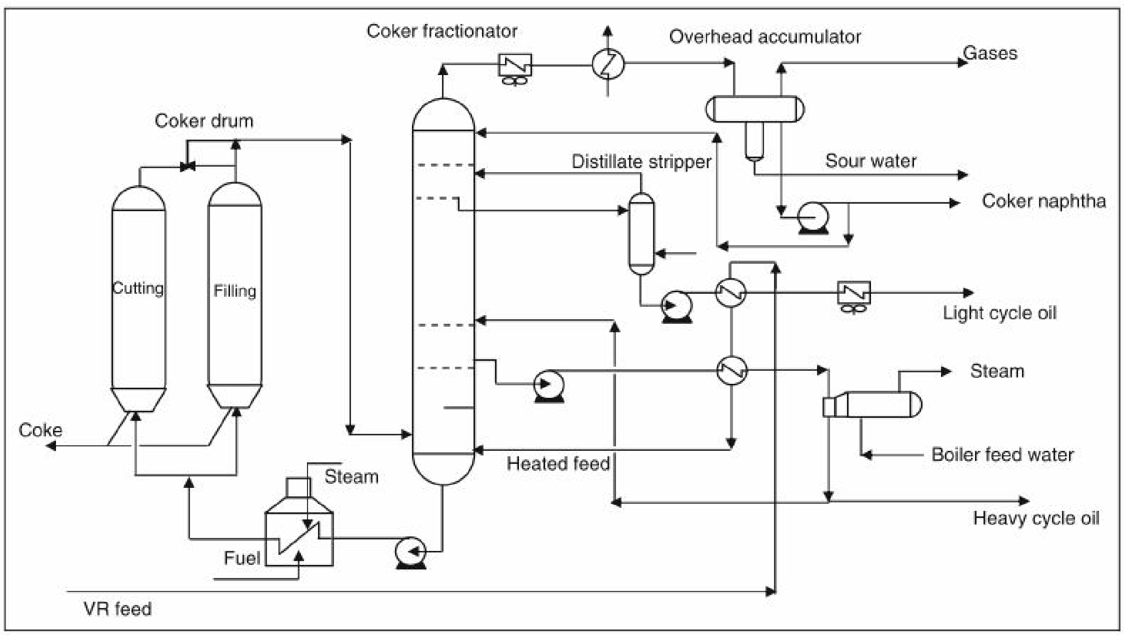
Delayed Coking

Delayed coking is a type of thermal cracking in which the heat required to complete the coking reactions is supplied by a furnace, while coking itself takes place in drums operating continuously on a 24 h filling and 24 h emptying cycles.
The feed to coker is usually vacuum residue which is high on asphaltenes, resins, aromatics, sulphur and metals. The deposited coke contains most of the asphaltenes, sulphur, and metals present in the feed, and the products are unsaturated gases (olefins) and highly aromatic liquids.

Process Description

A schematic flow diagram of the delayed coking is shown in Figure below. The process includes a furnace, two coke drums, fractionator and stripping section. Vacuum residue enters the bottom of the flash zone in the distillation column or just below the gas oil tray. Fractions lighter than heavy gas oil are flashed off and the remaining oil are fed to the coking furnace.



Delayed coker unit

Steam is injected in the furnace to prevent premature coking. The feed to the coker drums is heated to just above 482 °C (900 F). The liquid–vapour mixture leaving the furnace passes to one of the coking drum. Coke is deposited in this drum for 24 h period while the other drum is being decoked and cleaned. Hot vapors from the coke drum are quenched by the liquid feed. Vapors from the top of the coke drum are returned to the bottom of the fractionator.
These vapors consist of steam and the products of the thermal cracking reaction (gas, naphtha and gas oils). The vapors flow up through the quench trays of the fractionator. Steam and vaporized light ends are returned from the top of the gas oil stripper to the fractionator. Eight to ten trays are generally used between the gas oil draw and the naphtha draw or column top.

Delayed Coking Variables

There are three classes of variables affecting coking. They are related to process operating variables, feedstock characterization and engineering variables as shown in Table below.

Delayed coking variables

Process variables	Feedstock variables	Engineering variables
Cycle time	Characterization factor	Mode of operation
Temperature	Conradson carbon	
Pressure	Sulphur content	Capacity
Recycle ratio	Metal content, characterization	Equipment used for coke removal and handling

Temperature is used to control the severity of coking. In delayed coking, the temperature controls the quality of the coke produced. High temperature will remove more volatile materials. Coke yield decreases as temperature increases. If the furnace temperature is high this might lead to coke formation in the furnace. A low inlet furnace temperature will lead to incomplete coking. Short **cycle time** will increase capacity but will give lower amounts of liquid products and will shorten drum lifetime. Increasing **pressure** will increase coke formation and slightly increase gas yield. **Recycle ratio** is used to control the endpoint of the coker gas oil. It has the same effect as pressure. Feedstock variables are the **characterization factor** and the **Conradson carbon** which affect yield production. **Sulphur** and **metal content** are usually retained in the coke produced. Engineering variables also affect the process performance. These include **mode of operation, capacity, coke removal and handling equipment.**

Delayed Coker Yield Prediction

Estimation of product yields can be carried out using correlations based on the weight percent of Conradson carbon residue (wt% CCR) in the vacuum residue.

$$\text{Gas}(C_4^-)\text{wt\%} = 7.8 + 0.144 \times (\text{wt\% CCR})$$

$$\text{Naphtha wt\%} = 11.29 + 0.343 \times (\text{wt\% CCR})$$

$$\text{Coke wt\%} = 1.6 \times (\text{wt\% CCR})$$

$$\text{Gas oil wt\%} = 100 - \text{Gas wt\%} - \text{Naphtha wt\%} - \text{Coke wt\%}$$

The naphtha can be split in light naphtha (LN) and heavy naphtha (HN). The split in wt% is 33.22 and 66.78, respectively, respectively. The gas oil (GO) can be split also into light cycle gas oil (LCO) and heavy cycle gas oil (HCO). The spilt in wt% is 64.5 and 35.5, respectively. Typical sulphur distribution in the products for delayed coking is presented in Table below.

Delayed coker sulphur distribution based on the amount of sulphur in feed

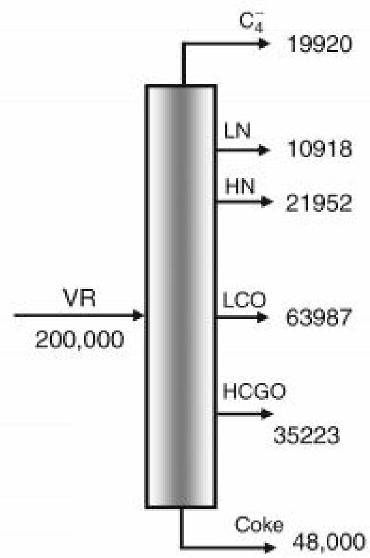
Products	Gas	LN	HN	LCO	HCO	Coke
S (wt%)	30	1.7	3.3	15.4	19.6	30

Ex.: A vacuum residue of Conradson carbon (wt% CCR = 15) is fed into a delayed coker at a rate of 200,000 lb/h, of API = 8.5 and with a sulphur content of 3.0 wt%. Find the amount of yield (lb/h) and their sulphur content. Calculate yield of liquid products in BPD.

Sol.: The solution of the example is summarized in Table below.

Delayed coker	Feed rate =	200,000	lb/h
	CCR =	15	wt%
	S_f =	3	wt%
	Feed API =	8.5	

Products yield	**wt%**	**lb/h**
Gas = (7.8+0.144 × CCR%)	9.96	19,920
Naphtha = (11.29 + 0.343 × CCR%)	16.44	32,870
Coke = (1.6 × CCR%)	24.00	48,000
Gas oil (100 − Gas% − Napthta% − Coke%)	49.61	99,210
	100.00	200,000
Naphtha (assumed split wt%)		
Light naphtha LN = 33.2%	33.22	10,918
Heavy naphtha HN = 66.78%	66.78	21,952
	100.00	32,870
Gas oil (assumed split wt%)		
Light gas oil LGO	64.50	63,987
Heavy gas oil HGO	35.50	35,223
	100.00	99,210
Sulphur distribution in delayed coker products (assumed wt%)		
S in gas	30.00	1800
S in light naphtha	1.70	102
S in heavy naphtha	3.30	198
S in light gas oil	15.40	924
S in heavy gas oil	19.60	1176
S in coke	30.00	1800
	100.00	6000



Gravity of products (assumed gravities)	**API**	**SG**	**BPD**
Light naphtha	65	0.72	1041.5
Heavy naphtha	50	0.78	2894.3
Light gas oil	30	0.88	4994.0
Heavy gas oil	13	0.98	2468.5

Gas composition

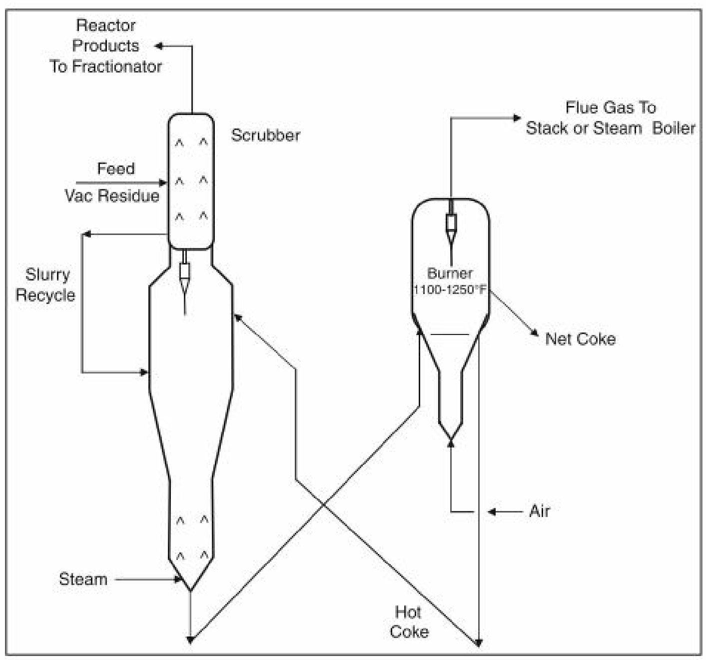
The gas produced is fuel gas, which can be sent to a fuel gas network after amine washing. The gas can also be used in the alkylation unit because of its high olefin content. A typical coker gas composition is given in Table below.

Typical gas composition from delayed coker (sulphur-free basis)

Gas	C_1	$C_2^=$	C_2	$C_3^=$	C_3	$C_4^=$	iC_4	C_4	H_2	CO_2
Mole %	51.4	1.5	15.9	3.1	8.2	2.4	1.0	2.6	13.7	0.2

Fluid Coking

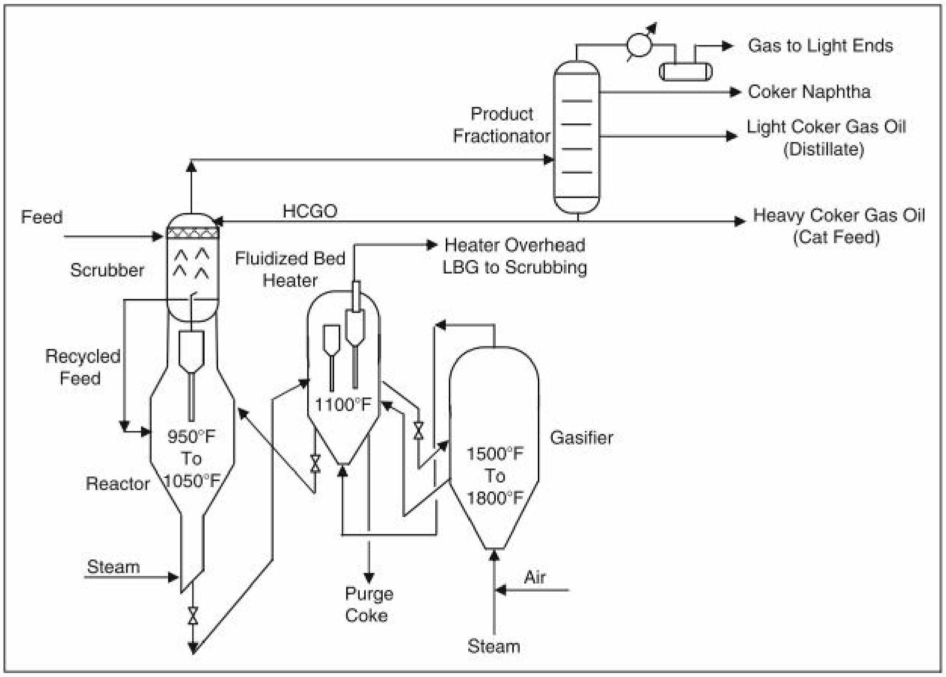
Fluid coking is a thermal cracking process consisting of a fluidized bed reactor and a fluidized bed burner as shown in Figure below. Vacuum residue is heated to 260 °C (500 F) and is fed into the scrubber which is located above the reactor for coke fine particle recovery, and it operates at 370 °C (700 F). The heavy hydrocarbons in the feed are recycled with the fine particles to the reactor as slurry recycle. The reactor operating temperature is 510–566 °C (950–1050 F). The heavy vacuum residue feed is injected through nozzles to a fluidized bed of coke particles. The feed is cracked to vapor and lighter gases which pass through the scrubber to the distillation column.



Fluid coking process

Flexicoking

The flexicoking process is a development of the fluid coking process where only 2 wt% of coke is produced, thus most of the coke is used to heat the feed. A fluidized bed is added to the process which acts as a gasifier in which steam and air are injected to produce synthesis gas called Low Btu Gas (LBG) as shown in Figure below.



Flexicoking process

Yield Correlations for Flexicoking

$$\text{Gas wt\%} = 0.171943 \times \text{CCR wt\%} + 5.206667$$

$$\text{Gasoline wt\%} = -0.115234 \times \text{CCR wt\%} + 18.594587$$

$$\text{Coke wt\%} = 1.037233 \times \text{CCR wt\%} + 1.875742$$

$$\text{Gas oil wt\%} = 100 - \text{Gas wt\%} - \text{Gasoline wt\%} - \text{Coke wt\%}$$

Gas composition:

$$C_4 \text{ wt\%} = -0.028627 \times \text{CCR wt\%} + 3.200754$$

$$C_2^- \text{ wt\%} = 0.647791 \times [\text{Gas wt\%} - C_4 \text{ wt\%}] + 0.456001$$

$$C_3 \text{ wt\%} = \text{Gas wt\%} - C_4 \text{ wt\%} - C_2^- \text{ wt\%}$$

Sulphur distribution in products:

$$S \text{ wt\% in Gasoline} = 0.193461 S_f$$

$$S \text{ wt\% in Gas oil} = 0.91482 S_f + 0.16921$$

$$S \text{ wt\% in Coke} = 1.399667 S_f + 0.18691$$

$$S \text{ in Gas} = S \text{ in Feed} - S \text{ in Gasoline} - S \text{ in Gas oil} - S \text{ in Coke}$$

Gravity of flexicoker feed and gas oil

$$\text{Feed API}_f = 0.5 \times \text{CCR wt\%} + 0.932644$$

$$\text{Gas oil API} = 1.264942 \times \text{API}_f + 0.506675 \times \text{CCR wt\%} - 0.79976$$