Gases from Carbonization Tests

The large number and varied rank of coals carbonized in the BM-AGA Survey of American Coals since 1929 afford abundant data for correlating properties of coal with those of carbonization products. From correlation of the yields and characteristics of gases56/ obtained from 79 coals at 900° C., the following conclusions were drawn:

1. Yields of gas from low-, medium-, and high-volatile A coals vary with rank of coal on a percentage-by-weight but not on a volume basis.

2. The rank of coal indicates the physical and chemical properties of gas from low-, medium-, and high-volatile A coals: (a) Specific gravity increases with decrease in rank, (b) heating value increases with decrease in rank, and (c) chemical composition changes with decrease in rank - carbon dioxide, illuminants, carbon monoxide, methane, and ethane increase while hydrogen decreases.

3. The rank of coal is unrelated to the hydrogen sulfide content of the gas.

High-B.t.u. Gas from Solid Fuels

In a statement prepared for the natural-gas studies of the Federal Power Commission, the manufacture of high-B.t.u. gas from solid fuels was considered in some detail.57/ It was pointed out that exhaustion of petroleums and natural-gas reserves with time and the ever-possible threat of war clearly dictate a national reserach and development policy looking to the realization of suitable processes for the manufacture of high-B.t.u. gases from solid fuels at levels economically attainable. The paper summarizes very briefly cognate British and European developments, including the synthesis of methane, the direct hydrogenation of coal or coke to a high-B.t.u. gas, and the direct manufacture of a high-B.t.u. gas in a steam-oxygen pressure producer. The paper concludes with the following recommendations:

> To implement a policy looking to the manufacture of high-B.t.u. gas from solid fuels, the following topics are suggested for research and development:
>
> (1) The conversion of low-cost, caking American coals into noncaking fuels suitable for water-gas production. This conversion must be made by processes showing high capacities and low investment and low operating costs.

56/ Wolfson, D. E., and Reynolds, D. A., Yields and Properties of Gases from BM-AGA Carbonization Tests at 900° C.: Bureau of Mines Tech. Paper 693, 1946, 12 pp.

57/ Huff, W. J., The Manufacture of High-B.t.u. Gas from Solid Fuels: Federal Power Commission, Natural Gas Investigations Docket G580, Hearings 8, pp. 9618-9641, June 19, 1946; pp. 9908-9924, June 21, 1946.

(2) The development of water-gas processes of the high-capacity, low-velocity type capable of handling light, small fuels.

As subdivisions under this topic are the examination of (a) continuous oxygen producers and (b) continuous producers of the revolving gas type.

(3) The conversion of blue water gas to a high-B.t.u. methane containing gas in (a) the oxygen-pressure producer; (b) the catalytic synthesis of methane; (c) the direct-pressure hydrogenation of solid fuels.

Of these the first, (a), appears to warrant priority.

Gasification of Buckwheat Anthracite

In cooperation with the Anthracite Institute, who financed the tests, which were planned by the Division of Fuel Technology, The Pennsylvania State College, a study was made on the gasification of Buckwheat No. 2 (Rice) and Buckwheat No. 3 (Barley) sizes of anthracite by means of oxygen.[58] The tests were conducted at Trail, British Columbia, in the plant of the Consolidated Mining & Smelting Co. of Canada, Ltd., during September 1947.

Six cars of Pennyslvania anthracite were gasified, and the test procedure followed was substantially the A.S.M.E. Test Code for Gas Producers.

It was found that synthesis gas can be produced from these two sizes of anthracite having the following typical analyses, in percent:

Constituent	Buckwheat No. 2	Buckwheat No. 3
CO_2	16.50	17.20
O_2	.15	.20
H_2	41.00	37.65
CO	40.00	42.40
CH_4	.85	.75
N_2	1.50	1.80

[58] Wright, C. C., and Newman, L. L., The Oxygen Gasification of Anthracite in the Wellman-Galusha Producer: Presented at Joint Conference of the Production and Chemical Committees of the American Gas Association, New York, June 4, 1947. Abridged in Chem. and Met. Eng., June 1947.

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The salient operating figures are given below:

	Buckwheat No. 2	Buckwheat No. 3
Duration of test ....hr.	25	12
Fuel, as fired ....lb.	69,280	15,919
Gas produced ....M cu. ft.	2,987	614
Fuel gasified ....lb./hr./sq. ft.	33	17
Fuel gasified ....lb./hr.	2,771	1,335
Gas per lb. fuel ....cu. ft.	43.1	38.6
Fuel per M. cu. ft. gas ....lb.	23.2	25.8
O_2 per M cu. ft. gas ....cu. ft.	201	220
O_2 per lb. fuel ....do.	8.66	8.73
Steam used per lb. fuel ....lb.	1.40	1.38
Steam used per M cu. ft. gas ....do.	32.5	35.6
Steam decomposed per lb. fuel ......do.	0.73	0.58
Carbon in dry refuse ....percent	2.6	3.0
Gasification efficiency ....do.	82.8	76.8
Gross heating value of gas .... B.t.u. per cu. ft.	271	266

Considerable information was obtained relative to operating technique, particularly with respect to the importance of maintaining uniform speed of rotation of the grate to maintain uniform fire conditions. As was expected, the depth of the fire zone was very thin when the Buckwheat No. 3 anthracite was used, with the result that the clinker was denser, and difficulty was experienced with the fire reaching the grate even when it operated at the slowest rates of rotation.

Gasification of Subbituminous Coal and Lignite

Research and development work on gasification of lignite and subbituminous coal in externally heated retorts was continued in the small pilot plant at Golden, Colo., and in the large pilot plant at Grand Forks, N. Dak. Improved coal-handling facilities were installed in the large plant. After one test in this plant it was observed that the welded seams in the Pluramelt alloy retort had failed. Examination revealed that the welds contained only 20.9 percent chromium, which was insufficient to withstand the operating temperatures of 1,900° to 2,000° F. The alloy retort was repaired and made ready to operate, but no further tests were completed in the large plant during the year because of limited personnel and funds.

At Golden, Colo., several tests were made in the small plant to determine the optimum width of the annular reaction zone. A summary report of investigations[59] was published which described the development of the large plant and all experimental data obtained thereon, with results of work done on the small pilot plant during 1945-46.

59/ Parry, V. F., Gernes, D. C., Wagner, E. O., Goodman, J. B., and Koth, A. W., Gasification of Lignite and Subbituminous Coal, Progress Report for 1945-46: Bureau of Mines Rept. of Investigations 4128, 1947.

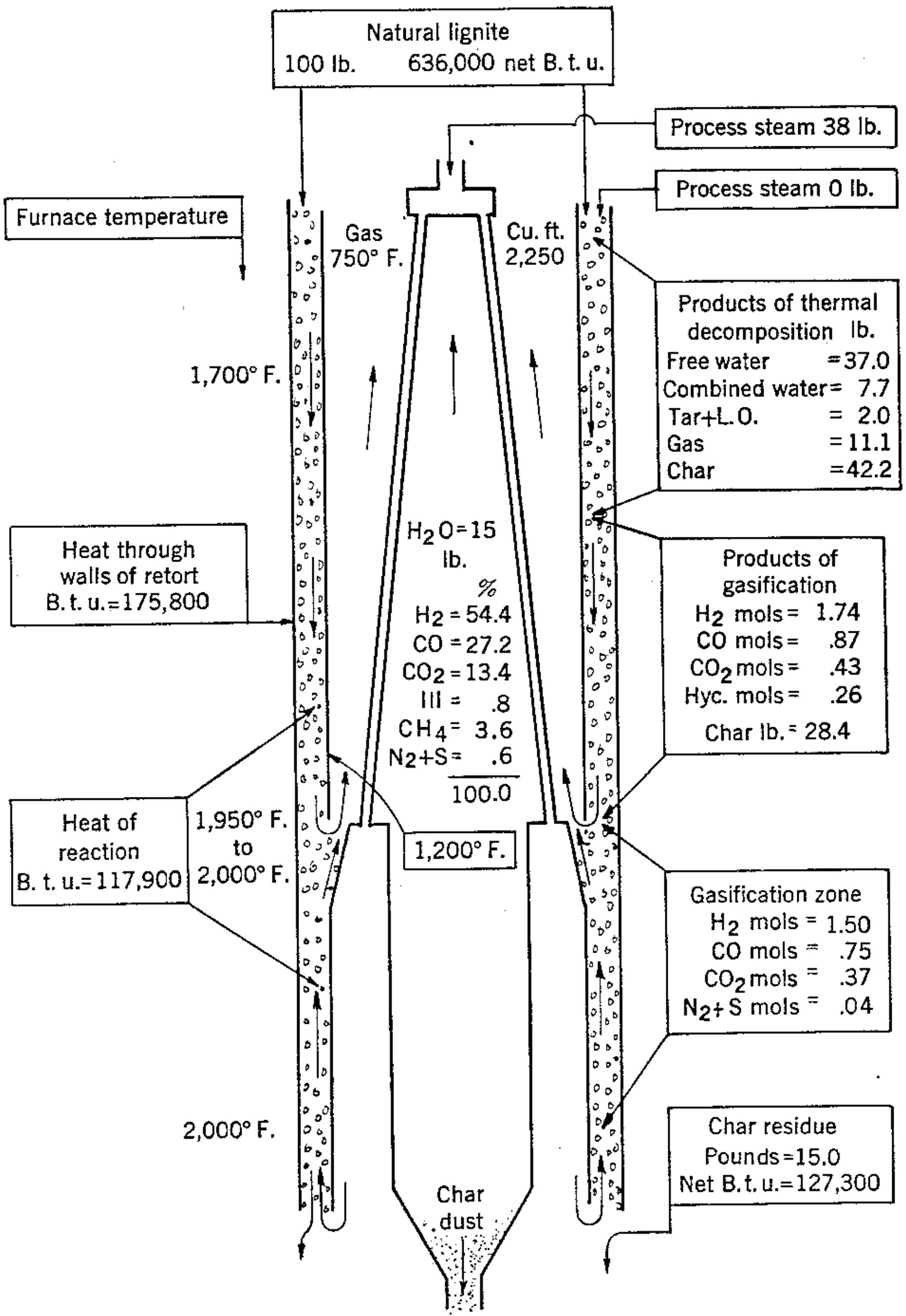

Figure 37. - Mechanism of gasification of natural lignite in externally heated annular retort.

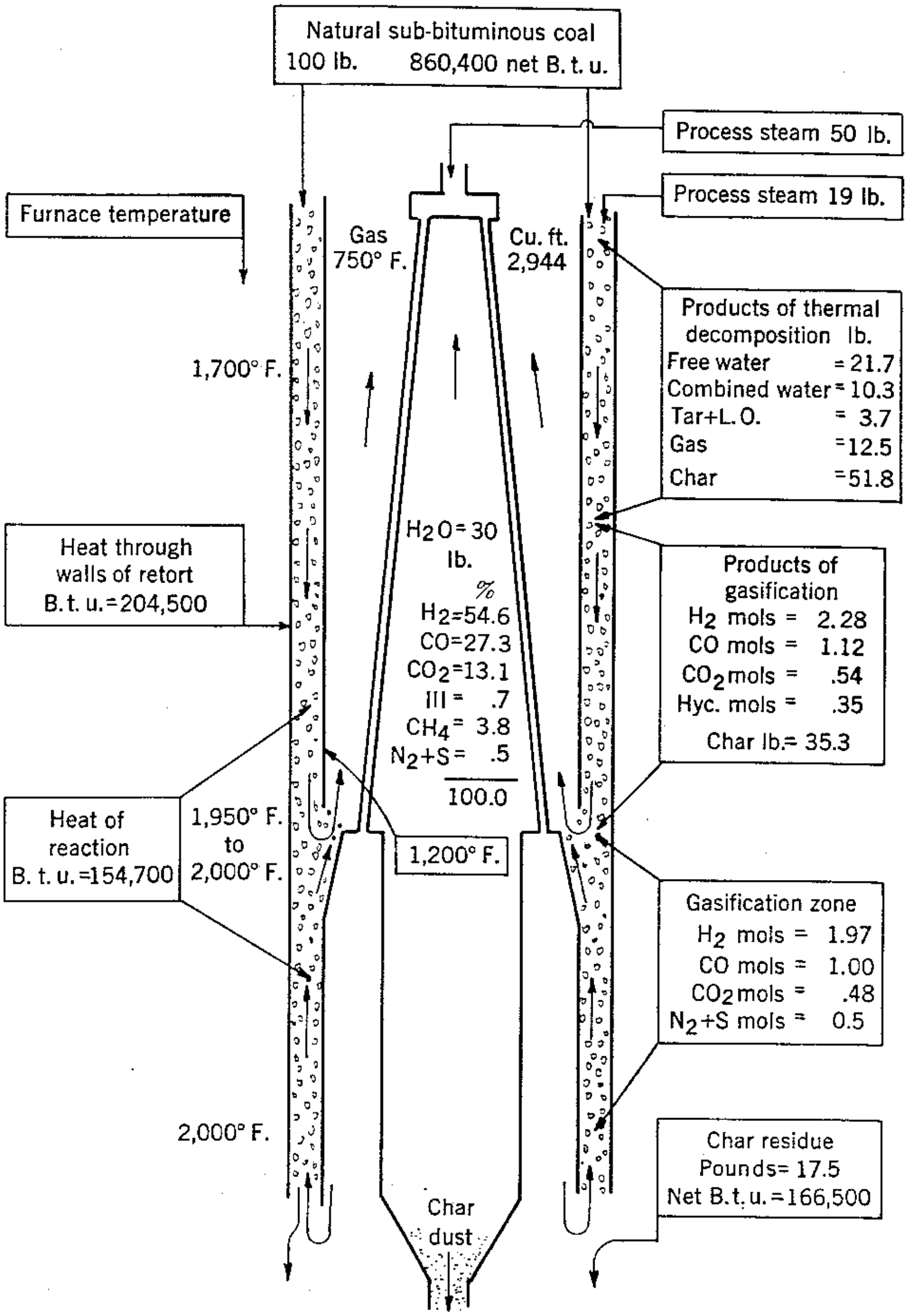

Figure 38. - Mechanism of gasification of natural subbituminous coal in externally heated annular retort.

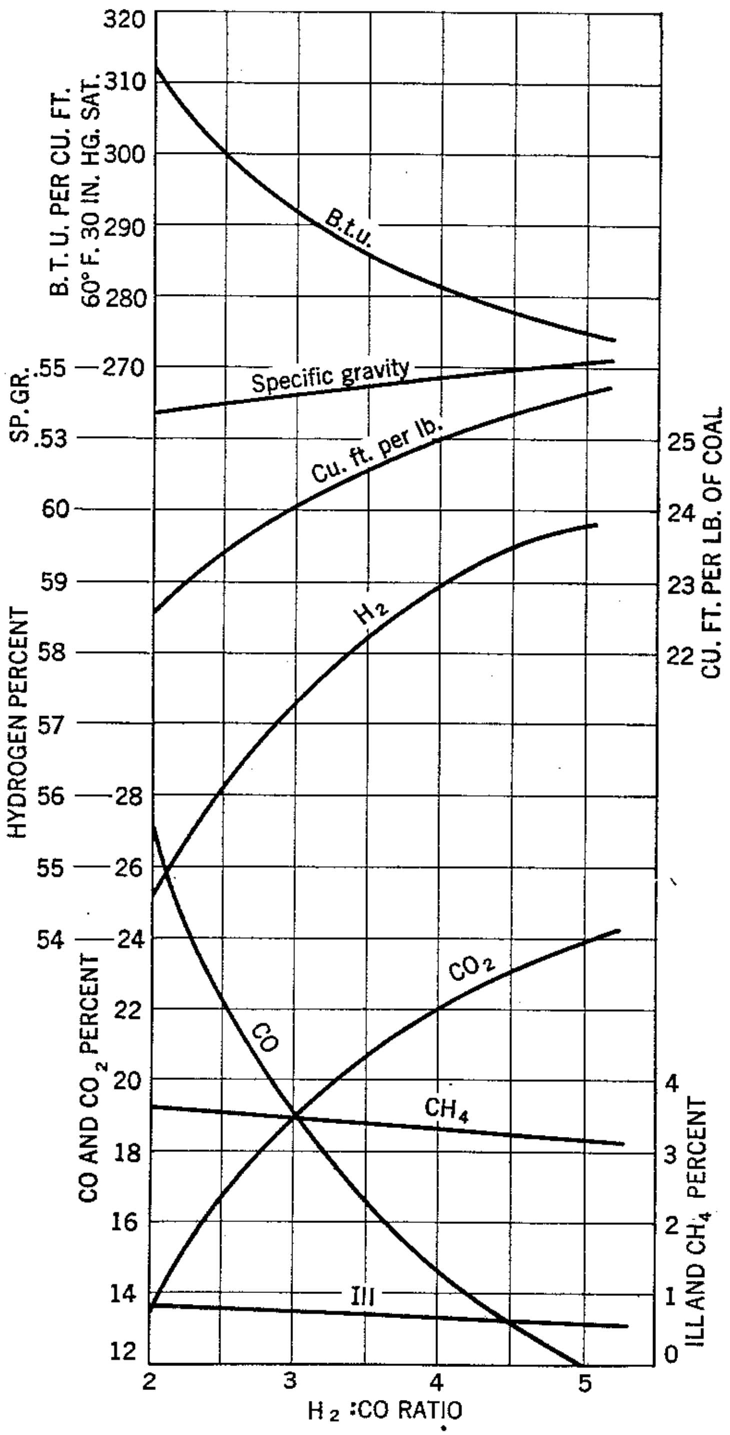

Figure 39. - Gasification of natural lignite (80 percent carbon converted).

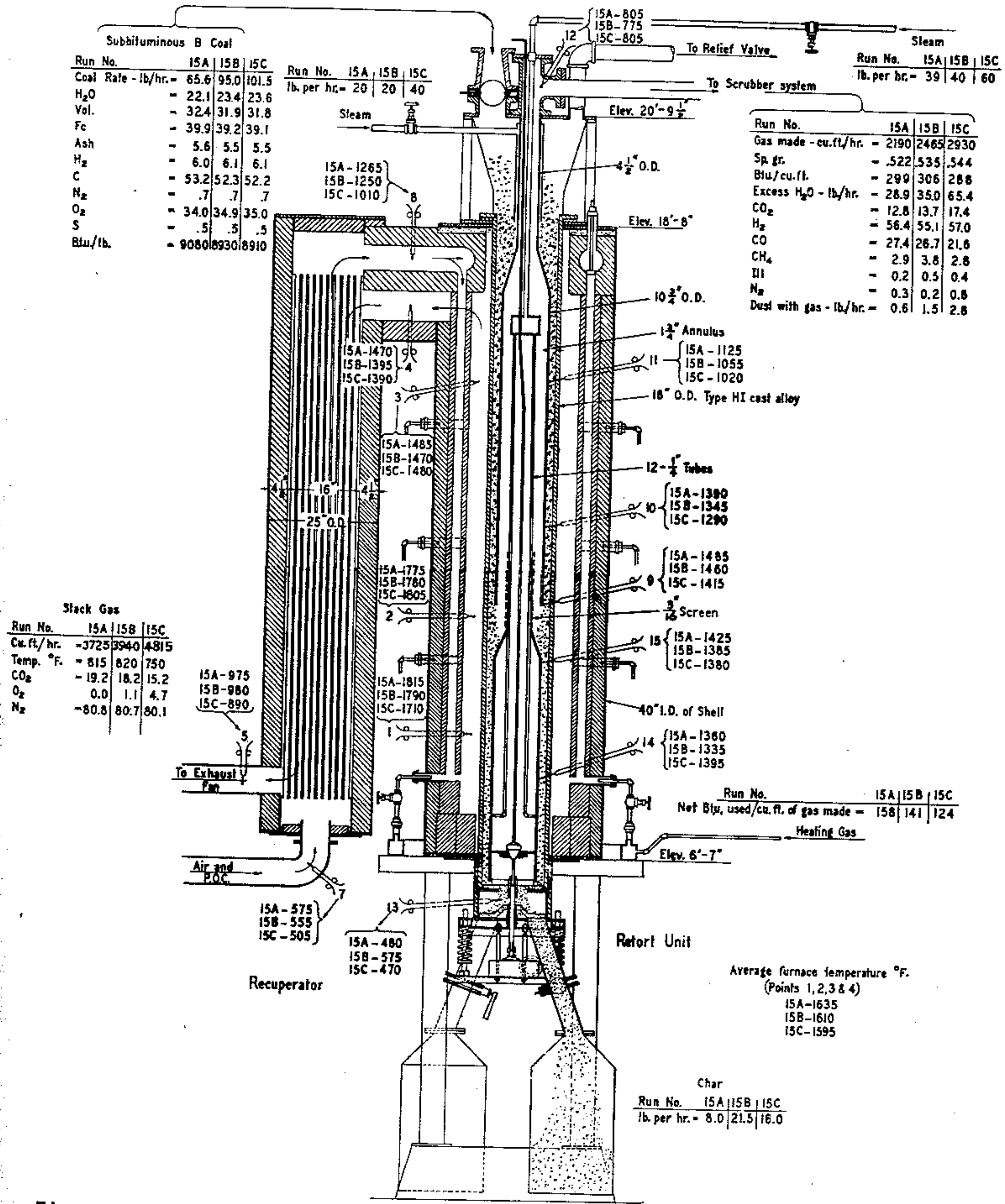

Figure 40. - Arrangement and design of small pilot plant for carbonization and gasification of noncoking coal, Golden, Colo., February 1947.

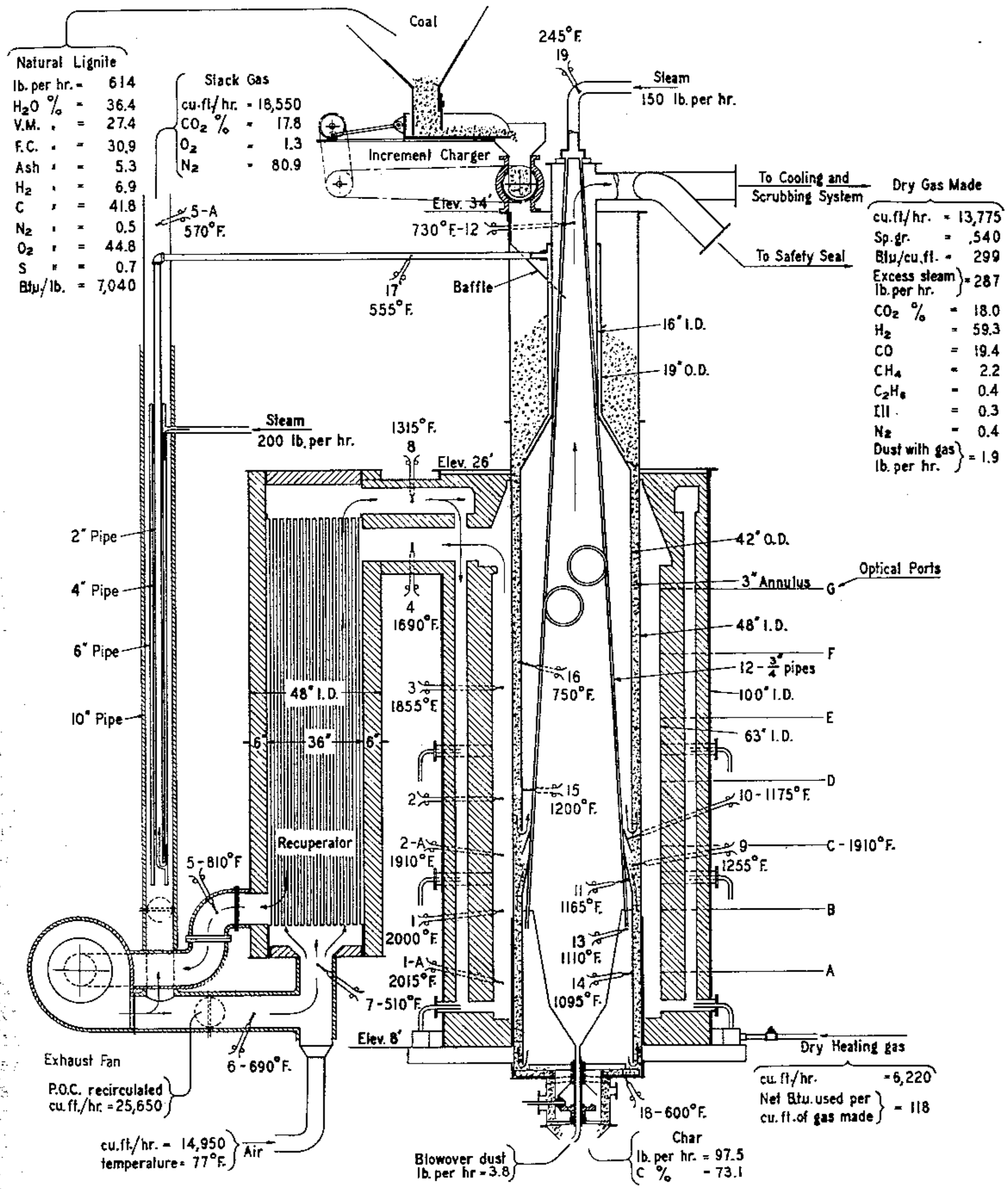

Figure 41. - Arrangement and design of large pilot plant for gasification of lignite, Grand Forks, N. Dak.

The probable mechanism of gasification of lignite and subbituminous coal in the externally heated annular retort varying amounts of steam is illustrated in figures 37 and 38 which show the theoretical balance of materials when 100 pounds of natural coal is passed through the retort while converting 80 percent of the carbon to gas. Coal entering the upper annulus moves downward continually into hotter zones. The products of thermal decomposition (water, tar, gas, and char) form in the upper section and move into the reaction zone, where they combine to form water gas. The char not consumed moves into the lower annulus, where it reacts with steam moving upward toward the common central gas offtake. The various grades of gas illustrated in figure 39 can be made by changing the temperature and steam flow. In order to make gases having low H_2:CO ratios, the concentration of steam must be low and the temperature relatively high. It has been found that annuli 2.0 to 2.5 inches wide require maximum temperatures of 1,850° to 1,900° F. in the combustion zone to make water gases having H_2:CO ratios of 1.9:2.2. Reduced temperatures produce gases having higher H_2:CO ratios.

During the year several coals were gasified in the small pilot plant, and natural lignite was gasified at low temperatures in the large pilot plant. Table 24 summarizes the results of two tests at Golden on subbituminous coal. The heat balance of run 15 in the small pilot plant at Golden is illustrated in figure 40. It should be noted that runs 15A and 15B check quite well with the theoretical data illustrated in figure 38, and that the maximum temperatures developed in the combustion zone are in the range of 1,800° to 1,815° F.

The heat balance obtained during run 4H on the large pilot plant at Grand Forks, when gas having a H_2:CO ratio of 3.29 was made, is illustrated in figure 41. The analysis of the gas from this run is in fair agreement with the theoretical data of figure 39, except that the illuminants and methane are lower. The small pilot plant (shown in fig. 40) has a 1.75-inch annulus, whereas the large pilot plant has a 3-inch annulus. It should be noted that a maximum temperature of 1,815° F. in the combustion zone outside the annulus was required to make a low-H_2:CO ratio gas in the small pilot plant, while a higher temperature was required to make a similar gas in the large plant because of the increased width of the annulus.

A sample of subbituminous A coal from Hyderabad-Deccan, India, was gasified in the small plant with results given in table 25, and the results of low-temperature experimentation on natural lignite in the large plant are given in table 26. The analyses of the coals gasified during the several tests herein reported are given in table 27, and the analyses of the gases made are given in table 28.

TABLE 24. - Summary data on gasification of Colorado subbituminous B coal in the Golden, Colo., pilot plant

RUN AND PERIOD NUMBER	(1)	13-A	13-C	15-A	15-C
Date, September 1946	(2)	10-11	15	11-12	13-14
Duration .... hours	(3)	24	12	24	15
	(4)				
COAL CHARGED .... lb. per hour	(5)	92	93	65.6	101.5
Moisture as charged .... percent	(6)	22.8	22.6	22.1	23.6
Ash as charged .... do.	(7)	5.6	5.6	5.6	5.5
Gasified .... do.	(8)	82.9	80.4	86.0	71.8
Coal per Mcf of gas .... do.	(9)	31.6	32.4	30.0	34.6
	(10)				
DRY RESIDUE .... lb. per hour	(11)	13.6	16.0	8.6	18.8
Char out of bottom	(12)	9.7	13.1	8.0	16.0
Dust with gas	(13)	1.7	1.0	.6	2.8
Ash in total residue .... percent	(14)	25.4	23.1	46.5	20.7
	(15)				
GAS MADE SGC .... Mcf per ton	(16)	63.30	61.60	66.77	57.73
McF per hour	(17)	2.91	2.87	2.19	2.93
B.t.u. per cu. ft. observed, gross	(18)	309	308	299	288
B.t.u. per cu. ft. calculated, net	(19)	278	276	267	257
Specific gravity, calculated	(20)	.523	.522	.522	.544
Ratio H_2:CO	(21)	1.97	2.01	2.06	2.64
	(22)				
STEAM USED .... lb. per hour	(23)				
With coal	(24)	40.6	40.6	20	40
In char zone	(25)	35.2	35.2	39	60
Undecomposed steam .... lb. per Mcf	(26)	9.6	10.5	13.4	22.7
	(27)				
HEATING SYSTEM DATA	(28)				
Net B.t.u. used per cu. ft. gas made ..	(29)	141	141	158	124
Heat released ..... M B.t.u. per cu.ft.	(30)	22.3	22.2	19.0	19.8
Make gas used .... Mcf per hour	(31)	1.47	1.47	1.30	1.41
CO_2 in Poc .... percent	(32)	16.0	16.7	19.2	15.2
Primary air .... Mcf per hour	(33)	3.72	3.74	3.02	4.01
Poc recirculated .... do.	(34)	5.23	5.54	6.34	7.20
	(35)				
TEMPERATURES .... °F.	(36)				
Average combustion chamber	(37)	1,745	1,745	1,635	1,595
Bottom of comb. chamber No. 1	(38)	2,000	1,905	1,815	1,710
Middle of comb. chamber No. 2	(39)	1,895	1,905	1,775	1,805
Top of comb. chamber No. 3	(40)	1,565	1,610	1,485	1,480
Outlet from comb. chamber No. 4	(41)	1,515	1,565	1,470	1,390
Inlet to fan 5	(42)	915	970	975	890
Air and Poc to recuperator 7	(43)	495	530	575	505
Air and Poc to furnace 8	(44)	1,200	1,245	1,265	1,010
Gas leaving retort 12	(45)	845	865	805	805
Stack 5a	(46)	775	820	815	750
Gas junction in furnace	(47)	1,435	1,450	1,485	1,415
Char zone opposite lower burners	(48)	1,315	1,285	1,360	1,395
	(49)				

TABLE 25. - Summary data on gasification of subbituminous A coal from Hyderabad-Deccan, India, in Golden, Colo., pilot plant

RUN AND PERIOD NUMBER	(1)	14-A	14-B	14-C	14-D
Date, September 1946	(2)	16	17	17-18	18
Duration ... hours	(3)	9	12	14	2
	(4)				
COAL CHARGED ... lb. per hour	(5)	39	105	109	200
Moisture as charged ... percent	(6)	11.9	12.0	12.4	12.4
Ash as charged ... do.	(7)	16.3	16.3	16.2	16.2
Gasified ... do.	(8)	86.1	51.4	52.1	34.6
Coal per Mcf of gas ... lb.	(9)	25.8	44.3	45.6	70.9
	(10)				
DRY RESIDUE ... lb. per hour	(11)	9.7	47.6	49.6	111.2
Char out of bottom ...	(12)	8.7	40.7	40.5	83.8
Dust with gas ...	(13)	.1	.4	.4	
Ash in total residue ... percent	(14)	61.5	36.6		
	(15)				
GAS MADE SGC ... Mcf per ton	(16)	77.64	45.05	43.91	28.18
Mcf per hour ...	(17)	1.51	2.37	2.39	2.82
B.t.u. per cu. ft. observed, gross ...	(18)	289	308	305	
B.t.u. per cu. ft. calculated, net ...	(19)	257	275	272	286
Specific gravity, calculated ...	(20)	.504	.509	.509	.514
Ratio H_2:CO ...	(21)	2.36	2.47	2.44	3.17
	(22)				
STEAM USED ... lb. per hour	(23)				
With coal ...	(24)	48.5	64.4	64.4	50.6
In char zone ...	(25)	35.2	50.0	50.0	90.0
Undecomposed steam ... lb. per Mcf	(26)	27.6	25.2		25.5
	(27)				
HEATING-SYSTEM DATA	(28)				
Net B.t.u. used per cu. ft. gas made ..	(29)	204	172	169	169
Heat released .... M B.t.u. per cu. ft.	(30)	16.85	22.24	22.00	26.10
Make gas used ... Mcf per hour	(31)	1.20	1.48	1.48	1.67
CO_2 in Poc ... percent	(32)	15.9	16.0	16.5	15.7
Primary air ... Mcf per hour	(33)	3.11	3.92	3.85	4.53
Poc recirculated ... do.	(34)	6.13	5.64	5.64	4.63
	(35)				
TEMPERATURES ... °F.	(36)				
Average combustion chamber ...	(37)	1,775	1,805	1,810	1,810
Bottom of comb. chamber No. 1 ...	(38)	1,910	2,000	1,995	2,025
Middle of comb. chamber No. 2 ...	(39)	1,915	1,970	1,985	1,965
Top of comb. chamber No. 3 ...	(40)	1,710	1,660	1,675	1,645
Outlet from comb. chamber No. 4 ...	(41)	1,570	1,590	1,585	1,605
Inlet to fan 5 ...	(42)	960	995	970	1,010
Air and Poc to recuperator 7 ...	(43)	575	530	525	465
Air and Poc to furnace 8 ...	(44)	1,230	1,305	1,260	1,330
Gas leaving retort 12 ...	(45)	990	975	985	940
Stack 5a ...	(46)	815	820	825	840
Gas junction in furnace ...	(47)	1,690	1,605	1,605	1,420
Char zone opposite lower burners ...	(48)	1,605	1,535	1,575	1,425
	(49)				

TABLE 26. - Summary data on gasification of Dakota Star Lignite in the Grand Forks, N.Dak., pilot plant

RUN AND PERIOD NUMBER	(1)	5-A	5-B	5-C	5-D
Date, December 1946	(2)	16-18	20-22	23-25	26-27
Duration .... hours	(3)	52.75	45.83	49.25	23.92
	(4)				
COAL CHARGED .... lb. per hour	(5)	380	323	295	380
Moisture as charged .... percent	(6)	37.2	37.6	38.4	37.2
Ash as charged .... do.	(7)	5.7	5.7	5.6	5.7
Gasified .... do.	(8)	55.0	71.5	69.7	56.4
Coal per Mcf of gas .... lb.	(9)	54.8	41.5	41.6	53.0
	(10)				
DRY RESIDUE .... lb. per hour	(11)	71.1	44.3	35.9	72.5
Char out of bottom	(12)	68.5	42.3	31.6	68.8
Blown over at gas offtake	(13)	1.7	1.6	3.9	2.5
Dust with gas	(14)	.9	.4	.4	1.2
Ash in total residue .... percent	(15)	23.7	26.2	30.2	20.6
	(16)				
GAS MADE SGC .... Mcf per ton	(17)	36.53	47.97	48.00	37.68
Mcf per hour	(18)	6.94	7.79	7.09	7.17
B.t.u. per cu. ft. observed, gross	(19)	272	266	257	270
B.t.u. per cu. ft. calculated, net	(20)	236	237	231	238
Specific gravity, calculated	(21)	.541	.542	.545	.549
Ratio H_2:CO	(22)	5.24	7.18	7.00	5.04
	(23)				
STEAM USED .... lb. per hour	(24)				
With coal	(25)	147	243	220	145
In char zone	(26)	235	260	395	245
Undecomposed steam .... lb. per Mcf	(27)	53.6	57.0	76.4	52.5
	(28)				
HEATING-SYSTEM DATA	(29)				
Net B.t.u. used per cu. ft. gas made...	(30)	139	126	144	140
Heat released ..... M B.t.u. per cu.ft.	(31)	8.41	8.55	8.86	8.75
Make gas used .... Mcf per hour	(32)	4.10	4.33	4.42	4.42
CO_2 in Poc .... percent	(33)	17.4			
Primary air .... Mcf per hour	(34)	9.52	9.61	9.73	9.04
Poc recirculated ....do.	(35)	36.97	38.36	38.02	38.49
	(36)				
TEMPERATURES .... °F.	(37)				
Average combustion chamber	(38)	1,500	1,510	1,535	1,535
Bottom of comb. chamber No. 1	(39)	1,775	1,750	1,750	1,770
Middle of comb. chamber No. 2	(40)	1,610	1,620	1,650	1,650
Top of comb. chamber No. 3	(41)	1,375	1,395	1,430	1,420
Outlet from comb. chamber No. 4	(42)	1,250	1,270	1,305	1,300
Inlet to fan 5	(43)	700	690	700	700
Air and Poc to recuperator 7	(44)	520	520	530	540
Air and Poc to furnace 8	(45)	995	1,010	1,030	1,025
Gas leaving retort 12	(46)	600	655	650	605
Stack 5a	(47)	495	480	490	495
Steam to char zone	(48)	250	275		250
Steam with coal	(49)	480	475	485	480
	(50)				

TABLE 27. - Proximate and ultimate analyses of coals used for runs 13, 14 and 15 at Golden, Colo., and for run 5 at Grand Forks, N. Dak.

Description	Run and period	Condition[1]	Pittsburgh lab. No.	Proximate, percent: Moisture	Volatile matter	Fixed carbon	Ash	Ultimate, percent: Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	B.t.u. per pound	Softening temp. ash, °F.
Colorado subbituminous B Caprock mine	13- A and C	1	C-63134	22.1	32.5	39.8	5.6	6.0	53.2	0.7	34.0	0.5	9,150	2,050
		2			41.8	51.0	7.2	4.6	68.3	.9	18.3	.7	11,750	
		3			45.0	55.0		4.9	73.6	.9	19.9	.7	12,660	
Colorado subbituminous B Caprock mine	15- A and C	1	C-69508	21.5	33.8	39.3	5.4	6.0	54.1	.7	33.1	.7	9,250	2,060
		2			43.0	50.1	6.9	4.6	69.0	.9	17.7	.9	11,790	
		3			46.2	53.8		4.9	74.1	1.0	19.1	.9	12,660	
Hyderabad-Deccan, India subbituminous A	14- A, B, C and D	1	C-63135	11.0	27.3	45.2	16.5	4.8	58.5	1.2	18.3	.7	10,020	2,610
		2			30.7	50.7	18.6	4.0	65.7	1.4	9.5	.8	11,260	
		3			37.7	62.3		4.9	80.6	1.7	11.8	1.0	13,820	
North Dakota lignite Dakota Star mine	5- A, B, C and D	1	C-67425	36.2	27.3	30.1	6.4	6.7	41.4	.6	44.2	.7	6,960	2,310
		2			42.7	47.3	10.0	4.2	64.8	1.0	18.8	1.2	10,910	
		3			47.5	52.5		4.6	72.0	1.1	21.0	1.3	12,110	

1/ Condition: (1) As received; (2) moisture-free; (3) moisture- and ash-free.

TABLE 28. - Analyses of gases from Colorado subbituminous B coal, subbituminous A coal from Hyderabad-Deccan, India, and North Dakota lignite[1]

Run and period	Analysis, percent								Specific gravity (air = 1.0)	Gross B.t.u. per cu. ft.	
	CO_2	Ill.[2]	O_2	CO	H_2	CH_4	C_2H_6	N_2	calculated	Obs.	Calc.
13-A	12.2	0.4	0.0	28.2	55.6	3.3	0.0	0.3	0.523	309	307
13-C	12.5	.3	.0	27.8	56.0	3.3	.0	.1	.522	307	307
15-A	12.7	.2	.0	27.3	56.4	2.9	.0	.5	.521	297	300
15-C	17.4	.4	.0	21.6	57.0	2.8	.0	.8	.545	288	287
14-A	13.4	.2	.0	25.1	59.1	1.8	.1	.3	.505	289	292
14-B	13.4	.6	.0	23.8	58.5	3.0	.3	.4	.516	308	310
14-C	13.3	.6	.0	23.9	58.3	3.0	.3	.6	.509	305	309
14-D	15.3	.9	.0	20.9	58.4	4.3	.0	.2	.515		314
5-A	23.6	.2	.0	11.7	61.3	2.4	.6	.2	.541	273	273
5-B	24.8	.2	.0	8.6	61.6	3.2	.6	1.0	.542	266	271
5-C	25.4	.2	.0	8.8	62.0	2.3	.6	.7	.545	257	265
5-D	23.6	.2	.0	12.0	60.1	3.3	.3	.5	.548	270	272

1/ Runs 13-A, 13-C, 15-A and 15-C made on Colorado subbituminous B coal - Golden pilot plant; runs 14-A, 14-B, 14-C and 14-D made on subbituminous A coal from Hyderabad-Deccan, India - Golden pilot plant; runs 5-A, 5-B, 5-C and 5-D made on North Dakota lignite - Grand Forks pilot plant.

2/ Illuminants as $C_{2.8}H_{5.6}$.

The development of the annular retort had required many changes in the pilot plants to find the best arrangement of the reaction zone and to determine the optimum width of the annulus. Much of this work has been done with mild-steel retorts because it was necessary to make changes to study new conditions. It is now indicated that the best arrangement of the retort assembly for the large plant is that illustrated in figure 42, which incorporates suitable alloy parts throughout. Materials to fabricate this assembly were ordered during 1947 and will be installed and tested during 1948. A cast-alloy retort having a 3/4-inch wall thickness and a composition of 25 percent chromium and 20 percent nickel has been procured for testing. The inner retort parts will be made of type 430 alloy having about 17 percent chromium, and the recuperator will be fabricated from type 309 alloy containing 25 percent chromium and 12 percent nickel.

During the year it was demonstrated in the small pilot plant that heating the retort to a maximum temperature of 1,900° F. resulted in a heat transfer of approximately 6,000 B.t.u. per hour per square foot and a production of 60 cubic feet of ($CO + H_2$) per hour per square foot. This important demonstration clearly indicates that the cost of the alloy for 10,000 hours of service will be about 1 cent per thousand cubic feet of ($CO + H_2$) or approximately one-fourth the cost of oxygen required to make the same quantity of gas.

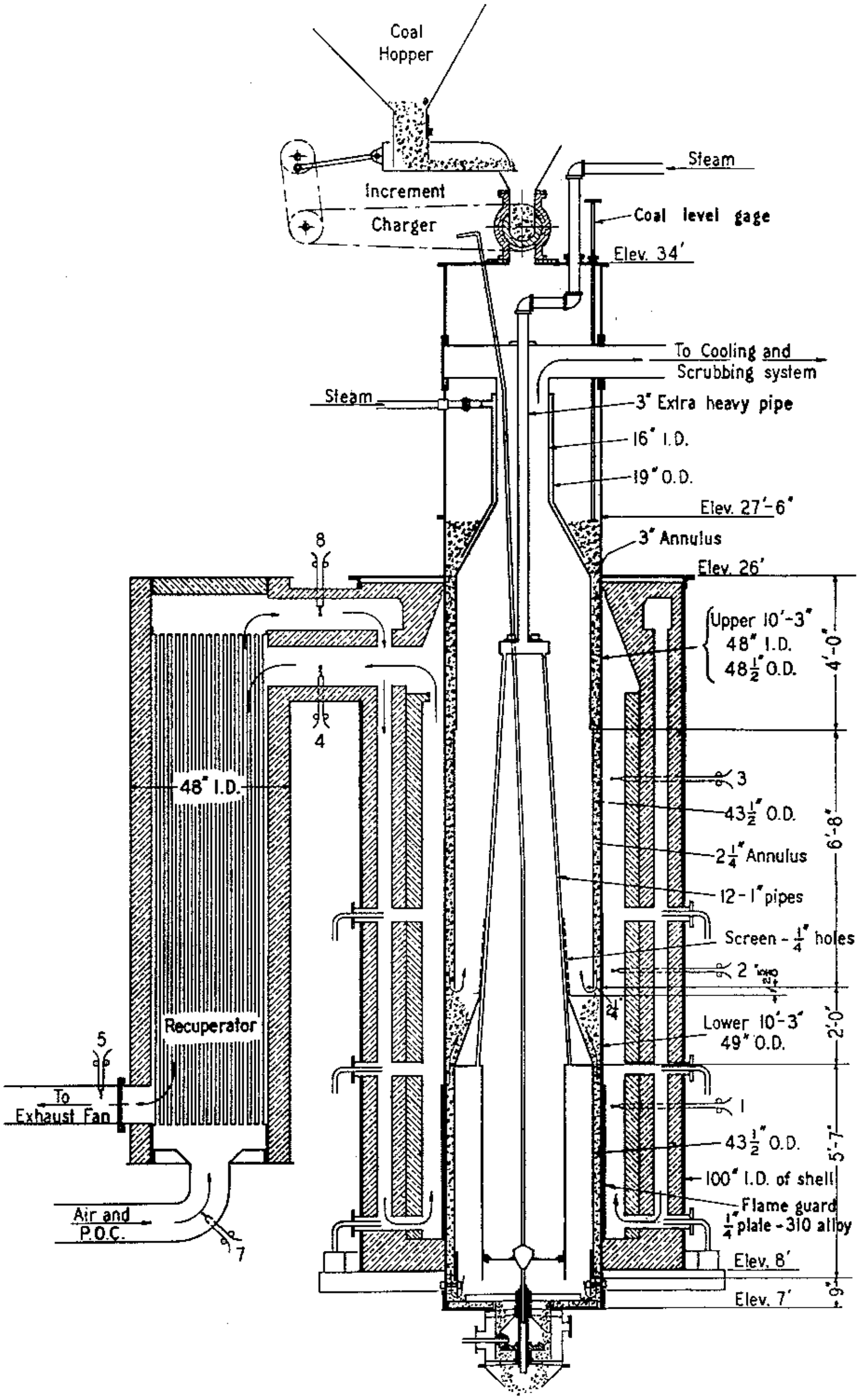

Figure 42. - Proposed arrangement of retort assembly for Grand Forks, N. Dak., pilot plant.