Products –

- Gasoline (Naphtha)
- Diesel (Light and Heavy Coker Gas Oil)
- LPG (Propane and Butane)
- Fuel gas
- Petroleum Coke (predominantly carbon)

Heavier, less expensive crude oil produces more residue to process (thus more coke) compared with lighter, more expensive crude oil.

Process Description – Basic Process Flow Diagram

In this section the delayed coking process will be described by walking through the individual pieces of equipment with a brief description of the various process steps within the equipment. Two diagrams are essential in this effort, Figure 1, the process flow diagram (PFD), and Figure 2, coke drum schematic. The PFD depicts a very simplified two drum delayed coker, showing the major equipment, flow lines, and valves and the coke drum schematic illustrates a few vital parts of the coke drums/table top/drill derrick. In the next section Figure 3 and Figure 4, the temperature-pressure profile, will then be utilized to describe the basic process in an alternate manner. Each of these basic description methods provide the same information but in a slightly different format. Then in a later section, both of these methods will be combined to describe the process in the context of a two drum concurrent, integrated operation with the aid of Figures 5 through 16.

The heavy feed, typically from the refinery's atmospheric and/or vacuum unit, is introduced into the bottom of the fractionator vessel, T-1. The fractionator tower (also known as the main fractionator or combination tower) receives the unit feed and the overhead hot vapors from the coking drum in the bottom tower section. In this bottom tower section the unit feed is both preheated by hot coke drum overhead vapors and provided necessary recycle. As the hot vapors travel vertically through the fractionator, the vapors cool at different rates and the various products are taken as side cuts from the fractionator. These products can be, from tower bottom to top, heavy coker gas oil, diesel, kerosene, and naphtha. Note the side cuts are not shown in the simplified PFD, but only shown as products going overhead from the fractionator. The preheated heavy feed is then pumped to the coker furnace.

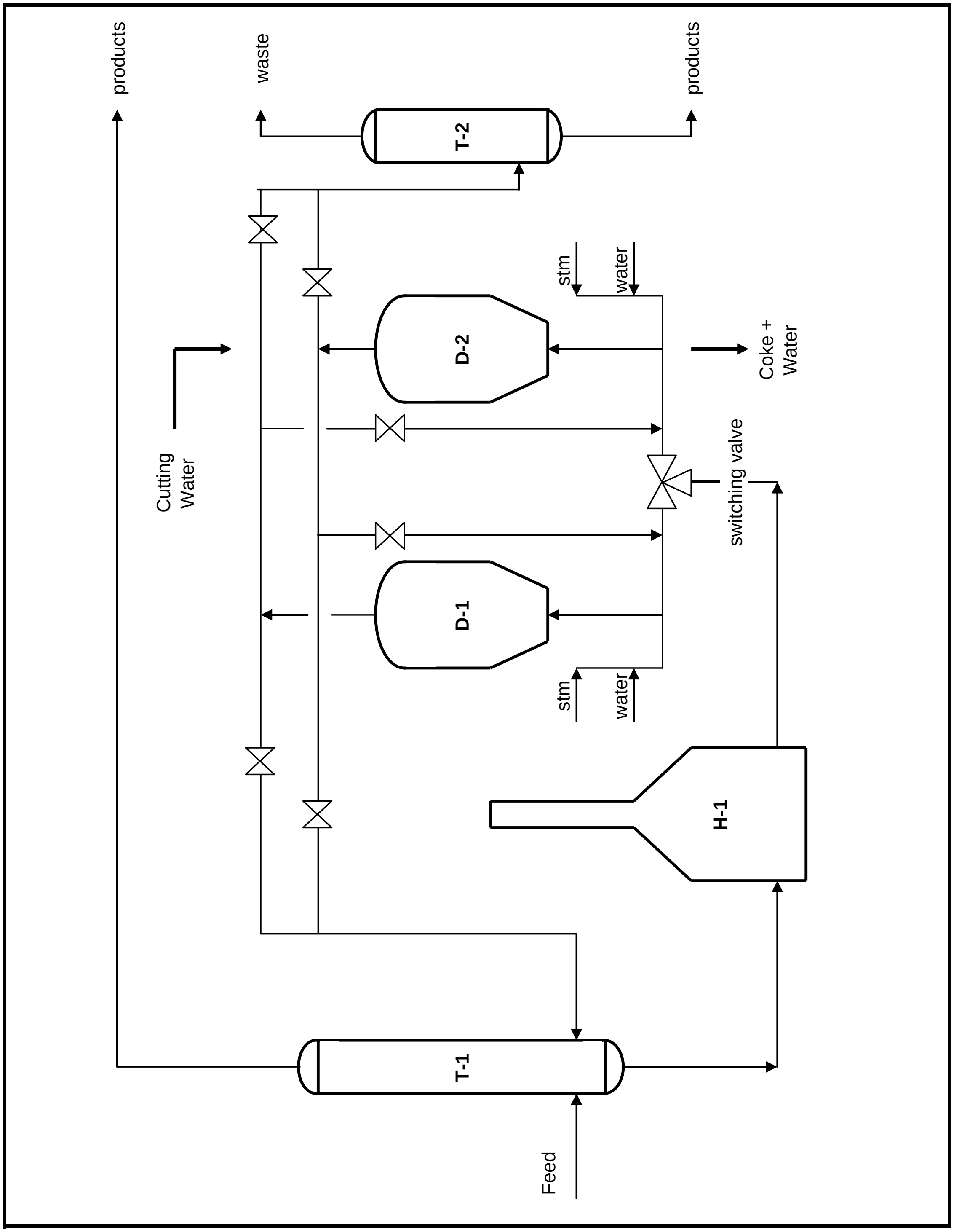

Figure 1 – Process Flow Diagram

The coker furnace or heater, H-1, heats the feed to the temperature at which thermal cracking occurs, typically between 900 ^{O}F and 950 ^{O}F. To delay the coking process and subsequent fouling of the furnace tubes with solid coke, the hot feed velocity through the tubes is controlled, typically between six to ten feet per second. Upon exiting the furnace, the hot feed is piped to the switching valve which routes the feed one of the drums to initiate the coking process.

The PFD shows coke drum D-1 as the coking drum. As the hot feed enters the empty drum, the coking process begins, with the large drum providing the necessary residence time to complete the cracking process. Within the drum, the hot liquid feed is first thermally cracked to coke and vapor, and then the vapor is thermally cracked as it passes upward through the drum. The solid coke collects in the bottom, the hot feed passed through the collected solid coke in random channels, the hot cracked vapor exits the top of the drum and routed to the fractionator bottom. Over time the drum is filled to a predetermined level at which time that drum is considered filled and ready to be emptied. This predetermined level is generally called outage and is measured as the distance from the top nozzle and when this level is reached, time to switch drums.

As can well be imagined with the quantity of solid coke being produced and with hot feed channeling upward through the solid coke, tremendous turbulence and internally applied forces are transmitted to the drum and supporting structures. Also as the coking process continues a froth or foam forms which can be a problem if allowed to exit the drum. To counter this, antifoam chemical is injected reduce carryover of tars and fines from the coke drums to the fractionator.

While coke drum D-1 is coking, drum D-2 is decoking, that is, the solid coke is first prepared for removal then emptied from the drum bottom. At the beginning of the decoking sequence drum D-2 contains both hot solid coke and residual hot vapor, and the vessel shell is also at its maximum temperature. Steam is introduced to initiate the cooling process. As the drum cooling process progresses the mixture of residual hot vapor and steam are routed to the quench tower, T-2 (sometimes called the blowdown tower). The quench tower separates the various products from the contaminated steam (waste) which then is further treated.

Then water is added to complete the cooling sequence. Upon completing the cooling phase, the drum is deheaded (sometimes described as unheaded), that is, first the top is removed, then the bottom head; the top head being removed first prevents the drum shell from collapsing due the vacuum caused by the water exiting the bottom head. The water is dumped to the coke pad, collected, and processed for reuse. The solid coke remains in the vessel and must be cut into smaller pieces to allow it to empty onto the coke pad. To cut the solid coke, high-pressure water is used.

Figure 2 is a simplified two drum arrangement consisting of two coke drums, a concrete supporting table top with unloading chutes to direct the dumped water and the cut solid coke to the concrete temporary storage pad. The water is gravity drained to a collection point to remove coke fines and process the water for subsequent coke cutting. The solid coke is removed from the pad by mechanical means such as overhead cranes or dozers. A steel structure is also supported by the concrete table top which in turn supports the drill derrick structure. The derrick is utilized to insert and withdraw the drill stem, a steel pipe rated for the high water pressure, with a cutting tool on the bottom and connected at the top to the high-pressure water source via a flexible high-pressure hose. The drill stem is raised and lowered by a motor driven hoist and the stem is rotated by another motor.

The top of the stem is connected to the crosshead, which facilitates the stem hoisting and rotating, and a free fall arrestor is installed to protect the installation from a hoist failure. The cutting tool is designed to direct the high-pressure water both vertically down and horizontally as the stem is raised and lowered. The cutting tool is also designed to automatically switch between vertical and horizontal cutting while the tool remains inside the drum.

When the drum is ready for decoking and the top and bottom nozzles opened, the cutting process begins. The drill stem is lowered into the coke drum with the cutting tool directing the high pressure water vertically down to cut a pilot hole in the solid coke the full length of the stem. Once pilot hole is cut the stem is raised, the tool reoriented to cut horizontally, and the stem both lowered and rotated to cut the coke, which falls out the drum bottom nozzle to the chute and onto the pad.

RULES OF THUMB

Coking Temperature and Pressure

Typical thermal cracking temperature at coke furnace is in the range of 900 to 950 F.

Typical coking pressures in coke drums are about 15 psig to 20 psig.

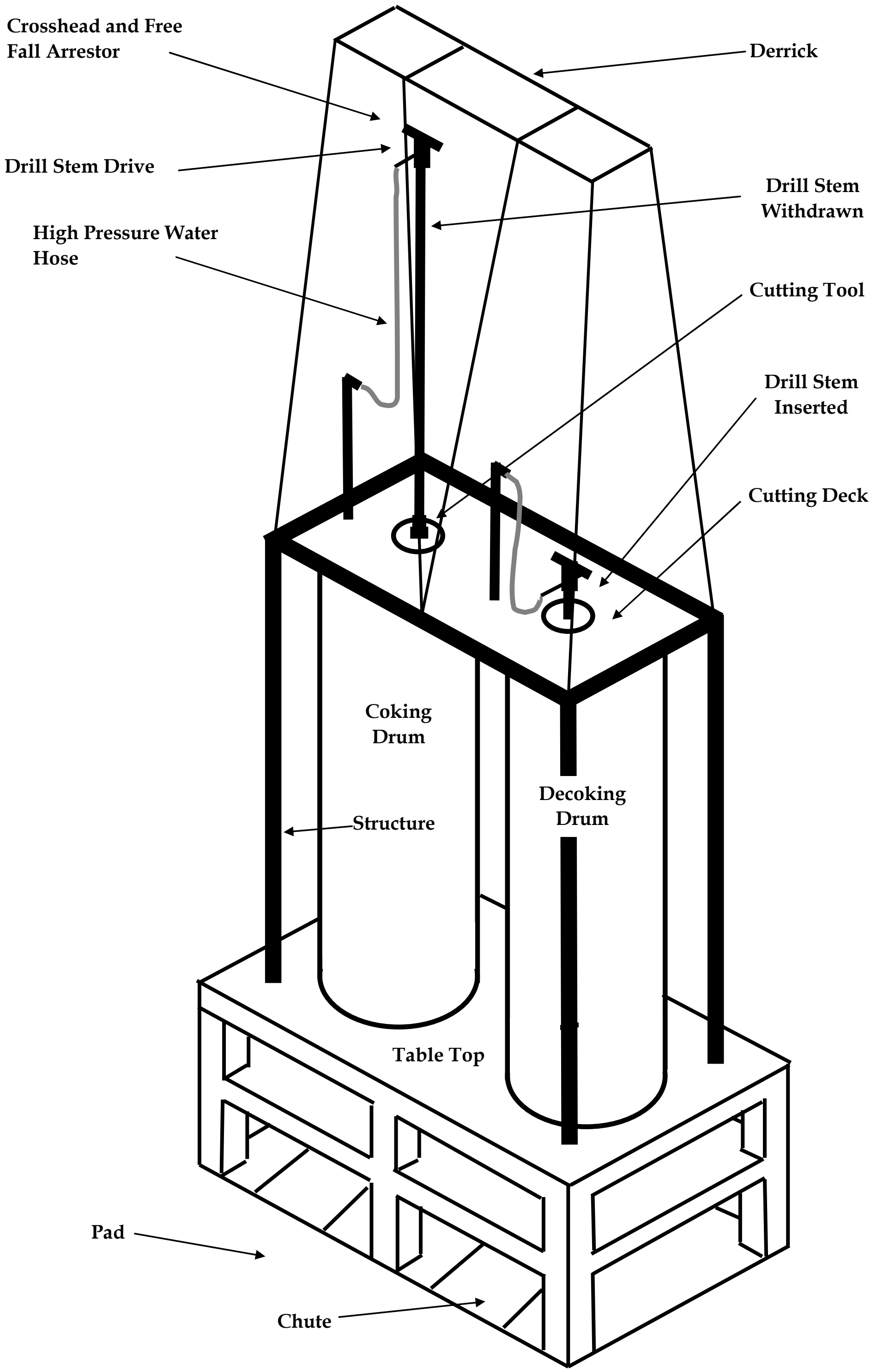

Figure 2 – Coke Drum Schematic

Process Description – Basic Pressure Temperature Profile

In the previous section, the delayed coking process was described by using the process flow diagram (PFD) and coke drum schematic. Another way to illustrate the basic coke drum operation will be employed in this section, the pressure-temperature profile for one complete cycle. In the next section, both of these methods will be combined to describe the process in the context of a two drum concurrent, integrated operation with the aid of Figures 3 through 16.

Below are two simplified pressure-temperature profiles for one complete coke drum cycle, the first depicts the temperature and pressure over time as an individual drum progresses through an entire coking cycle. The second profile overlays a description of what is causing the pressure and temperature to change. A brief explanation of each sequence segment is also provided.

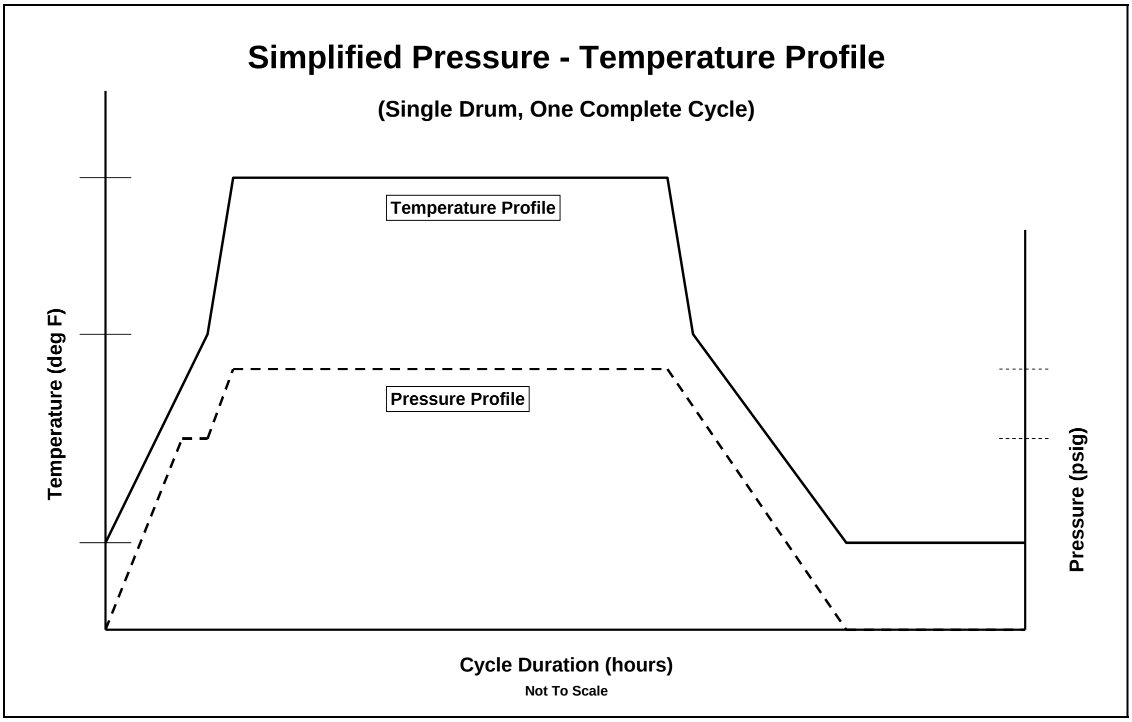

Figure 3 – Simplified Pressure-Temperature Profile

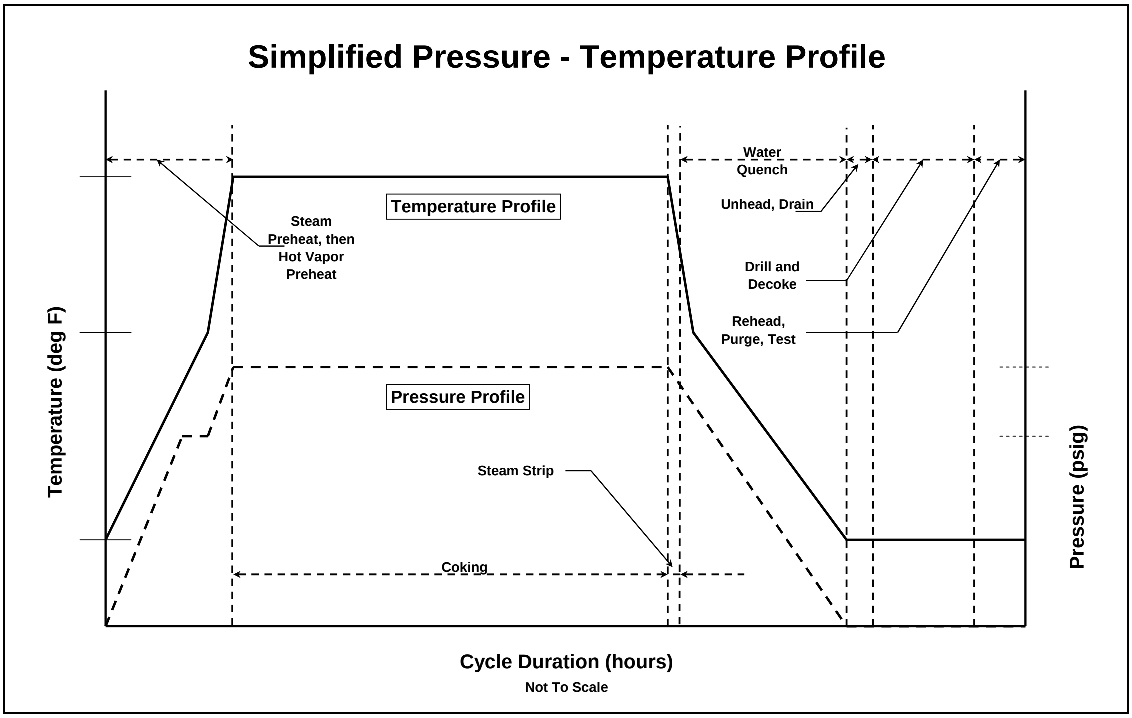

Figure 4 - Simplified Pressure-Temperature Profile

Preheat (or warm up) period – Preheat is the coke drum warm-up period prior to introducing hot feed from the furnace. With the drum having been previously emptied of coke, re-headed, purged of oxygen with steam, and tested for gasket leaks, the vessel temperature is relatively cold, but not ambient. The preheat period is a controlled temperature and pressure increase to bring the vessel closer to the hot feed temperature; first with steam preheat, then hot vapor preheat from the coking drum. This controlled temperature increase is necessary to minimize adverse thermal stress and strain on the drum, primarily the skirt/cone/shell junction.

Coking segment (feed fill portion of cycle) – After the drum has been preheated, feed is introduced into the drum from the furnace and the thermal cracking process begins. Hot feed entering the bottom of the drum forms coke and releases light ends (hydrocarbon vapors) overhead to the fractionator tower. This is the longest segment in the sequence and is half (50%) of the total cycle duration.

Steam stripping (also referred to as steam out and steam to blowdown) – High pressure steam is introduced initially to the overhead vapors en route to the fractionator tower to remove additional light ends remaining on coke. Then the balance of steam and hydrocarbon vapors are sent to the quench tower for separation of sour water (waste) and additional light ends recovery. Steam stripping also acts as the first stage in the cooling down process prior to decoking the drum.

Quench water segment – Water is introduced into drum to cool or quench the coke, at first at a slow rate, until the water has cooled the drum level at least above the skirt/cone/shell junction. Then after this level is achieved, the quench water rate can be accelerated to speed this portion of the cycle. The initial slower rate is necessary to reduce the thermal shock of cooling on the crack susceptible skirt/cone/shell junction and bulge creation in the lower portion of the cylindrical portion of the shell.

Unhead, Drain segment – the top and bottom heads are removed, and the quench water is drained from drum to pad.

Drill portion – The drill stem is first lowered from the derrick and inserted through the top manway nozzle with the cutting tool set to blast high-pressure water vertically down to drill a pilot hole the full length of the coke.

Decoking period (or coke cutting) – After the pilot hole is completed, the drill stem is raised and the cutting tool hydroblasting nozzle is reoriented to blast horizontally. The drill stem is then both rotated and reinserted, cutting the coke, and allowing coke and cutting water to exit bottom nozzle.

Re-heading, Purge, Test – The top and bottom heads are then reinstalled (re-headed), the drum purged with steam to remove air, and the drum steam tested to ensure top and bottom gaskets are sealed. The cycle is then repeated.

RULES OF THUMB

Coking cycle time

Typical cycle range 30 to 40 hours TOTAL, but could be lower or higher, and the cycle segments are approximately:

- Preheat 10% to 12%
- Coking 50%
- Steam Stripping 4% to 5%
- Quench 14% to 15%
- Drain 5% to 6%
- Drill and Decoking 10%
- Rehead, Purge, Test 4% to 5%
- TOTAL CYCLE 100%

Caution – sometimes in the literature 'coking cycle' is described as being in the 15 to 20 hour range, when described this way, only the Coking portion (50%) of the Total Cycle is being expressed. This can be misleading at times, and in this document, 'coking cycle' is defined to mean the Total Cycle.

Process Description – Two Drum Operation

In the previous two sections, the delayed coking process was described by using two different methods to explain the steps in the process. The first utilized the process flow diagram (PFD), and coke drum schematic. The next section used the pressure-temperature profile. The following pages combine the process flow diagram and the pressure temperature profile to follow the many steps of a complete two drum operation.

Cycle Step One

Drum D-1 has previously been pressure tested with steam to ensure there are no leaks prior to continuing the cycle. Steam is applied to drum D-1 as the first step (steam pre-heat) in the warm-up process and the temperature begins to increase. The vapors are routed to the quench tower T-2.

At this point, drum D-2 is ending the coking portion of the cycle and the drum temperature is relatively constant at the coking temperature. Overhead gas from D-2 continues to be sent to the fractionator T-1 for the feed preheat and subsequent product separation. Feed enters the lower section of the fractionator T-1 to be preheated by the hot overhead vapors from the on-line drum's (D-2) coking cycle. The preheated feed is pumped to the furnace H-1 where the feed is heated to coking temperature and routed via the switching valve (shown as the three way valve) to the coking drum D-2. When drum D-2 is full, it is switched off line to begin the decoking sequences.

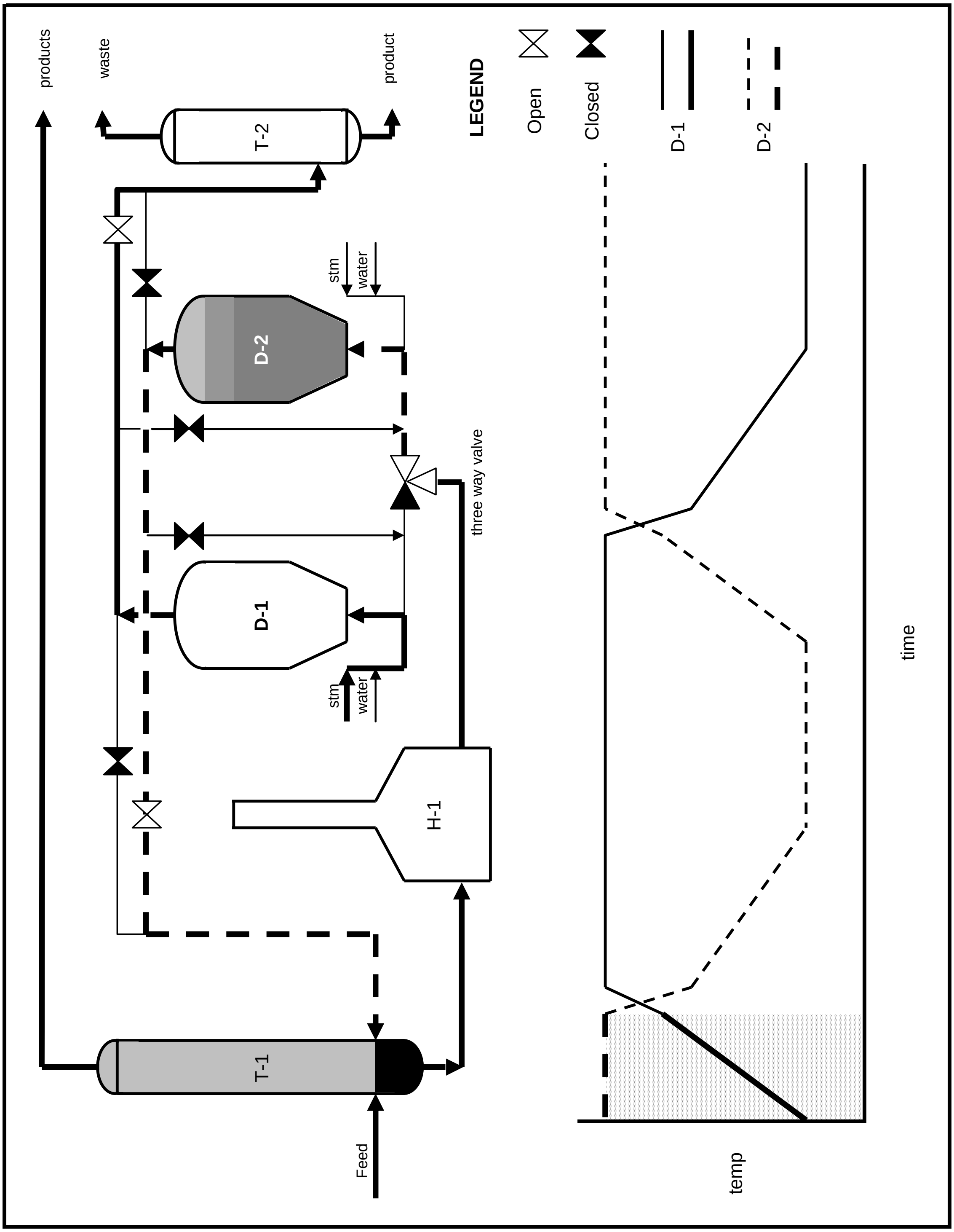

Figure 5 – Cycle Step 1

Cycle Step Two

Drum D-1's warm-up (pre-heat) continues with the hot overhead vapor rerouted from drum D-2. The warming gas is first routed to the quench tower T-2, but during Step Two the vapor is diverted to the fractionator T-1.

The warm-up steps, both steam pre-heat and hot overhead vapor, are measures taken to reduce the thermal shock of introducing hot feed from the furnace H-1 to the relatively cold drum D-1.

With the feed no longer being sent to drum D-2 and the overhead vapors being routed to D-1, D-2 temperature begins to decrease.

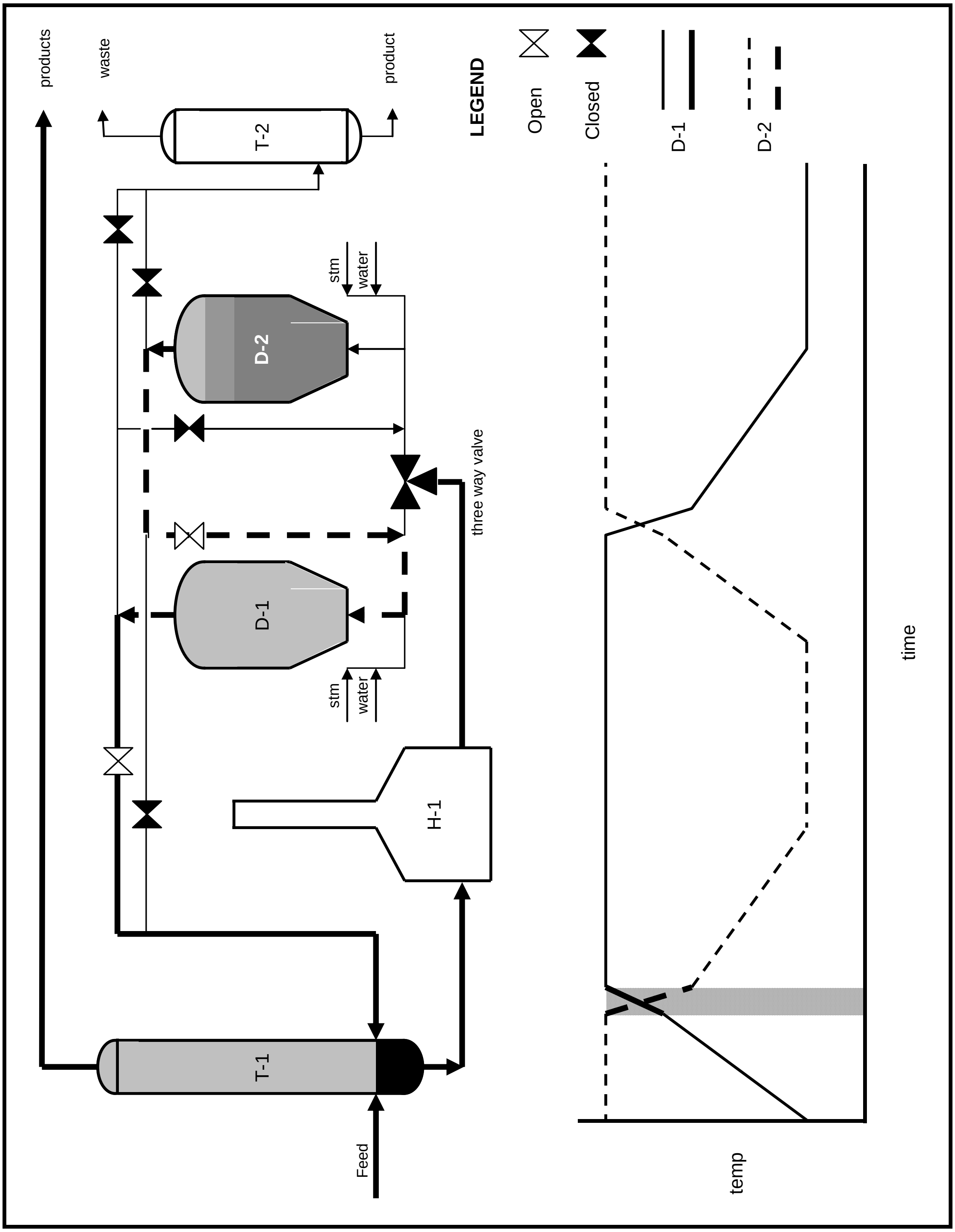

Figure 6 - Cycle Step 2

Cycle Step Three

D-2 is then steamed out (purged with steam) to recover the balance of the product oils remaining on the coke, the temperature of D-2 continues to decrease. The steam and oil vapor are routed initially to the fractionator T-1 before switching to the quench tower T-2 when most of the recoverable hydrocarbons have been stripped from the coke. As the vapor rises through T-2, residual products are separated and the sour water vapor is recovered for further processing.

D-1 has been preheated and the hot feed at coking temperature from the furnace H-1 is switched into drum D-1 to start the coking portion of it's cycle.

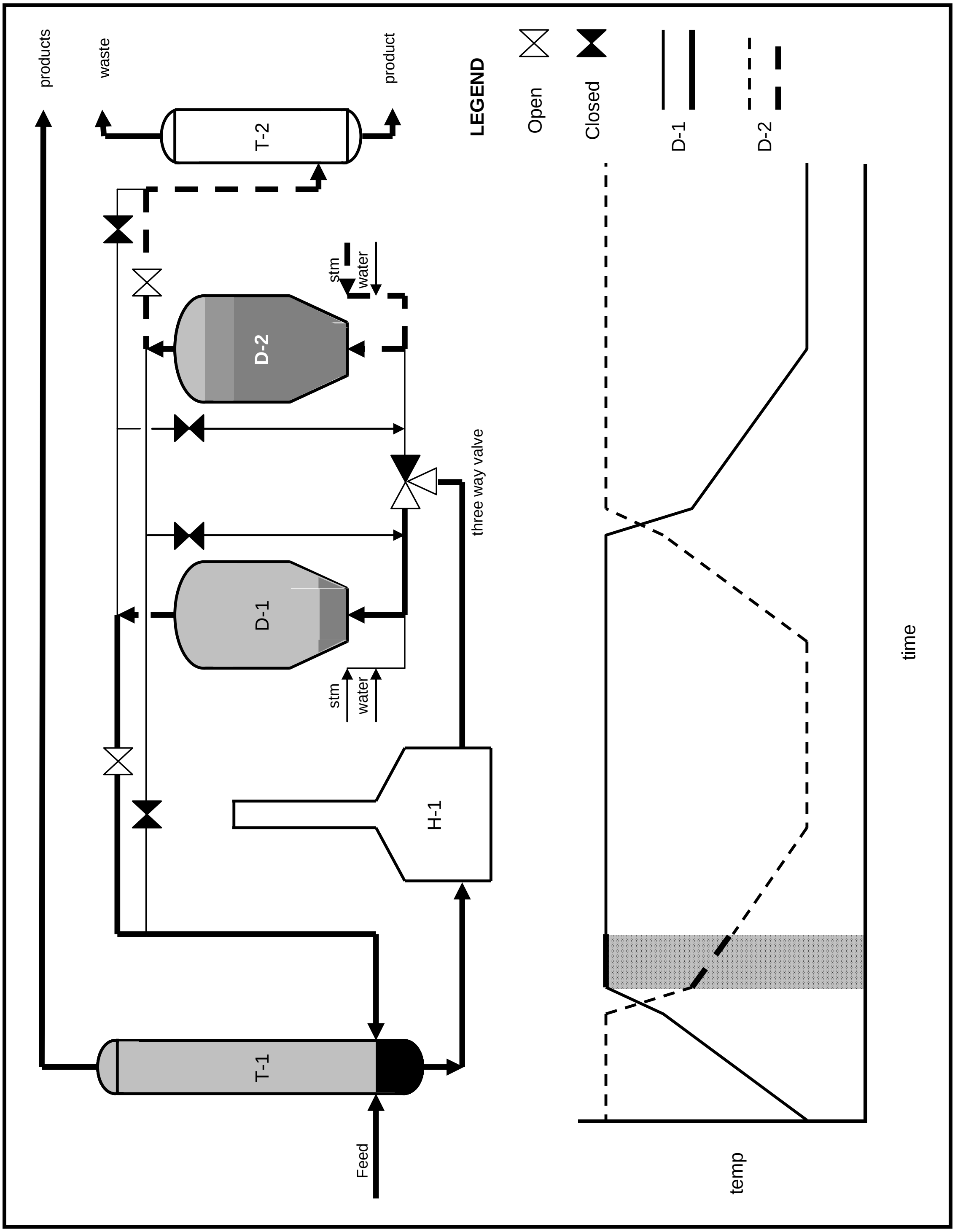

Figure 7 - Cycle Step 3

Cycle Step Four

Drum D-1 continues the coking portion of the cycle and remains at coking temperature.

Quench water is then added to drum D-2 to cool the coke in preparation of cutting and dumping from the drum. The quench water is added slowly until the drum is cooled above the skirt/cone/shell junction area. After this point is reached, the quench water rate is increased to speed the coke cool down time with the water flow controlled to ensure the pressure generated by the vaporization of water does not exceed the relief valve set pressure. The steam and oil vapors formed during the water quench are routed to the quench tower T-2.

After drum D-2 has cooled, the water is drained to the coke pad, and the drum unheaded, both top and bottom.

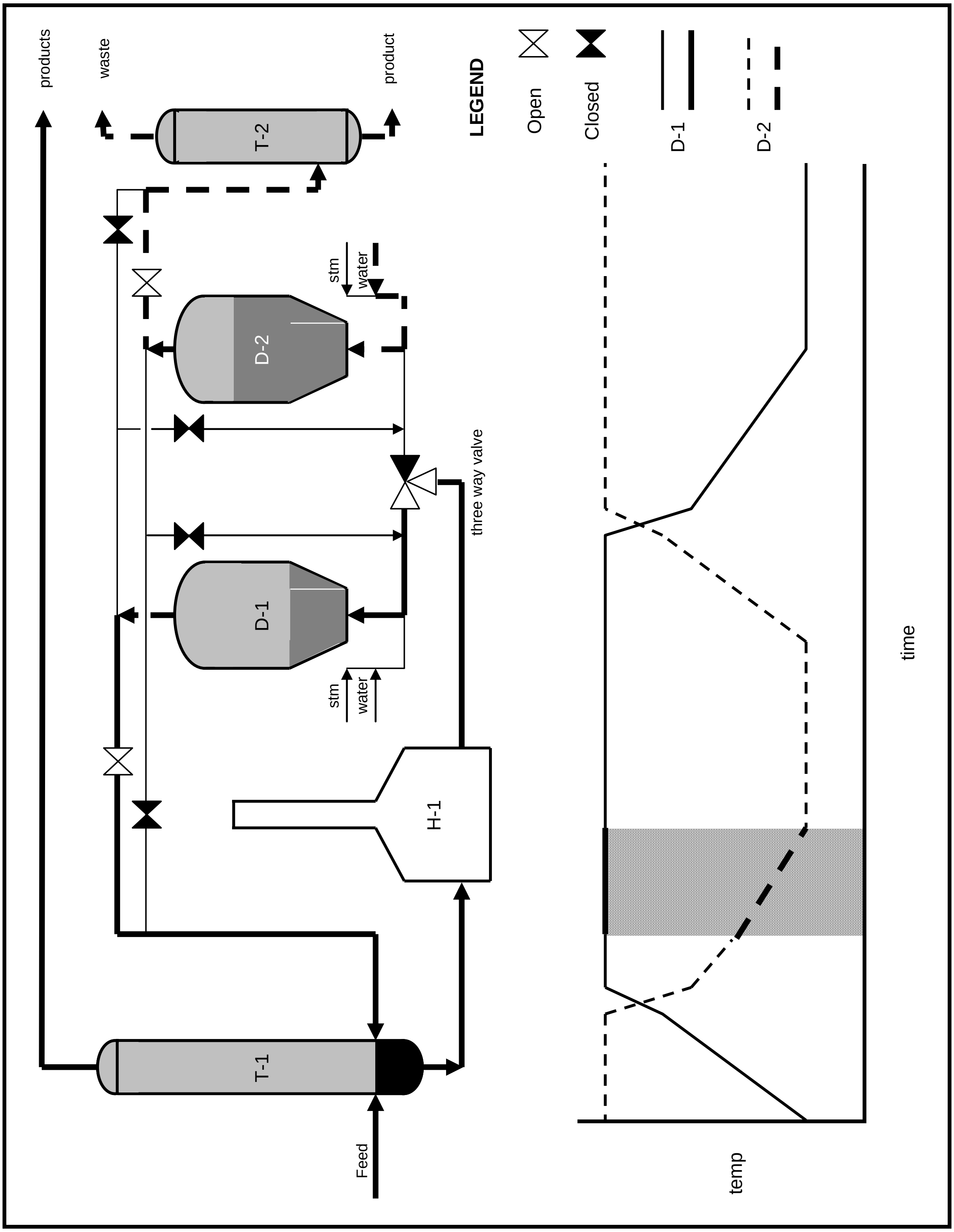

Figure 8 - Cycle Step 4

Cycle Step Five

Drum D-1 continues the coking portion of the cycle at coking temperature.

After drum D-2 has been deheaded, the drill stem is lowered into the top of the drum with the cutting head positioned for vertical down cutting, the high pressure water pump started, and the pilot hole is drilled through the entire length of the coke bed.

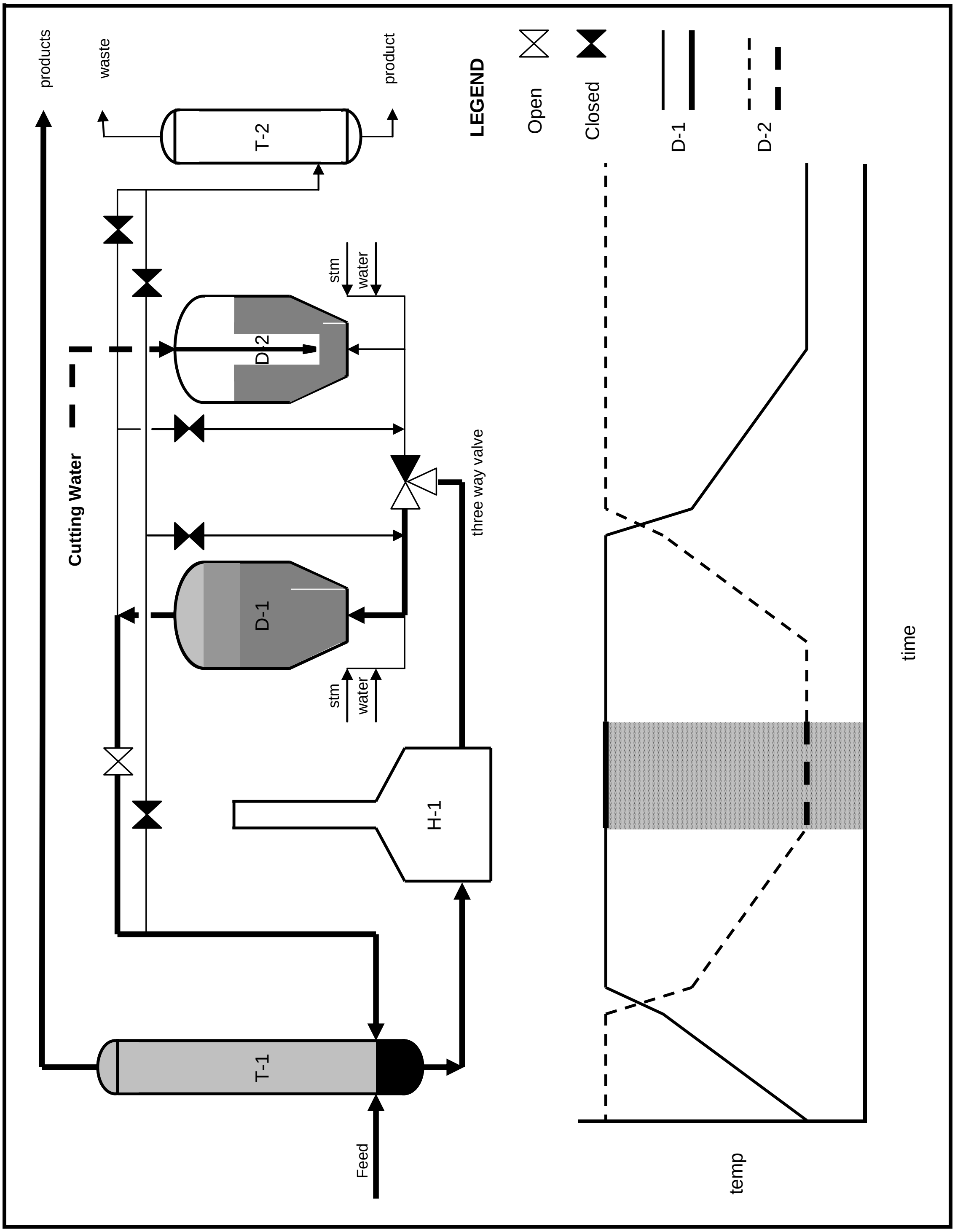

Figure 9 - Cycle Step 5

Cycle Step Six

Drum D-1 continues the coking portion of the cycle at coking temperature.

In drum D-2, the drill stem is raised , the cutting head repositioned for horizontal cutting, and the coke is then cut from the top down. The coke and cutting water empty onto the coke pad via the chute at the bottom of the coke drum table top. Drum D-2's temperature is significantly lower, but does not reach ambient temperature during this decoking process.

After the coke is removed from drum D-2, the drum is reheaded, purged of air, and pressure tested with steam.

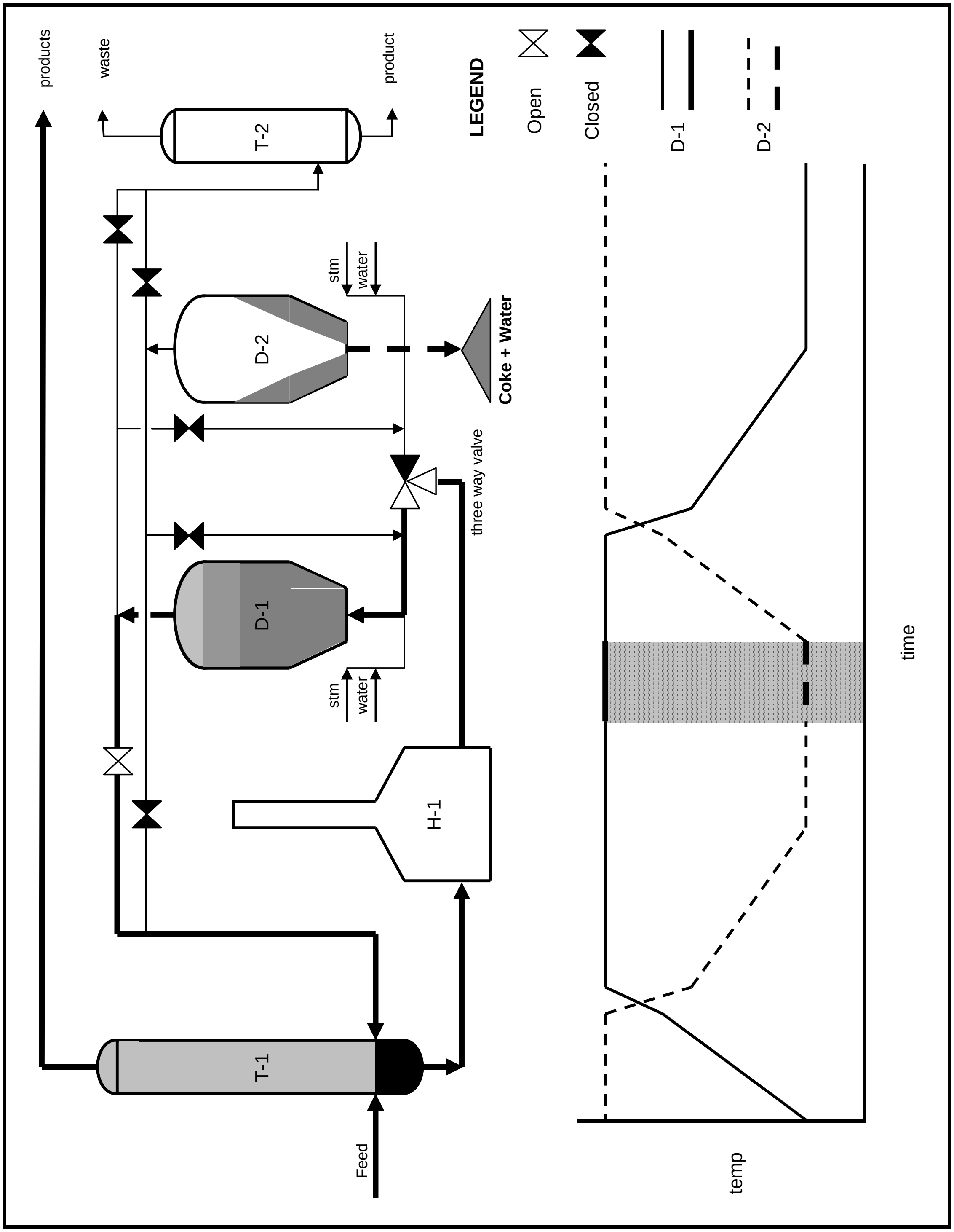

Figure 10 - Cycle Step 6

Cycle Step Seven

At this point, drum D-1 is ending the coking portion of the cycle and remains at coking temperature. When drum D-1 is full, it is switched off line to begin the decoking portion of the cycle.

Drum D-2 has been pressure tested with steam and steam is then continued to be applied to drum D-2 as the first step (steam pre-heat) in the warm-up process with the vapor routed to the quench tower T-2.

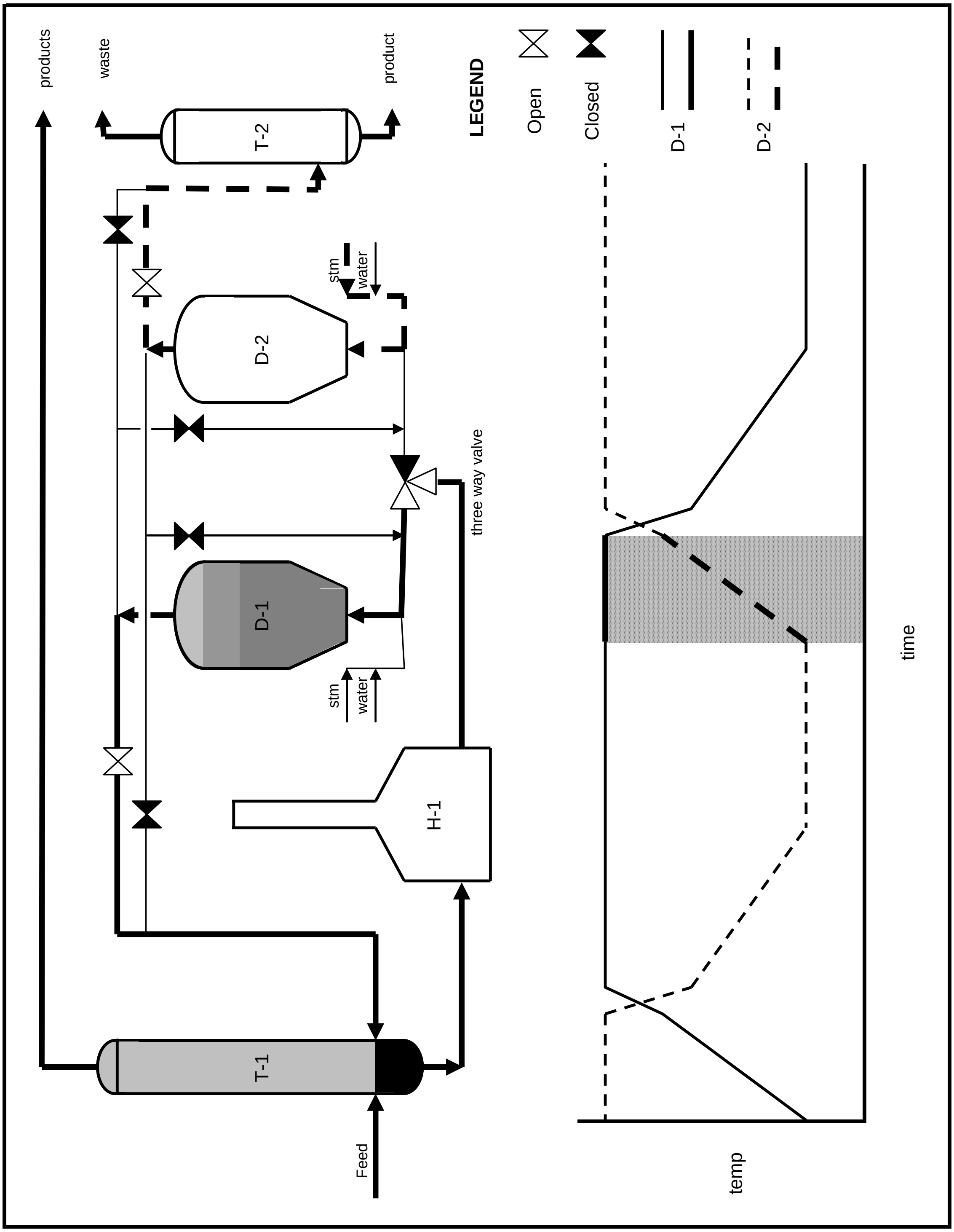

Figure 11 - Cycle Step 7

Cycle Step Eight

Drum D-2's warm-up (pre-heat) continues with the hot overhead vapor rerouted from drum D-1 which also initiates D-1 cooling. The warming gas is first routed to the quench tower T-2, but during Step Eight the vapor is diverted to the fractionator T-1.

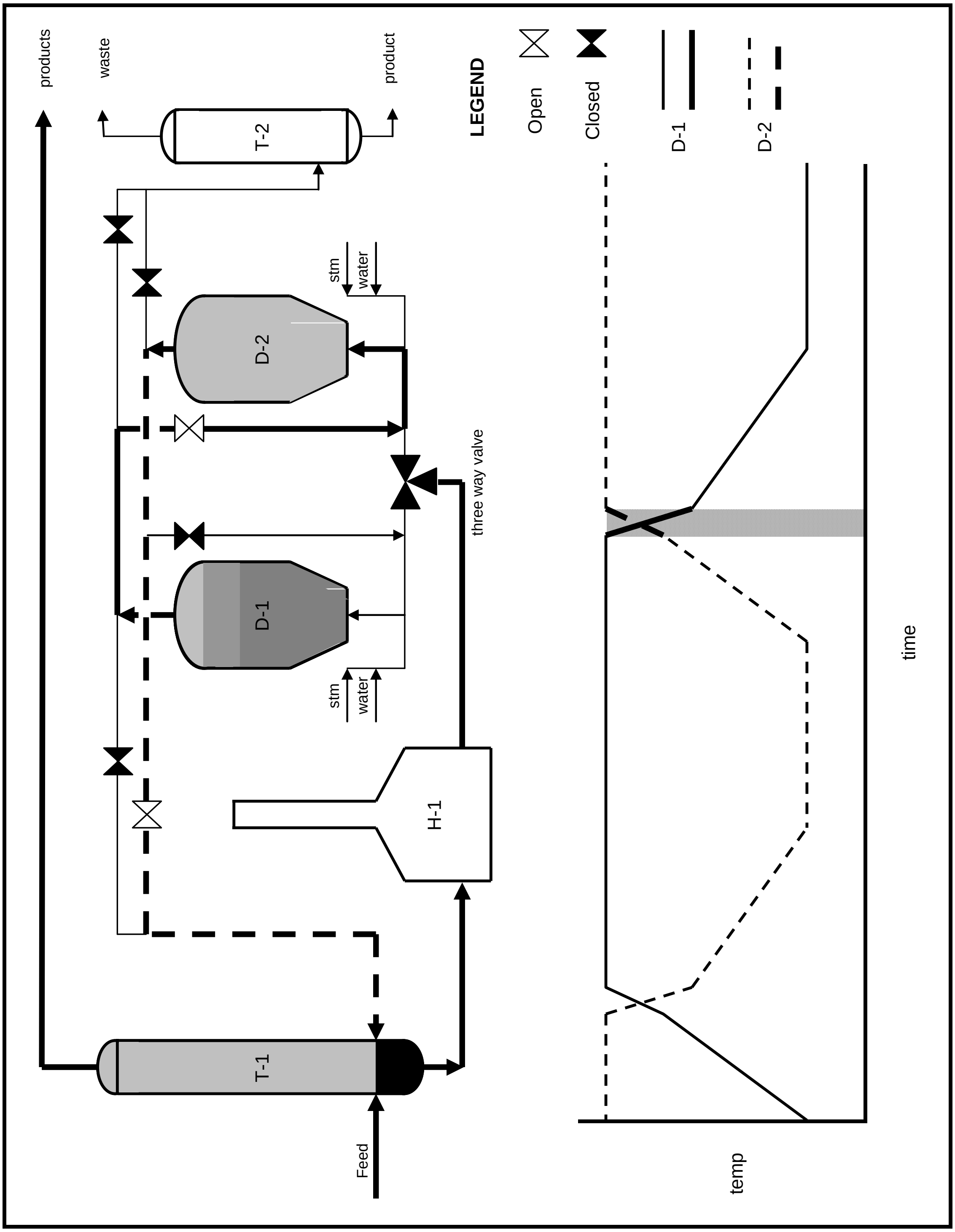

Figure 12 - Cycle Step 8

Cycle Step Nine

D-1 is then steamed out (purged with steam) to recover the balance of the product oils remaining on the coke. The steam and oil vapor are routed initially to the fractionator T-1 before switching to the quench tower T-2 when most of the recoverable hydrocarbons have been stripped from the coke. D-1's temperature continues to cool.

Hot feed from the furnace H-1 is then switched into drum D-2 to start the coking portion of the cycle.

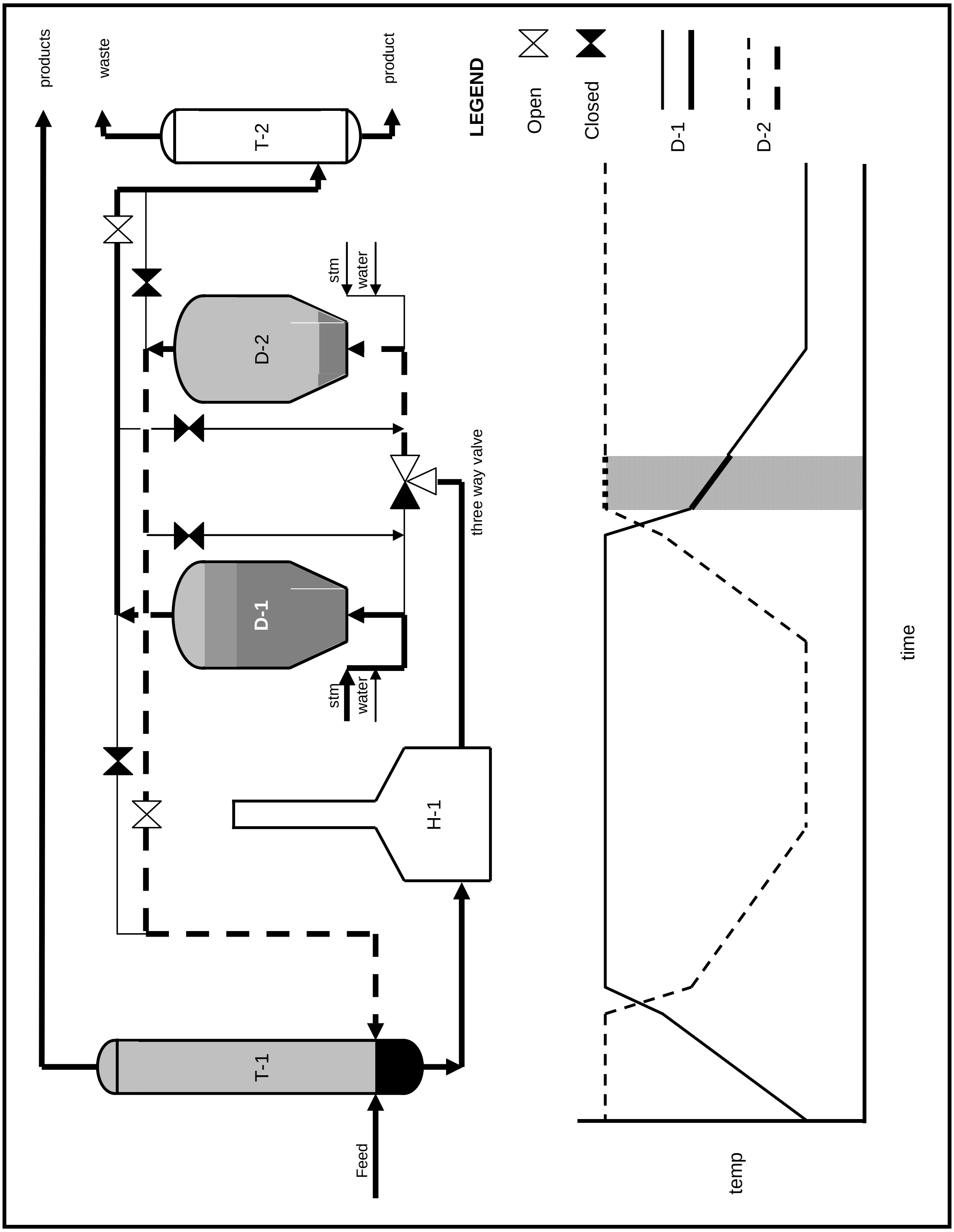

Figure 13 - Cycle Step 9

Cycle Step Ten

Drum D-2 continues the coking portion of the cycle at coking temperature.

Quench water is then added to drum D-1 to cool the coke in preparation of cutting and dumping from the drum. The steam and oil vapors formed during the water quench are routed to the quench tower T-2. The quench water is added slowly until the drum is cooled above the skirt/cone/shell junction area. After this level is reached, the quench water rate is increased to speed the coke cool down time with the water flow controlled to ensure the pressure generated by the vaporization of water does not exceed the relief valve set pressure.

After drum D-1 has cooled, the water is drained to the coke pad, and the drum unheaded, both top and bottom.

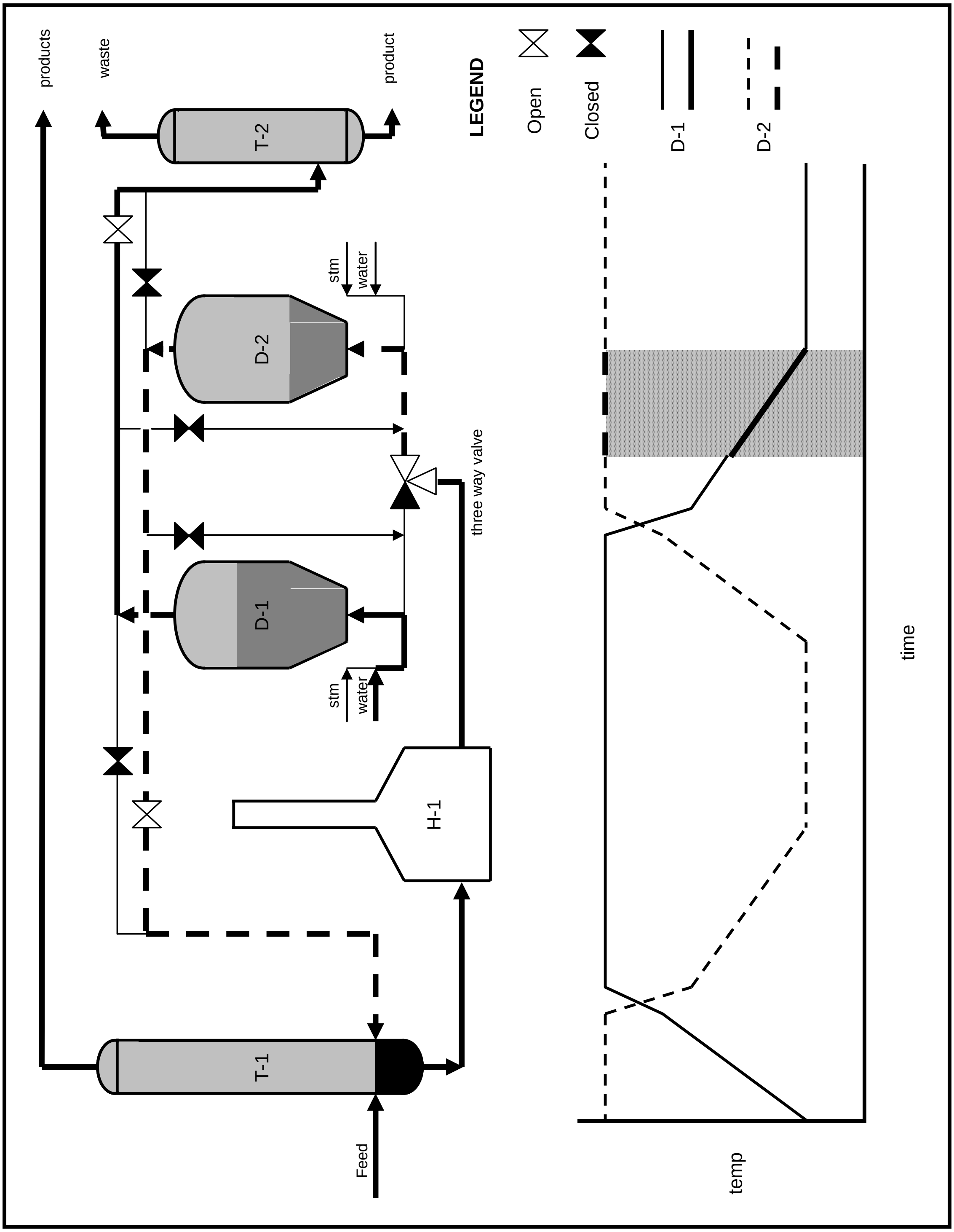

Figure 14 - Cycle Step 10

Cycle Step Eleven

Drum D-2 continues the coking portion of the cycle at coking temperature.

After drum D-1 has been deheaded, the drill stem is lowered into the top of the drum with the cutting head positioned for vertical down cutting, the high pressure water pump started, and the pilot hole is drilled through the entire length of the coke bed.

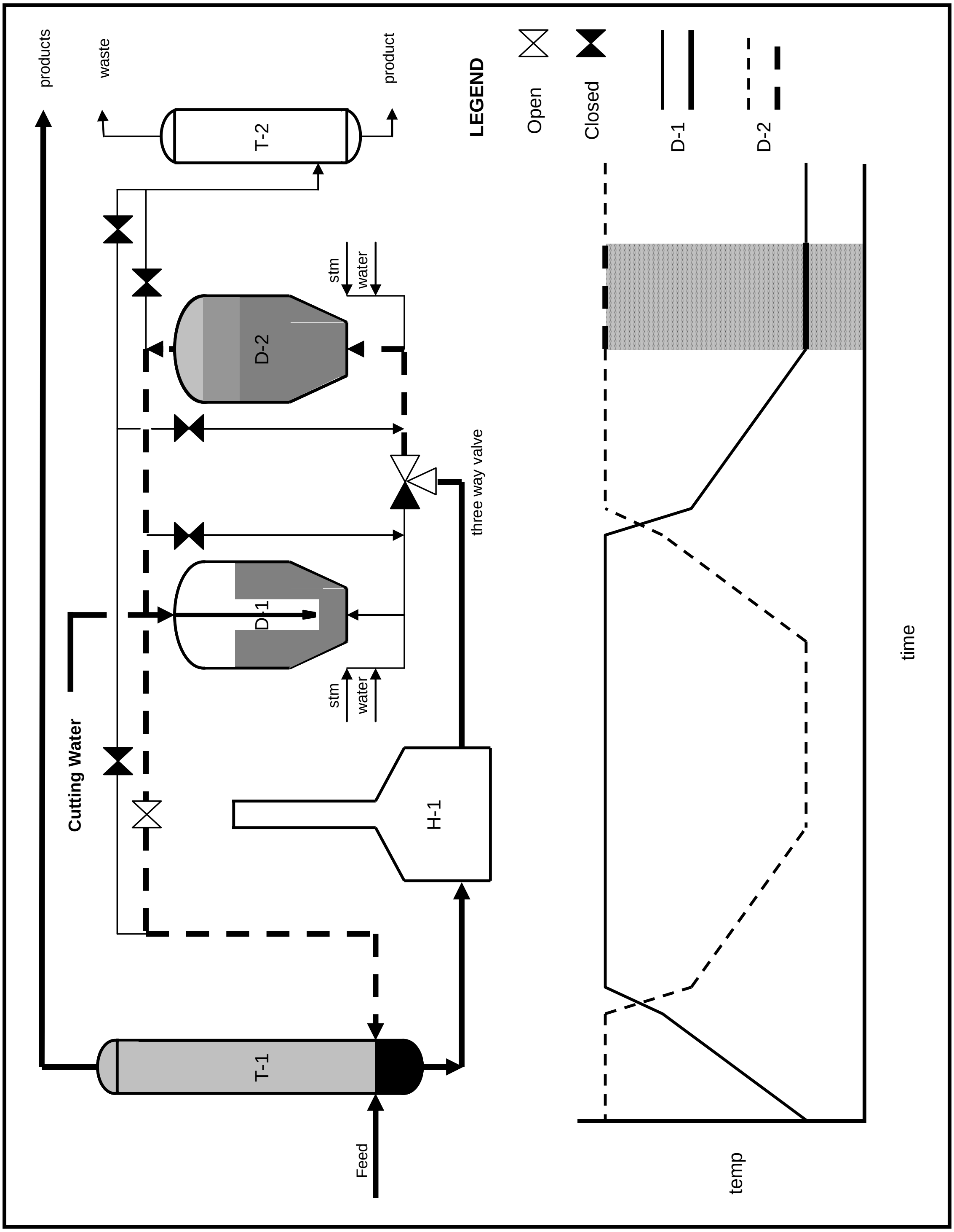

Figure 15 - Cycle Step 11

Cycle Step Twelve

Drum D-2 continues the coking portion of the cycle at coking temperature.

In drum D-1, the drill stem is raised , the cutting head repositioned for horizontal cutting, and the coke is then cut from the top down. The coke and cutting water empty onto the coke pad via the chute at the bottom of the coke drum table top. Drum D-1's temperature is significantly lower, but again does not reach ambient temperature during this decoking process.

After the coke is removed from drum D-1, the drum is reheaded, purged of air, and pressure tested with steam.

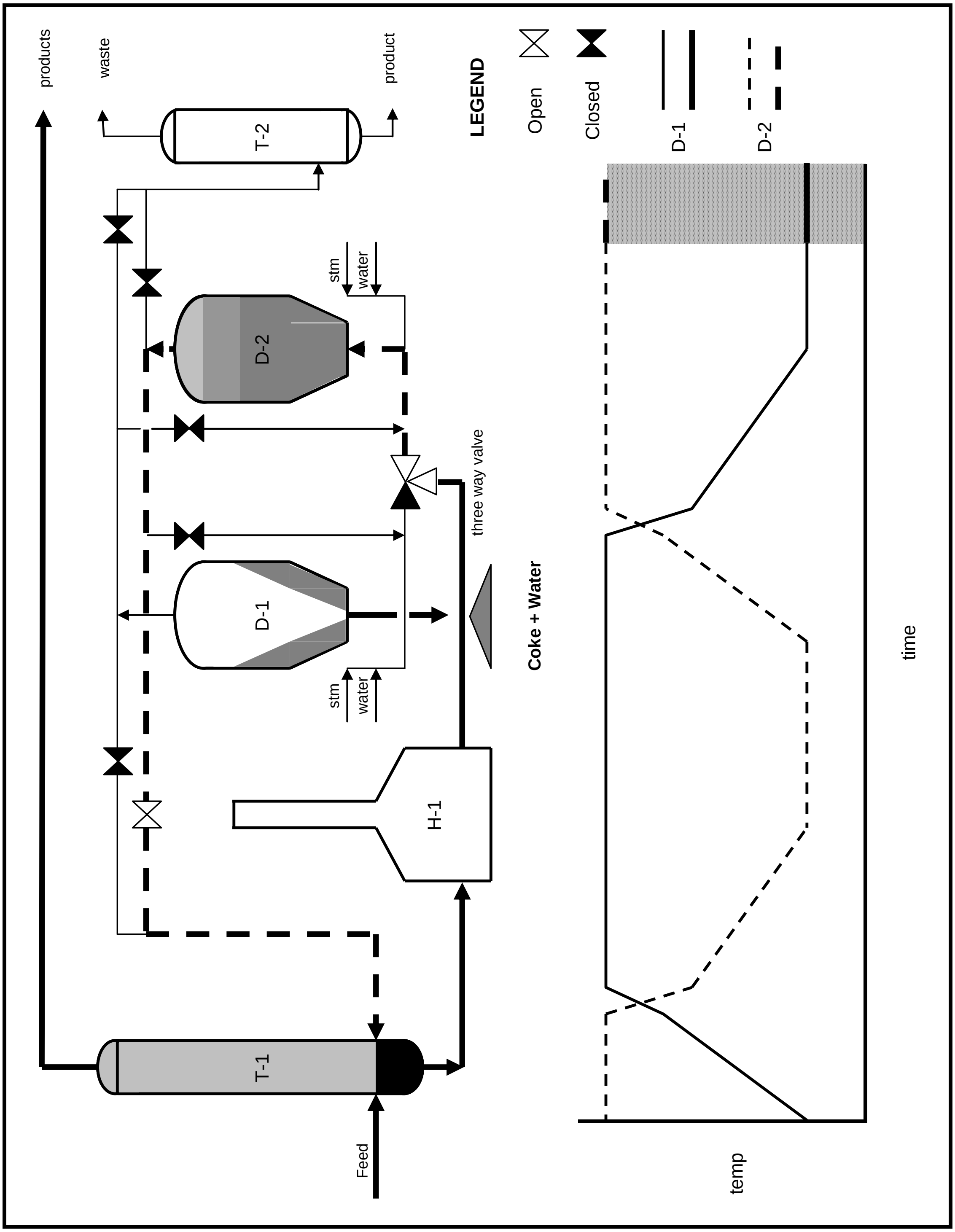

Figure 16 - Cycle Step 12

T.E. Wolf has over 40 years petroleum and petrochemical experience, including 25 years in project management. He holds a BS degree in Mechanical Engineering and is a registered Professional Engineer.