature	628.0	F
Pressure	44.50	psig
Molar Flow	627.8	lbmole/hr
Mass Flow	1.977e+005	lb/hr
Molecular Weight	314.9	
Actual Liquid Flow	554.4	USGPM
Mass Density	44.46	lb/ft3
Viscosity	0.1062	cP

Figure 4.39-Backwarming at t=6

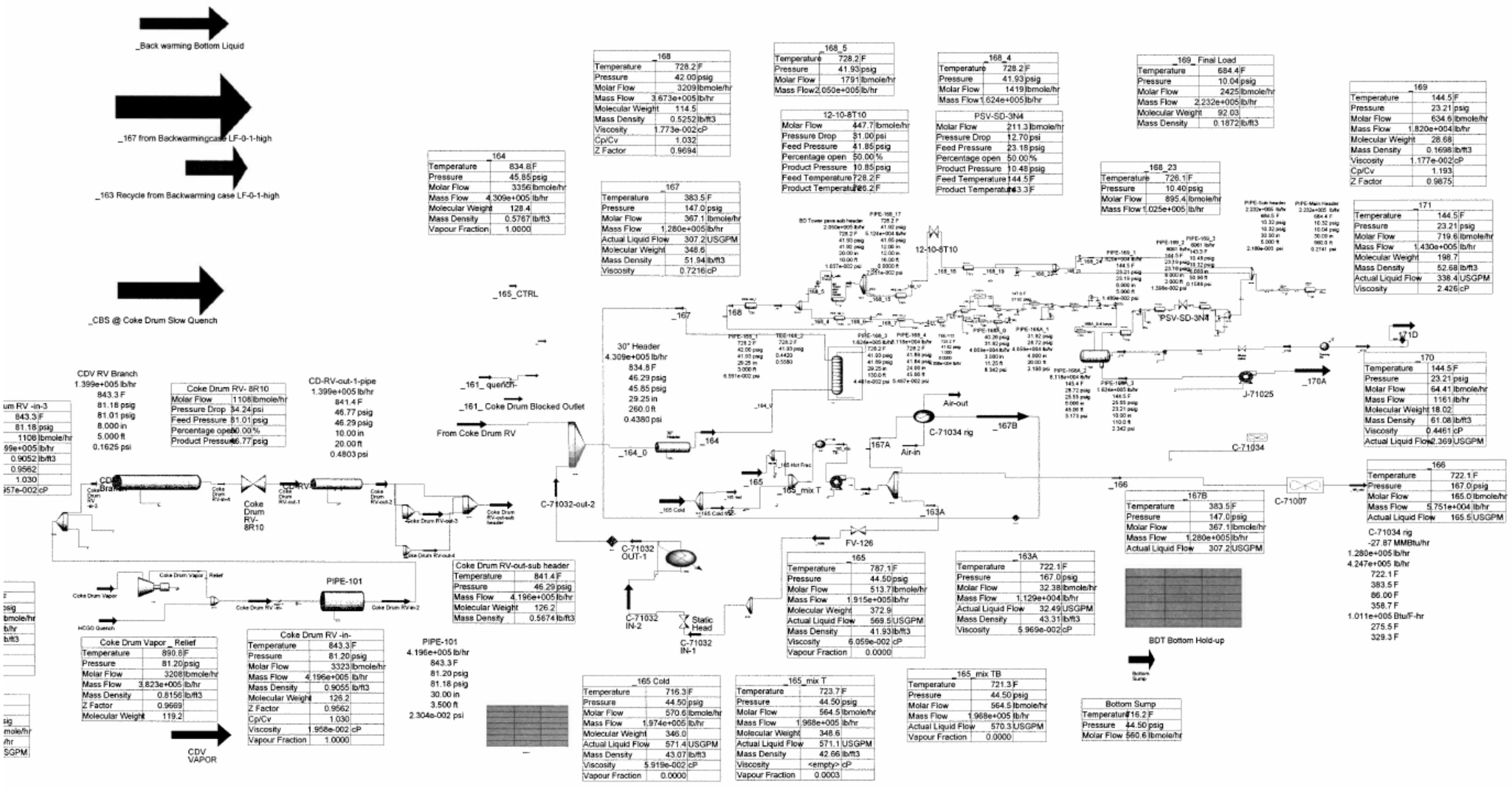
BDT Bottom Hold-up



Environment: Case (Main)
Mode: Steady State

	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volur	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	554.6 USGPM		
14	Relief Duration	min	2.000		
15	Hot liquid added	USGallons	1109 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.2064	0.2064 USGPM	Dimension less	
18	Ratio of cold liquid	0.7936	0.7936 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flov	lb/hr	1.864e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	41.91 lb/ft3		
22	Cold Fluid Density	lb/ft3	45.15 lb/ft3		
23	Cold fluid Mass con	lb/hr	2.009e+005 lb/hr		

Figure 4.40-Backwarming, ratio at t=6



CDV RV Branch
1.399e+005 lb/hr
843.3 F
81.18 psig
81.01 psig
8.000 in
5.000 ft
0.1625 psi

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

CD-RV-out-1-pipe
1.399e+005 lb/hr
841.4 F
46.77 psig
46.29 psig
10.00 in
20.00 ft
0.4803 psi

30" Header
4.309e+005 lb/hr
834.8 F
46.29 psig
45.85 psig
29.25 in
260.0 ft
0.4380 psi

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9669	
Molecular Weight	119.2	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

PIPE-101
4.196e+005 lb/hr
843.3 F
81.20 psig
81.18 psig
30.00 in
3.500 ft
2.304e-002 psi

_164		
Temperature	834.8	F
Pressure	45.85	psig
Molar Flow	3356	lbmole/hr
Mass Flow	4.309e+005	lb/hr
Molecular Weight	128.4	
Mass Density	0.5767	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	728.2	F
Pressure	42.00	psig
Molar Flow	3209	lbmole/hr
Mass Flow	3.673e+005	lb/hr
Molecular Weight	114.5	
Mass Density	0.5252	lb/ft3
Viscosity	1.773e-002	cP
Cp/Cv	1.032	
Z Factor	0.9694	

_167		
Temperature	383.5	F
Pressure	147.0	psig
Molar Flow	367.1	lbmole/hr
Mass Flow	1.280e+005	lb/hr
Actual Liquid Flow	307.2	USGPM
Molecular Weight	348.6	
Mass Density	51.94	lb/ft3
Viscosity	0.7216	cP

_168_5		
Temperature	728.2	F
Pressure	41.93	psig
Molar Flow	1791	lbmole/hr
Mass Flow	2.050e+005	lb/hr

12-10-8T10		
Molar Flow	447.7	lbmole/hr
Pressure Drop	31.00	psi
Feed Pressure	41.85	psig
Percentage open	50.00	%
Product Pressure	10.85	psig
Feed Temperature	728.2	F
Product Temperature	726.2	F

_168_4		
Temperature	728.2	F
Pressure	41.93	psig
Molar Flow	1419	lbmole/hr
Mass Flow	1.624e+005	lb/hr

PSV-SD-3N4		
Molar Flow	211.3	lbmole/hr
Pressure Drop	12.70	psi
Feed Pressure	23.18	psig
Percentage open	50.00	%
Product Pressure	10.48	psig
Feed Temperature	144.5	F
Product Temperature	143.3	F

_169_ Final Load		
Temperature	684.4	F
Pressure	10.04	psig
Molar Flow	2425	lbmole/hr
Mass Flow	2.232e+005	lb/hr
Molecular Weight	92.03	
Mass Density	0.1872	lb/ft3

_168_23		
Temperature	726.1	F
Pressure	10.40	psig
Molar Flow	895.4	lbmole/hr
Mass Flow	1.025e+005	lb/hr

_169		
Temperature	144.5	F
Pressure	23.21	psig
Molar Flow	634.6	lbmole/hr
Mass Flow	1.820e+004	lb/hr
Molecular Weight	28.68	
Mass Density	0.1698	lb/ft3
Viscosity	1.177e-002	cP
Cp/Cv	1.193	
Z Factor	0.9875	

_171		
Temperature	144.5	F
Pressure	23.21	psig
Molar Flow	719.6	lbmole/hr
Mass Flow	1.430e+005	lb/hr
Molecular Weight	198.7	
Mass Density	52.68	lb/ft3
Actual Liquid Flow	338.4	USGPM
Viscosity	2.426	cP

_170		
Temperature	144.5	F
Pressure	23.21	psig
Molar Flow	64.41	lbmole/hr
Mass Flow	1161	lb/hr
Molecular Weight	18.02	
Mass Density	61.08	lb/ft3
Viscosity	0.4461	cP
Actual Liquid Flow	2.369	USGPM

_166		
Temperature	722.1	F
Pressure	167.0	psig
Molar Flow	165.0	lbmole/hr
Mass Flow	5.751e+004	lb/hr
Actual Liquid Flow	165.5	USGPM

C-71034 rig
-27.87 MMBtu/hr
1.280e+005 lb/hr
4.247e+005 lb/hr
722.1 F
383.5 F
86.00 F
358.7 F
1.011e+005 Btu/F-hr
275.5 F
329.3 F

_167B		
Temperature	383.5	F
Pressure	147.0	psig
Molar Flow	367.1	lbmole/hr
Mass Flow	1.280e+005	lb/hr
Actual Liquid Flow	307.2	USGPM

_165		
Temperature	787.1	F
Pressure	44.50	psig
Molar Flow	513.7	lbmole/hr
Mass Flow	1.915e+005	lb/hr
Molecular Weight	372.9	
Actual Liquid Flow	569.5	USGPM
Mass Density	41.93	lb/ft3
Viscosity	6.059e-002	cP
Vapour Fraction	0.0000	

_163A		
Temperature	722.1	F
Pressure	167.0	psig
Molar Flow	32.38	lbmole/hr
Mass Flow	1.129e+004	lb/hr
Actual Liquid Flow	32.49	USGPM
Mass Density	43.31	lb/ft3
Viscosity	5.969e-002	cP

_165 Cold		
Temperature	716.3	F
Pressure	44.50	psig
Molar Flow	570.6	lbmole/hr
Mass Flow	1.974e+005	lb/hr
Molecular Weight	346.0	
Actual Liquid Flow	571.4	USGPM
Mass Density	43.07	lb/ft3
Viscosity	5.919e-002	cP
Vapour Fraction	0.0000	

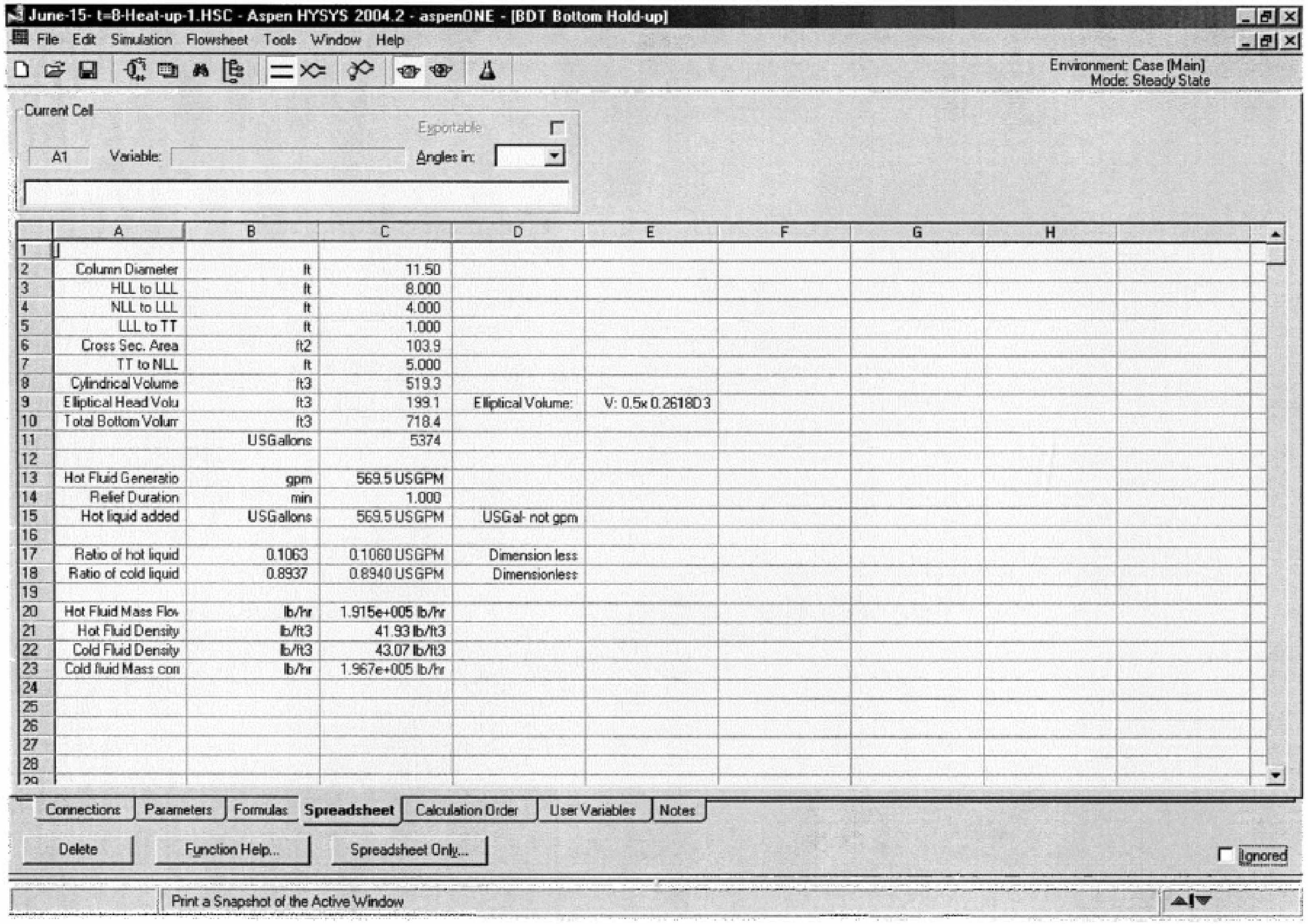
_165_mix T		
Temperature	723.7	F
Pressure	44.50	psig
Molar Flow	564.5	lbmole/hr
Mass Flow	1.968e+005	lb/hr
Molecular Weight	348.6	
Actual Liquid Flow	571.1	USGPM
Mass Density	42.66	lb/ft3
Viscosity	<empty>	cP
Vapour Fraction	0.0003	

_165_mix TB		
Temperature	721.3	F
Pressure	44.50	psig
Molar Flow	564.5	lbmole/hr
Mass Flow	1.968e+005	lb/hr
Actual Liquid Flow	570.3	USGPM
Vapour Fraction	0.0000	

Bottom Sump		
Temperature	716.2	F
Pressure	44.50	psig
Molar Flow	560.6	lbmole/hr

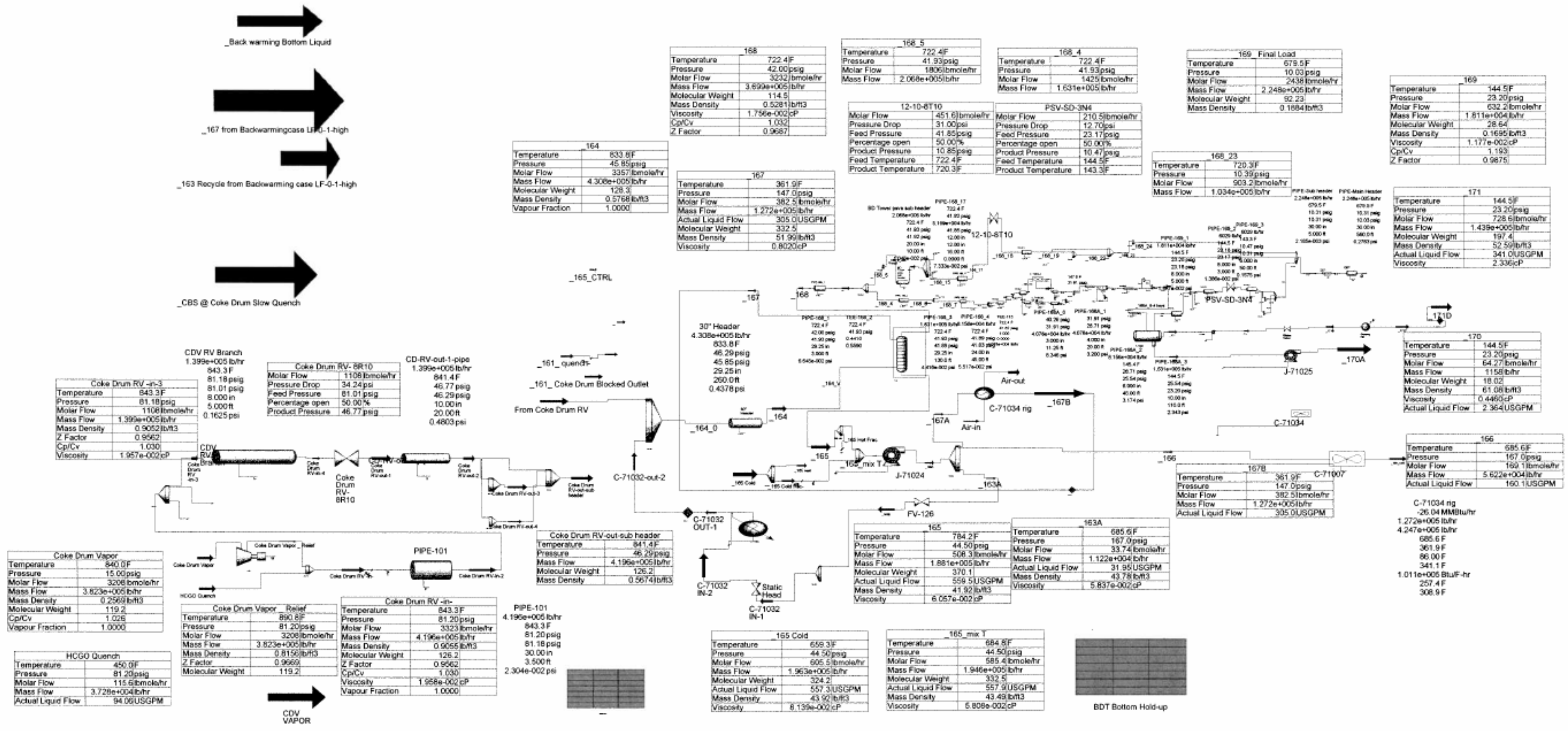
Figure 4.41-Backwarming t=8

BDT Bottom Hold-up



	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volum	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	569.5 USGPM		
14	Relief Duration	min	1.000		
15	Hot liquid added	USGallons	569.5 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.1063	0.1060 USGPM	Dimension less	
18	Ratio of cold liquid	0.8937	0.8940 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flov	lb/hr	1.915e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	41.93 lb/ft3		
22	Cold Fluid Density	lb/ft3	43.07 lb/ft3		
23	Cold fluid Mass con	lb/hr	1.967e+005 lb/hr		

Figure 4.42-Backwarming, Ratio at t=8



_168		
Temperature	722.4	F
Pressure	42.00	psig
Molar Flow	3232	lbmole/hr
Mass Flow	3.699e+005	lb/hr
Molecular Weight	114.5	
Mass Density	0.5281	lb/ft3
Viscosity	1.756e-002	cP
Cp/Cv	1.032	
Z Factor	0.9687	

_168_5		
Temperature	722.4	F
Pressure	41.93	psig
Molar Flow	1806	lbmole/hr
Mass Flow	2.068e+005	lb/hr

_168_4		
Temperature	722.4	F
Pressure	41.93	psig
Molar Flow	1425	lbmole/hr
Mass Flow	1.631e+005	lb/hr

_169_ Final Load		
Temperature	679.5	F
Pressure	10.03	psig
Molar Flow	2438	lbmole/hr
Mass Flow	2.248e+005	lb/hr
Molecular Weight	92.23	
Mass Density	0.1684	lb/ft3

_169		
Temperature	144.5	F
Pressure	23.20	psig
Molar Flow	632.2	lbmole/hr
Mass Flow	1.811e+004	lb/hr
Molecular Weight	28.64	
Mass Density	0.1695	lb/ft3
Viscosity	1.177e-002	cP
Cp/Cv	1.193	
Z Factor	0.9875	

_164		
Temperature	833.8	F
Pressure	45.85	psig
Molar Flow	3357	lbmole/hr
Mass Flow	4.308e+005	lb/hr
Molecular Weight	128.3	
Mass Density	0.5768	lb/ft3
Vapour Fraction	1.0000	

12-10-8T10		
Molar Flow	451.6	lbmole/hr
Pressure Drop	31.00	psi
Feed Pressure	41.85	psig
Percentage open	50.00	%
Product Pressure	10.85	psig
Feed Temperature	722.4	F
Product Temperature	720.3	F

PSV-SD-3N4		
Molar Flow	210.5	lbmole/hr
Pressure Drop	12.70	psi
Feed Pressure	23.17	psig
Percentage open	50.00	%
Product Pressure	10.47	psig
Feed Temperature	144.5	F
Product Temperature	143.3	F

_167		
Temperature	361.9	F
Pressure	147.0	psig
Molar Flow	382.5	lbmole/hr
Mass Flow	1.272e+005	lb/hr
Actual Liquid Flow	305.0	USGPM
Molecular Weight	332.5	
Mass Density	51.99	lb/ft3
Viscosity	0.8020	cP

_168_23		
Temperature	720.3	F
Pressure	10.39	psig
Molar Flow	903.2	lbmole/hr
Mass Flow	1.034e+005	lb/hr

_171		
Temperature	144.5	F
Pressure	23.20	psig
Molar Flow	728.6	lbmole/hr
Mass Flow	1.439e+005	lb/hr
Molecular Weight	197.4	
Mass Density	52.59	lb/ft3
Actual Liquid Flow	341.0	USGPM
Viscosity	2.336	cP

_170		
Temperature	144.5	F
Pressure	23.20	psig
Molar Flow	64.27	lbmole/hr
Mass Flow	1158	lb/hr
Molecular Weight	18.02	
Mass Density	61.08	lb/ft3
Viscosity	0.4460	cP
Actual Liquid Flow	2.364	USGPM

Coke Drum RV -in-3		
Temperature	843.3	F
Pressure	81.18	psig
Molar Flow	1108	lbmole/hr
Mass Flow	1.399e+005	lb/hr
Mass Density	0.9052	lb/ft3
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.957e-002	cP

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

_166		
Temperature	685.6	F
Pressure	167.0	psig
Molar Flow	169.1	lbmole/hr
Mass Flow	5.622e+004	lb/hr
Actual Liquid Flow	160.1	USGPM

_167B		
Temperature	361.9	F
Pressure	147.0	psig
Molar Flow	382.5	lbmole/hr
Mass Flow	1.272e+005	lb/hr
Actual Liquid Flow	305.0	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	784.2	F
Pressure	44.50	psig
Molar Flow	508.3	lbmole/hr
Mass Flow	1.881e+005	lb/hr
Molecular Weight	370.1	
Actual Liquid Flow	559.5	USGPM
Mass Density	41.92	lb/ft3
Viscosity	6.057e-002	cP

_163A		
Temperature	685.6	F
Pressure	167.0	psig
Molar Flow	33.74	lbmole/hr
Mass Flow	1.122e+004	lb/hr
Actual Liquid Flow	31.95	USGPM
Mass Density	43.78	lb/ft3
Viscosity	5.837e-002	cP

Coke Drum Vapor		
Temperature	840.0	F
Pressure	15.00	psig
Molar Flow	3206	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.2569	lb/ft3
Molecular Weight	119.2	
Cp/Cv	1.026	
Vapour Fraction	1.0000	

Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3206	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9669	
Molecular Weight	119.2	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

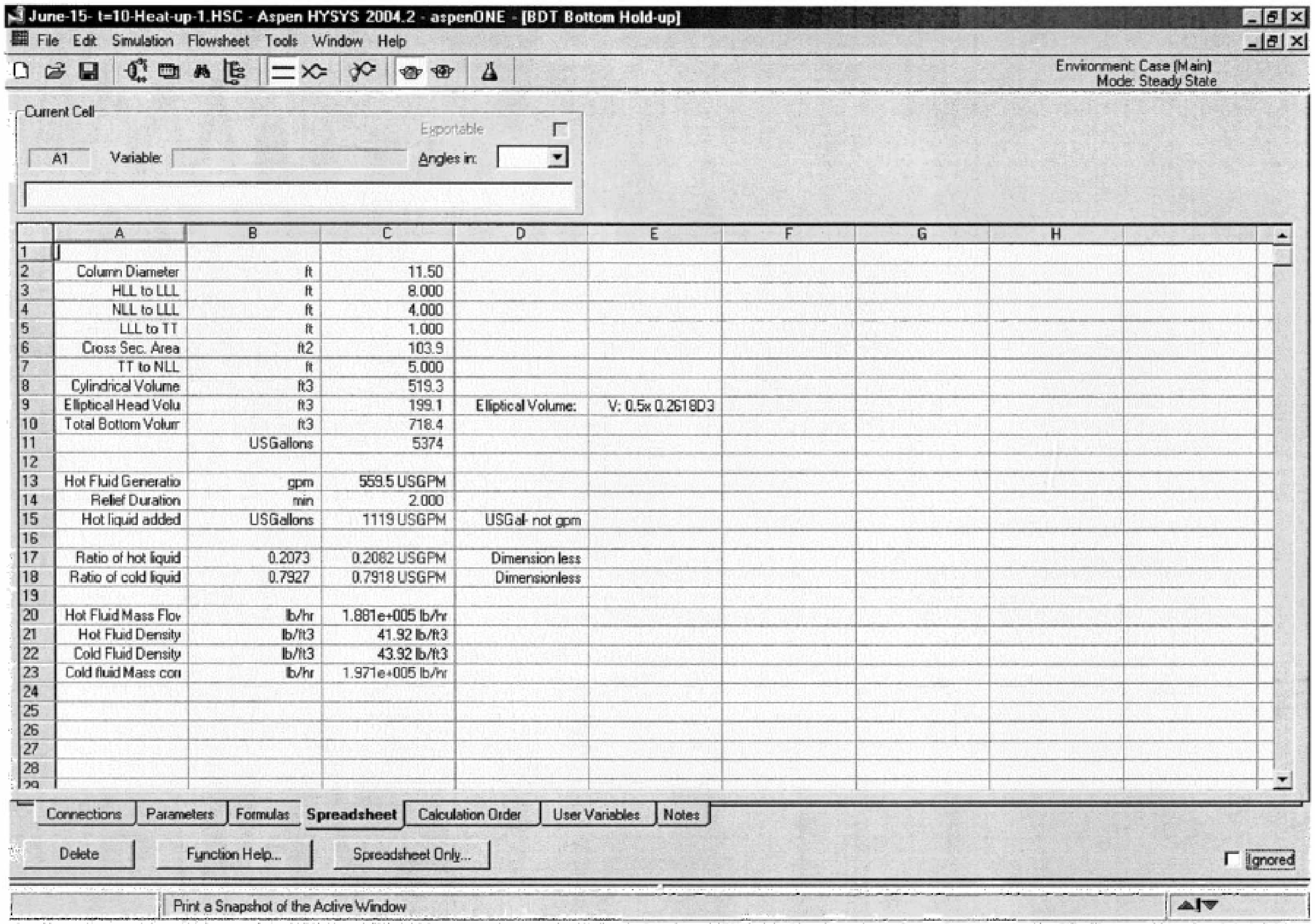
HCGO Quench		
Temperature	450.0	F
Pressure	81.20	psig
Molar Flow	115.6	lbmole/hr
Mass Flow	3.728e+004	lb/hr
Actual Liquid Flow	94.06	USGPM

_165 Cold		
Temperature	659.3	F
Pressure	44.50	psig
Molar Flow	605.5	lbmole/hr
Mass Flow	1.963e+005	lb/hr
Molecular Weight	324.2	
Actual Liquid Flow	557.3	USGPM
Mass Density	43.92	lb/ft3
Viscosity	8.139e-002	cP

_165_mix T		
Temperature	684.8	F
Pressure	44.50	psig
Molar Flow	585.4	lbmole/hr
Mass Flow	1.946e+005	lb/hr
Molecular Weight	332.5	
Actual Liquid Flow	557.9	USGPM
Mass Density	43.49	lb/ft3
Viscosity	5.808e-002	cP

Figure 4.43-Backwarming t=10

BDT Bottom Hold-up



	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volur	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	559.5 USGPM		
14	Relief Duration	min	2.000		
15	Hot liquid added	USGallons	1119 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.2073	0.2082 USGPM	Dimension less	
18	Ratio of cold liquid	0.7927	0.7918 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flov	lb/hr	1.881e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	41.92 lb/ft3		
22	Cold Fluid Density	lb/ft3	43.92 lb/ft3		
23	Cold fluid Mass con	lb/hr	1.971e+005 lb/hr		

Figure 4.44-Backwarming, Ratio at t=10

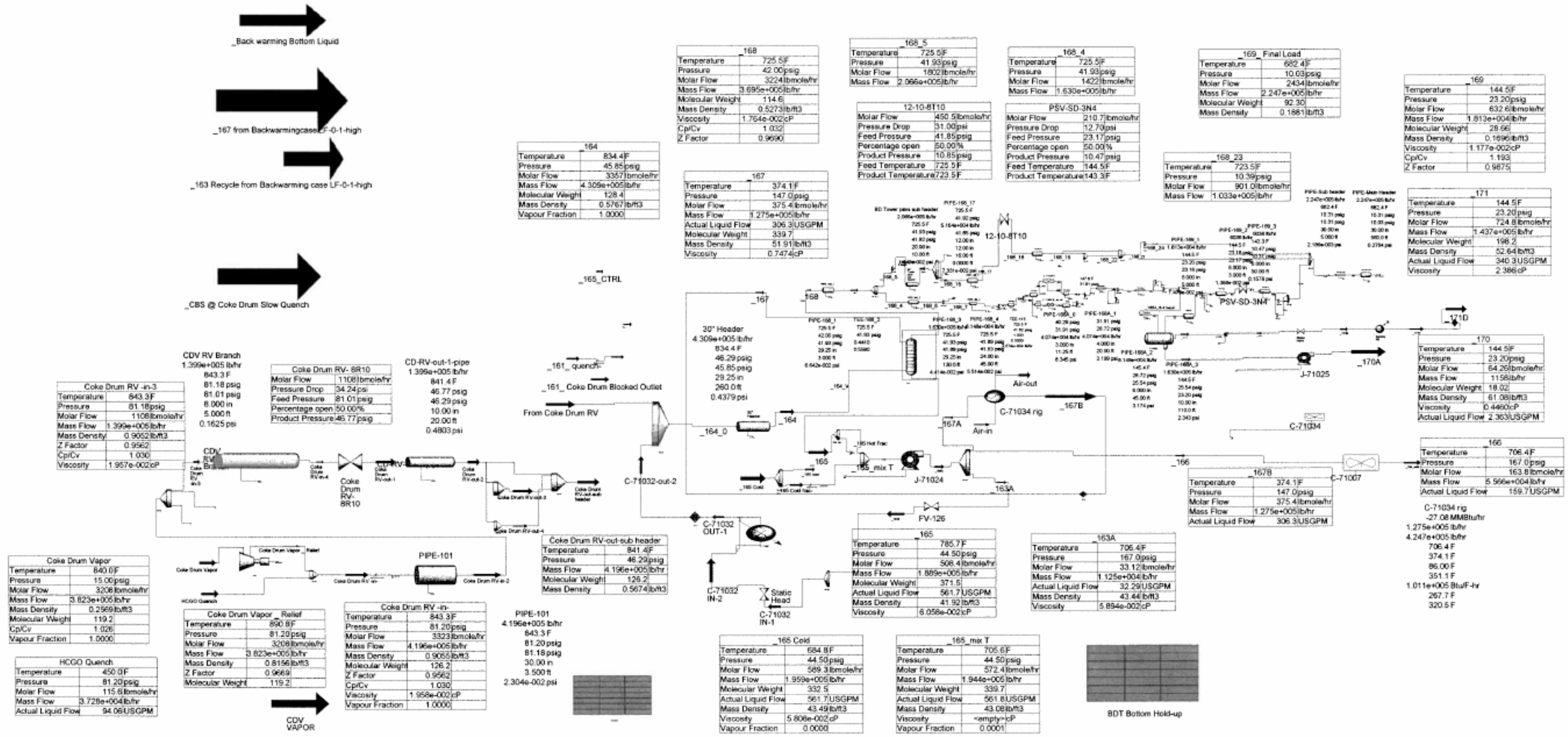
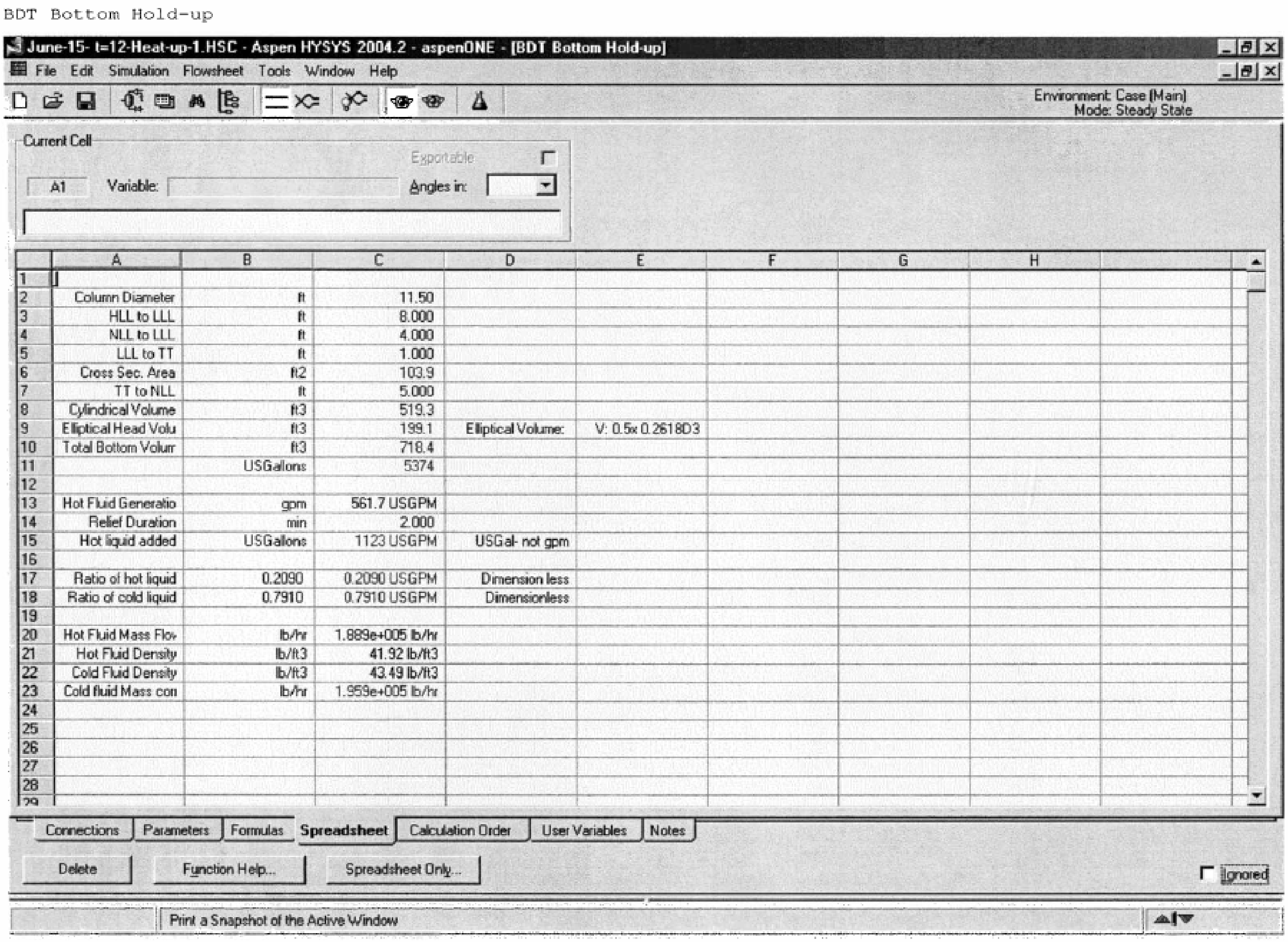


Figure 4.45 Backwarming t=12



BDT Bottom Hold-up

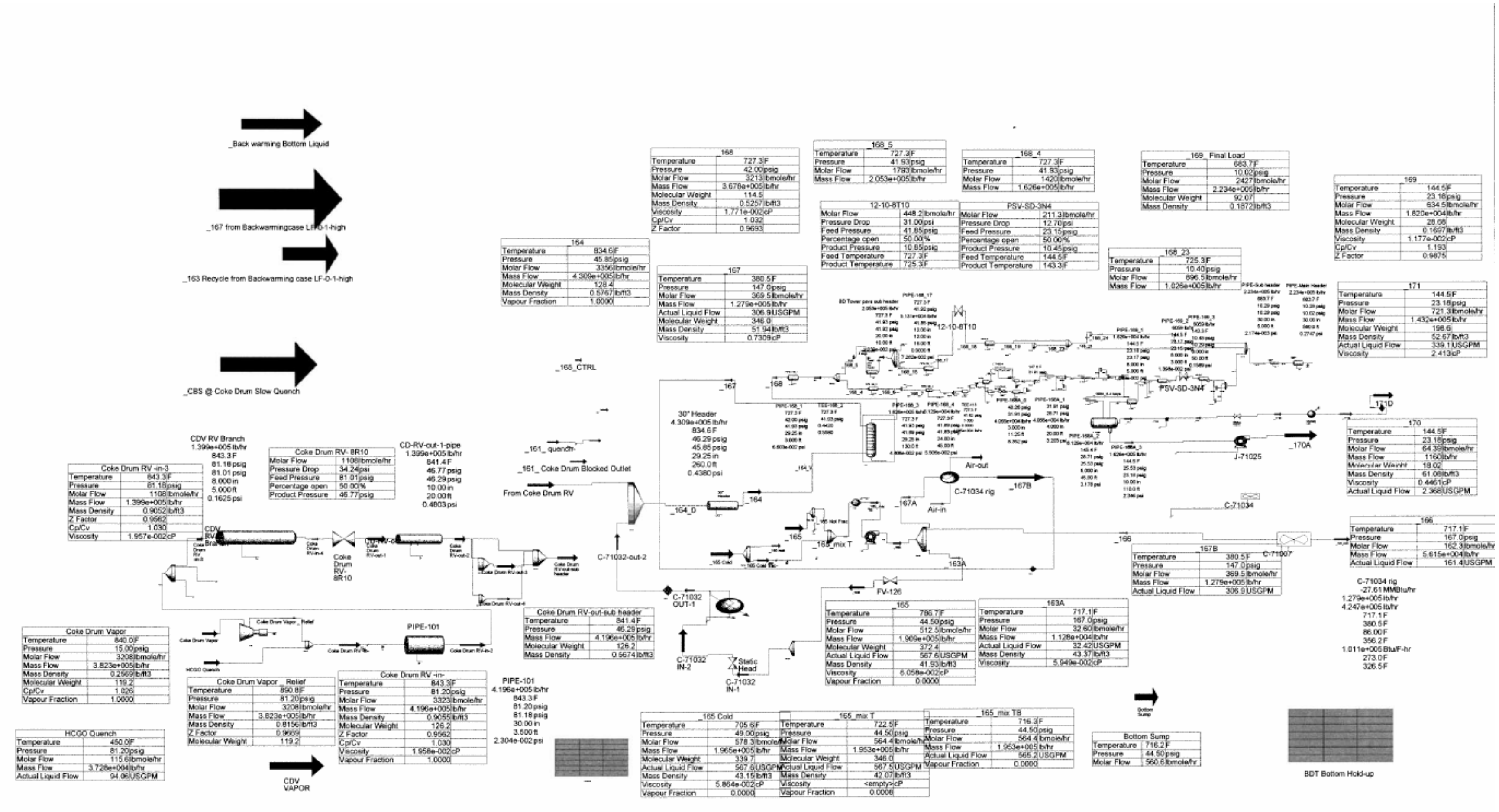
Environment: Case (Main)
Mode: Steady State

Current Cell: A1 Variable:

	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volur	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	561.7 USGPM		
14	Relief Duration	min	2.000		
15	Hot liquid added	USGallons	1123 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.2090	0.2090 USGPM	Dimension less	
18	Ratio of cold liquid	0.7910	0.7910 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flov	lb/hr	1.889e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	41.92 lb/ft3		
22	Cold Fluid Density	lb/ft3	43.49 lb/ft3		
23	Cold fluid Mass con	lb/hr	1.959e+005 lb/hr		

Print a Snapshot of the Active Window

Figure 4.46-Backwarming, Ratio at t=12



_154		
Temperature	834.6	F
Pressure	45.85	psig
Molar Flow	3356	lbmole/hr
Mass Flow	4.309e+005	lb/hr
Molecular Weight	128.4	
Mass Density	0.5767	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	727.3	F
Pressure	42.00	psig
Molar Flow	3213	lbmole/hr
Mass Flow	3.678e+005	lb/hr
Molecular Weight	114.5	
Mass Density	0.5257	lb/ft3
Viscosity	1.771e-002	cP
Cp/Cv	1.032	
Z Factor	0.9693	

_167		
Temperature	380.5	F
Pressure	147.0	psig
Molar Flow	369.5	lbmole/hr
Mass Flow	1.279e+005	lb/hr
Actual Liquid Flow	306.9	USGPM
Molecular Weight	346.0	
Mass Density	51.94	lb/ft3
Viscosity	0.7309	cP

_168_5		
Temperature	727.3	F
Pressure	41.93	psig
Molar Flow	1783	lbmole/hr
Mass Flow	2.053e+005	lb/hr

_168_4		
Temperature	727.3	F
Pressure	41.93	psig
Molar Flow	1420	lbmole/hr
Mass Flow	1.626e+005	lb/hr

12-10-8T10		
Molar Flow	448.2	lbmole/hr
Pressure Drop	31.00	psi
Feed Pressure	41.85	psig
Percentage open	50.00	%
Product Pressure	10.85	psig
Feed Temperature	727.3	F
Product Temperature	725.3	F

PSV-SD-3N4		
Molar Flow	211.3	lbmole/hr
Pressure Drop	12.70	psi
Feed Pressure	23.15	psig
Percentage open	50.00	%
Product Pressure	10.45	psig
Feed Temperature	144.5	F
Product Temperature	143.3	F

_169_ Final Load		
Temperature	683.7	F
Pressure	10.02	psig
Molar Flow	2427	lbmole/hr
Mass Flow	2.234e+005	lb/hr
Molecular Weight	92.07	
Mass Density	0.1872	lb/ft3

_168_23		
Temperature	725.3	F
Pressure	10.40	psig
Molar Flow	896.5	lbmole/hr
Mass Flow	1.026e+005	lb/hr

_169		
Temperature	144.5	F
Pressure	23.18	psig
Molar Flow	634.5	lbmole/hr
Mass Flow	1.820e+004	lb/hr
Molecular Weight	28.68	
Mass Density	0.1697	lb/ft3
Viscosity	1.177e-002	cP
Cp/Cv	1.193	
Z Factor	0.9875	

_171		
Temperature	144.5	F
Pressure	23.18	psig
Molar Flow	721.3	lbmole/hr
Mass Flow	1.432e+005	lb/hr
Molecular Weight	198.6	
Mass Density	52.67	lb/ft3
Actual Liquid Flow	339.1	USGPM
Viscosity	2.413	cP

_170		
Temperature	144.5	F
Pressure	23.18	psig
Molar Flow	64.39	lbmole/hr
Mass Flow	1160	lb/hr
Molecular Weight	18.02	
Mass Density	61.06	lb/ft3
Viscosity	0.4461	cP
Actual Liquid Flow	2.368	USGPM

30" Header
4.309e+005 lb/hr
834.6 F
46.29 psig
45.85 psig
29.25 in
260.0 ft
0.4380 psi

CDV RV Branch
1.399e+005 lb/hr
843.3 F
81.18 psig
81.01 psig
8.000 in
5.000 ft
0.1625 psi

Coke Drum RV -in-3		
Temperature	843.3	F
Pressure	81.18	psig
Molar Flow	1108	lbmole/hr
Mass Flow	1.399e+005	lb/hr
Mass Density	0.9052	lb/ft3
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.957e-002	cP

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

CD-RV-out-1-pipe
1.399e+005 lb/hr
841.4 F
46.77 psig
46.29 psig
10.00 in
20.00 ft
0.4803 psi

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

Coke Drum Vapor		
Temperature	840.0	F
Pressure	15.00	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.2569	lb/ft3
Molecular Weight	119.2	
Cp/Cv	1.026	
Vapour Fraction	1.0000	

HCGO Quench		
Temperature	450.0	F
Pressure	81.20	psig
Molar Flow	115.6	lbmole/hr
Mass Flow	3.728e+004	lb/hr
Actual Liquid Flow	94.06	USGPM

Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9669	
Molecular Weight	119.2	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

PIPE-101
4.196e+005 lb/hr
843.3 F
81.20 psig
81.18 psig
30.00 in
3.500 ft
2.304e-002 psi

_165		
Temperature	786.7	F
Pressure	44.50	psig
Molar Flow	512.5	lbmole/hr
Mass Flow	1.909e+005	lb/hr
Molecular Weight	372.4	
Actual Liquid Flow	567.6	USGPM
Mass Density	41.93	lb/ft3
Viscosity	6.058e-002	cP
Vapour Fraction	0.0000	

_163A		
Temperature	717.1	F
Pressure	167.0	psig
Molar Flow	32.60	lbmole/hr
Mass Flow	1.128e+004	lb/hr
Actual Liquid Flow	32.42	USGPM
Mass Density	43.37	lb/ft3
Viscosity	5.949e-002	cP

_167B		
Temperature	380.5	F
Pressure	147.0	psig
Molar Flow	369.5	lbmole/hr
Mass Flow	1.279e+005	lb/hr
Actual Liquid Flow	306.9	USGPM

_166		
Temperature	717.1	F
Pressure	167.0	psig
Molar Flow	162.3	lbmole/hr
Mass Flow	5.615e+004	lb/hr
Actual Liquid Flow	161.4	USGPM

C-71034 rig
-27.61 MMBtu/hr
1.279e+005 lb/hr
4.247e+005 lb/hr
717.1 F
380.5 F
86.00 F
356.2 F
1.011e+005 Btu/F-hr
273.0 F
326.5 F

_165 Cold		
Temperature	705.6	F
Pressure	49.00	psig
Molar Flow	578.3	lbmole/hr
Mass Flow	1.965e+005	lb/hr
Molecular Weight	339.7	
Actual Liquid Flow	567.6	USGPM
Mass Density	43.15	lb/ft3
Viscosity	5.864e-002	cP
Vapour Fraction	0.0000	

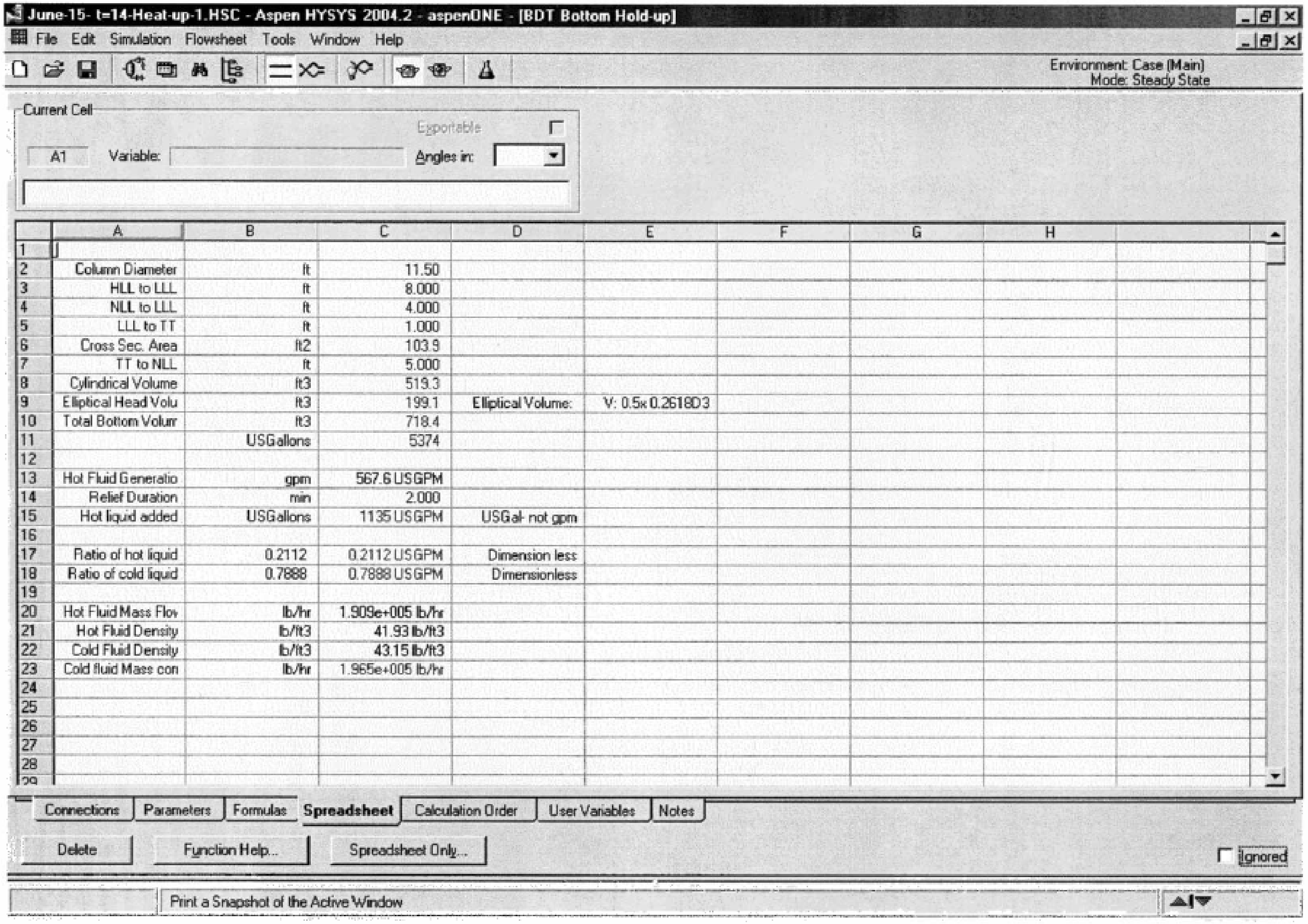
_165_mix T		
Temperature	722.5	F
Pressure	44.50	psig
Molar Flow	564.4	lbmole/hr
Mass Flow	1.953e+005	lb/hr
Molecular Weight	346.0	
Actual Liquid Flow	567.5	USGPM
Mass Density	42.07	lb/ft3
Viscosity	<empty>	cP
Vapour Fraction	0.0008	

_165_mix TB		
Temperature	716.3	F
Pressure	44.50	psig
Molar Flow	564.4	lbmole/hr
Mass Flow	1.953e+005	lb/hr
Actual Liquid Flow	565.2	USGPM
Vapour Fraction	0.0000	

Bottom Sump		
Temperature	716.2	F
Pressure	44.50	psig
Molar Flow	560.6	lbmole/hr

Figure 4.47-Backwarming t-14

BDT Bottom Hold-up

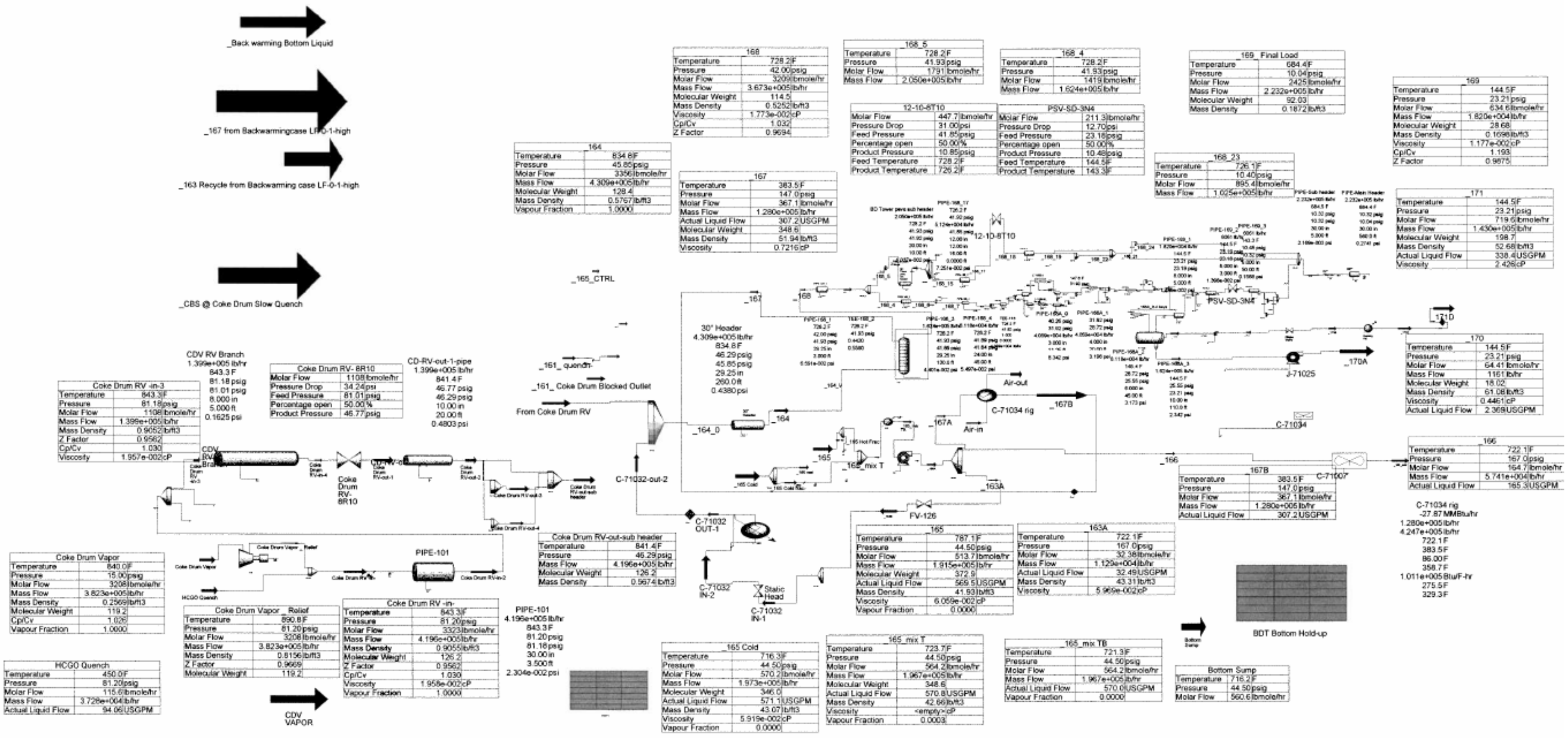


Environment: Case (Main)
Mode: Steady State

Current Cell: A1

	A	B	C	D	E
1					
2	Column Diameter	ft	11.50		
3	HLL to LLL	ft	8.000		
4	NLL to LLL	ft	4.000		
5	LLL to TT	ft	1.000		
6	Cross Sec. Area	ft2	103.9		
7	TT to NLL	ft	5.000		
8	Cylindrical Volume	ft3	519.3		
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3
10	Total Bottom Volum	ft3	718.4		
11		USGallons	5374		
12					
13	Hot Fluid Generatio	gpm	567.6 USGPM		
14	Relief Duration	min	2.000		
15	Hot liquid added	USGallons	1135 USGPM	USGal- not gpm	
16					
17	Ratio of hot liquid	0.2112	0.2112 USGPM	Dimension less	
18	Ratio of cold liquid	0.7888	0.7888 USGPM	Dimensionless	
19					
20	Hot Fluid Mass Flov	lb/hr	1.909e+005 lb/hr		
21	Hot Fluid Density	lb/ft3	41.93 lb/ft3		
22	Cold Fluid Density	lb/ft3	43.15 lb/ft3		
23	Cold fluid Mass con	lb/hr	1.965e+005 lb/hr		

Figure 4.48-Backwarming, Ratio at t=14



Coke Drum RV -in-3		
Temperature	843.3	F
Pressure	81.18	psig
Molar Flow	1108	lbmole/hr
Mass Flow	1.399e+005	lb/hr
Mass Density	0.9052	lb/ft3
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.957e-002	cP

Coke Drum RV- 8R10		
Molar Flow	1108	lbmole/hr
Pressure Drop	34.24	psi
Feed Pressure	81.01	psig
Percentage open	50.00	%
Product Pressure	46.77	psig

Coke Drum Vapor		
Temperature	840.0	F
Pressure	15.00	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.2569	lb/ft3
Molecular Weight	119.2	
Cp/Cv	1.026	
Vapour Fraction	1.0000	

HCGO Quench		
Temperature	450.0	F
Pressure	81.20	psig
Molar Flow	115.6	lbmole/hr
Mass Flow	3.728e+004	lb/hr
Actual Liquid Flow	94.06	USGPM

Coke Drum Vapor _ Relief		
Temperature	890.8	F
Pressure	81.20	psig
Molar Flow	3208	lbmole/hr
Mass Flow	3.823e+005	lb/hr
Mass Density	0.8156	lb/ft3
Z Factor	0.9669	
Molecular Weight	119.2	

Coke Drum RV -in-		
Temperature	843.3	F
Pressure	81.20	psig
Molar Flow	3323	lbmole/hr
Mass Flow	4.196e+005	lb/hr
Mass Density	0.9055	lb/ft3
Molecular Weight	126.2	
Z Factor	0.9562	
Cp/Cv	1.030	
Viscosity	1.958e-002	cP
Vapour Fraction	1.0000	

_164		
Temperature	834.8	F
Pressure	45.85	psig
Molar Flow	3356	lbmole/hr
Mass Flow	4.309e+005	lb/hr
Molecular Weight	128.4	
Mass Density	0.5767	lb/ft3
Vapour Fraction	1.0000	

_168		
Temperature	728.2	F
Pressure	42.00	psig
Molar Flow	3209	lbmole/hr
Mass Flow	3.673e+005	lb/hr
Molecular Weight	114.5	
Mass Density	0.5252	lb/ft3
Viscosity	1.773e-002	cP
Cp/Cv	1.032	
Z Factor	0.9694	

_167		
Temperature	383.5	F
Pressure	147.0	psig
Molar Flow	367.1	lbmole/hr
Mass Flow	1.280e+005	lb/hr
Actual Liquid Flow	307.2	USGPM
Molecular Weight	348.6	
Mass Density	51.94	lb/ft3
Viscosity	0.7216	cP

_168_5		
Temperature	728.2	F
Pressure	41.93	psig
Molar Flow	1791	lbmole/hr
Mass Flow	2.050e+005	lb/hr

_168_4		
Temperature	728.2	F
Pressure	41.93	psig
Molar Flow	1419	lbmole/hr
Mass Flow	1.624e+005	lb/hr

12-10-8T10		
Molar Flow	447.7	lbmole/hr
Pressure Drop	31.00	psi
Feed Pressure	41.85	psig
Percentage open	50.00	%
Product Pressure	10.85	psig
Feed Temperature	728.2	F
Product Temperature	726.2	F

PSV-SD-3N4		
Molar Flow	211.3	lbmole/hr
Pressure Drop	12.70	psi
Feed Pressure	23.18	psig
Percentage open	50.00	%
Product Pressure	10.48	psig
Feed Temperature	144.5	F
Product Temperature	143.3	F

_169_ Final Load		
Temperature	684.4	F
Pressure	10.04	psig
Molar Flow	2425	lbmole/hr
Mass Flow	2.232e+005	lb/hr
Molecular Weight	92.03	
Mass Density	0.1872	lb/ft3

_168_23		
Temperature	726.1	F
Pressure	10.40	psig
Molar Flow	895.4	lbmole/hr
Mass Flow	1.025e+005	lb/hr

_169		
Temperature	144.5	F
Pressure	23.21	psig
Molar Flow	634.6	lbmole/hr
Mass Flow	1.820e+004	lb/hr
Molecular Weight	28.68	
Mass Density	0.1698	lb/ft3
Viscosity	1.177e-002	cP
Cp/Cv	1.193	
Z Factor	0.9875	

_171		
Temperature	144.5	F
Pressure	23.21	psig
Molar Flow	719.6	lbmole/hr
Mass Flow	1.430e+005	lb/hr
Molecular Weight	198.7	
Mass Density	52.68	lb/ft3
Actual Liquid Flow	338.4	USGPM
Viscosity	2.426	cP

_170		
Temperature	144.5	F
Pressure	23.21	psig
Molar Flow	64.41	lbmole/hr
Mass Flow	1161	lb/hr
Molecular Weight	18.02	
Mass Density	61.08	lb/ft3
Viscosity	0.4461	cP
Actual Liquid Flow	2.369	USGPM

_166		
Temperature	722.1	F
Pressure	167.0	psig
Molar Flow	164.7	lbmole/hr
Mass Flow	5.741e+004	lb/hr
Actual Liquid Flow	165.3	USGPM

_167B		
Temperature	383.5	F
Pressure	147.0	psig
Molar Flow	367.1	lbmole/hr
Mass Flow	1.280e+005	lb/hr
Actual Liquid Flow	307.2	USGPM

Coke Drum RV-out-sub header		
Temperature	841.4	F
Pressure	46.29	psig
Mass Flow	4.196e+005	lb/hr
Molecular Weight	126.2	
Mass Density	0.5674	lb/ft3

_165		
Temperature	787.1	F
Pressure	44.50	psig
Molar Flow	513.7	lbmole/hr
Mass Flow	1.915e+005	lb/hr
Molecular Weight	372.9	
Actual Liquid Flow	569.5	USGPM
Mass Density	41.93	lb/ft3
Viscosity	6.059e-002	cP
Vapour Fraction	0.0000	

_163A		
Temperature	722.1	F
Pressure	167.0	psig
Molar Flow	32.38	lbmole/hr
Mass Flow	1.129e+004	lb/hr
Actual Liquid Flow	32.49	USGPM
Mass Density	43.31	lb/ft3
Viscosity	5.969e-002	cP

_165 Cold		
Temperature	716.3	F
Pressure	44.50	psig
Molar Flow	570.2	lbmole/hr
Mass Flow	1.973e+005	lb/hr
Molecular Weight	346.0	
Actual Liquid Flow	571.1	USGPM
Mass Density	43.07	lb/ft3
Viscosity	5.919e-002	cP
Vapour Fraction	0.0000	

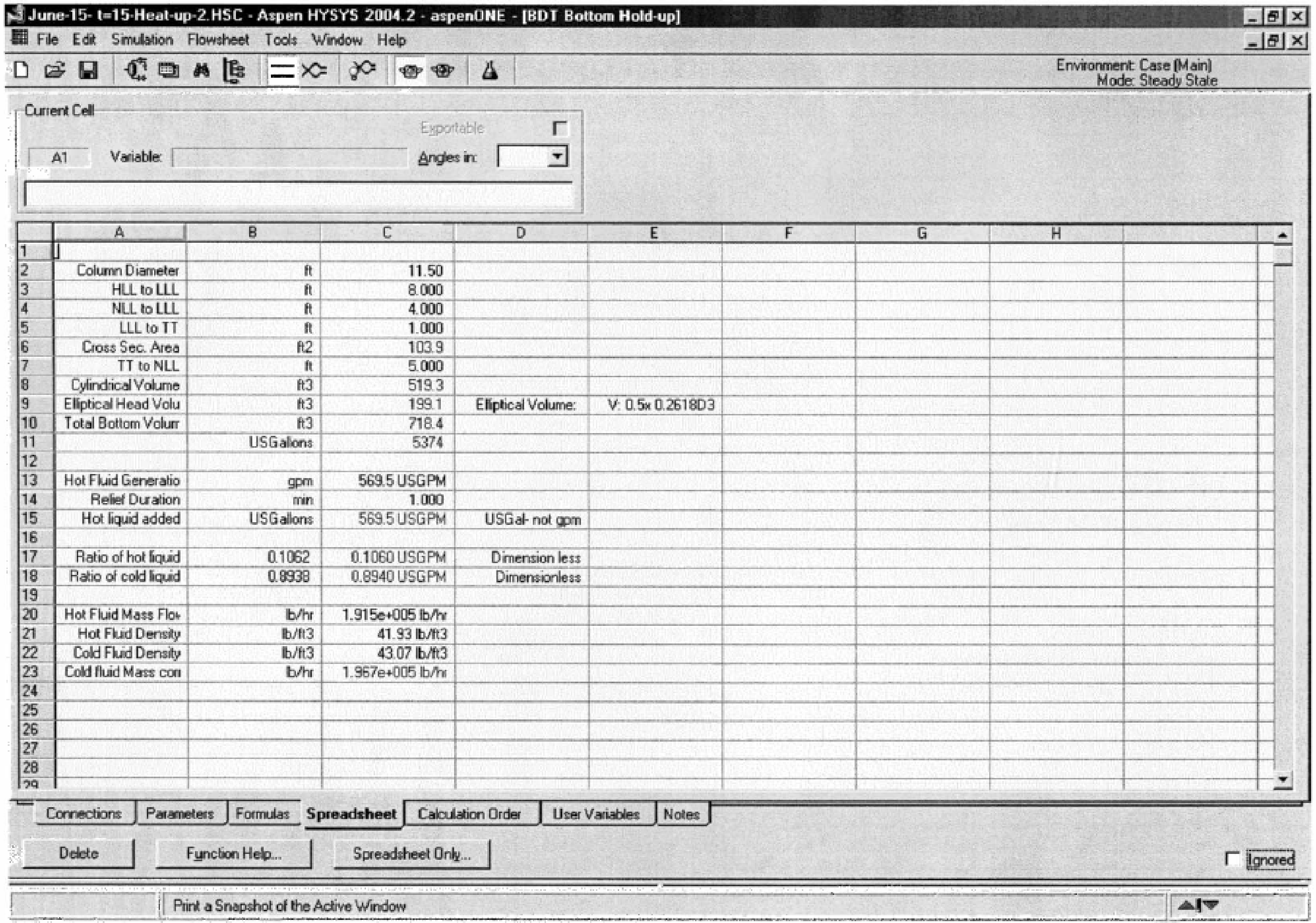
_165_mix T		
Temperature	723.7	F
Pressure	44.50	psig
Molar Flow	564.2	lbmole/hr
Mass Flow	1.967e+005	lb/hr
Molecular Weight	348.6	
Actual Liquid Flow	570.8	USGPM
Mass Density	42.66	lb/ft3
Viscosity	<empty>	cP
Vapour Fraction	0.0003	

_165_mix TB		
Temperature	721.3	F
Pressure	44.50	psig
Molar Flow	564.2	lbmole/hr
Mass Flow	1.967e+005	lb/hr
Actual Liquid Flow	570.0	USGPM
Vapour Fraction	0.0000	

Bottom Sump		
Temperature	716.2	F
Pressure	44.50	psig
Molar Flow	560.6	lbmole/hr

Figure 4.49-Backwarming t=15

BDT Bottom Hold-up



	A	B	C	D	E	F	G	H
1								
2	Column Diameter	ft	11.50					
3	HLL to LLL	ft	8.000					
4	NLL to LLL	ft	4.000					
5	LLL to TT	ft	1.000					
6	Cross Sec. Area	ft2	103.9					
7	TT to NLL	ft	5.000					
8	Cylindrical Volume	ft3	519.3					
9	Elliptical Head Volu	ft3	199.1	Elliptical Volume:	V: 0.5x 0.2618D3			
10	Total Bottom Volur	ft3	718.4					
11		USGallons	5374					
12								
13	Hot Fluid Generatio	gpm	569.5 USGPM					
14	Relief Duration	min	1.000					
15	Hot liquid added	USGallons	569.5 USGPM	USGal- not gpm				
16								
17	Ratio of hot liquid	0.1062	0.1060 USGPM	Dimension less				
18	Ratio of cold liquid	0.8938	0.8940 USGPM	Dimensionless				
19								
20	Hot Fluid Mass Flo	lb/hr	1.915e+005 lb/hr					
21	Hot Fluid Density	lb/ft3	41.93 lb/ft3					
22	Cold Fluid Density	lb/ft3	43.07 lb/ft3					
23	Cold fluid Mass con	lb/hr	1.967e+005 lb/hr					
24								
25								
26								
27								
28								

Figure 4.50-Backwarming, Ratio at t=15

4.6. Layers of Protection Analysis:

During the failure analysis, the process control design (that is called nowadays as DCS) is being evaluated as the first layer of protection to control the main process parameters. However, normally process control systems are mainly designed to maintain the process parameters to achieve the Feed/Process specifications defined within the unit operation and limitation. Besides, control systems design will also analyze the overshoot conditions during the intermittent conditions as well as disturbances occurred and assign the controllers with different types and gains to bring back the process to steady state operations with or without offset. In addition, process control systems are designed to fail in a safe mode (for example control valve actuators failure must lead to safe condition for both equipment and process protection) or provide override control system to take the control of process in low or high select conditions. Then obviously, process control systems are not sufficient for controlling upset conditions.

The next layer of protections is Safety Instrumented System (SIS) or PCS (Protective Control Systems) that must work independent of associated process control system and acts as an inactive (contrast to normal process control system that is active) control system till the upset conditions observed. The SIS system would lead and direct the process operation to a situation that may activate some equipment to reduce the severity of incident.

The next layer of protection is PSV (Process Safety Valve) that will release the materials to safe locations and must work independently and without any mitigation credit taken by either DCS and/or SIS system in place. This will ensure that the PSV is being sized for full relief load occurring during the upset scenarios.

Sometimes it is also necessary to consider some relief mitigations if the existing capacity can not handle the additional load. One example is adding a new unit to an existing refinery (expansion as well as revamp) that will add some additional relief load to the current flare system. In this condition it is necessary to advocate some extra safety/mitigation measure to reduce the relief load.

Chapter 5: Conclusion

5.1. Introduction:

As it has been discussed in the previous chapters of this thesis, Delayed Coker Unit design and engineering is one of the most challenging design projects in an EPC company specialized in the refinery field. There are only few licensors that devoted such a long time and big investments (and sometime with failures) to develop some design methods to overcome the challenges and it is still under continuous improvement. There are some licensors/EPC companies that monitor the operations/maintenance of their unit designed in the past, to collect and analyze their design flaws with application of advanced statistical methods and specialists like Six Sigma Black Belts. In this teamwork effort different specialties including process, instrument, mechanical and material, piping, operations and maintenance work together on a regular basis meeting that normally chaired by a safety specialist and facilitated by a six sigma black belt. These regular meetings often discuss their observations of problems with some figures and facts and team will discuss about all possible root causes and ways of resolving the issues to incorporate in their future unit design accompanying with control methods/charts to monitor and/or prove the effectiveness of resolution.

The author of this project thesis hopes, with the subject discussions presented in the previous chapters, to highlight some of the design considerations in the Delayed Coker unit with an emphasis on process safety point of view and narrow it down in the relief conditions of Coke drum operations in case of any upset situation that lead to overpressure the coke drum and therefore the ways of controlling of hot and heavy hydrocarbons to minimize its environmental impacts. Since, blocked outlet conditions of normally open path of Coke drum to the main Fractionator is one of the most interesting subject in this field, therefore PSV calculations for this particular topic has been chosen to show its dynamic behaviour of relief during this time with an assumption that operational team will recognize the problem with sudden abnormal pressure fluctuations and can intervene the upset conditions in less than 15 minutes.

5.2. Findings:

The author of this thesis had a great and extraordinary chance to get involved in many aspects of design challenges of delayed coker unit in different phases of design in a period of 2.5 years with a main focus in Coker Island Section. Therefore, it was also challenging to narrow down the topic of this thesis into one or two subjects and focus only in that area as the rest were also so interesting and inter related subjects or at least had the same analogy and type of approach to resolve their issues.

However, in order to address the findings related to this thesis, they can be summarized as below:

- Understanding the mode of operations of coke drums and their interactions to Main Fractionator during the online mode and closed blow down section during the offline mode.
- Understanding the control logic and importance of its reliability to ensure that all valving systems are working properly as well as orderly with maintaining a set of permissive to prevent any potential hazard.
- Understanding the importance of hydraulics in the piping system considering the gradual coking residue occurring within the piping system.
- Understanding and analyzing all credible scenarios of potential safe relief of coke drums.
- Understanding the nature of PSV relief of coke drums during the blocked outlet condition that relieves to closed blow down section as a sink in a cascade system and finally to flare and this makes a complicated hydraulic calculations as well as equipment design of all components in the loop.
- Understanding the dynamic behaviour and temperature increase of relieved materials that finally specifies the design conditions of system and equipment of closed blown section.

5.3. Future Work:

There are many other detailed discussion (that are beyond the scope of this project thesis) and necessary to be analyzed with this topic including:

- Detailed hydraulics of piping system (with their exact piping layout) and their reaction to sudden increase of flow into the Blowdown section that will establish the back pressure to specify the PSV size.

- Flare network in the refinery should also be analyzed to ensure that this much hot release materials can be handled with existing refinery capacity (if Delayed Coker Unit is part of a refinery expansion project) or design the flare system to be able to absorb this much hot hydrocarbon release.

- The outlet temperature of overhead condenser is receiving hotter materials gradually. Therefore, this has some impact on real geometry of air coolers as well as LMTD(corrected) to give more realistic results that current simulation does not cover this idea.

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