Purified gas made per square foot of equivalent grate area (area internal horizontal section), dry gas basis	cu.ft. per hr.	1,450
Purified gas yield per 2,000 pounds of coal:		
Saturated at 60° F. and 30 inches mercury pressure	cu.ft.	21,750
Dry gas at 60° F. and 30 inches mercury pressure	do.	21,370
Tar yield per short ton of coal	lb.	112.2
Tar yield per short ton of coal	U. S. gal.	14.0
Tar yield per 1,000 cubic feet of purified gas dry basis	do.	0.655
Benzine (light oil) yield per short ton of coal	lb.	48.4
Benzine (light oil) yield per short ton of coal	U. S. gal.	6.9
Benzine (light oil) yield per 1,000 cubic feet of purified gas, dry basis	gal.	0.323

Although the generators were operated at a mean hourly production of 1,450 cubic feet of gas per hour per square foot of equivalent grate area, the rated capacity is said to be 1,812 cubic feet per hour.

Capacity of the Lurgi generator and standard water-gas sets compared

The capacity of the gas-generating plant at Böhlen is approximately 5,670 million cubic feet of city gas per year. The plant comprises 10 generators, 5 of which were built in 1940 and 5 in 1944. The newer ones are improved as to the charging hopper, ash reservoir, grate-driving mechanism, and carbon scrapers. Although each generator is said to have a rated capacity of 111,600 cubic feet of purified gas per hour, they are actually producing 94,500 cubic feet per hour when operating at apparent capacity. It is also noted that thus far a generator could be operated 250 consecutive days, which included "time out" for 30 miscellaneous shut-downs totaling 90 hours. The total time lost for major and minor repairs is approximately 2,000 hours per year. It was stated by German engineers that some of the loss of time due to shut-down was occasioned by the war and use of slave labor. Accordingly, estimates based upon the actual capacity to produce gas must take into consideration necessary shut-down time. The dry purified gas has a calorific value of 438 B.t.u. per cubic foot, as shown above; hence, true capacity comparison can best be made upon the basis of a chosen standard calorific value. Such a comparison is made in table 1.

The values used in making this comparison are not the possible maximum but represent results attainable in good gas-works practice. The table shows that on the therm basis the Lurgi process, making gas at 20 atmospheres pressure, is comparable, as to daily capacity, with a standard water-gas generator of the same inside diameter. The capacities given in columns (5) and (2) of the table are not strictly comparable, because in a carbureted water-gas set not all the gas is made in the generator. However, because one of the unique features of the Lurgi process is the possibility of producing city gas without the use of oil for enrichment, it is interesting to make the comparison. In the carbureted gas shown in column (2), approximately 3.3 gallons of gas oil are consumed in the carbureting step per 1,000 cubic feet of finished gas, and in making a carbureted water gas of 483 B.t.u. per cubic foot, the oil required would be 2.2 gallons. Thus, the possibility exists of reducing the enricher-oil requirements by the latter amount in making city gas.

TABLE 1. - Composition of water gas and Lurgi pressure gas and the comparative production capacity[a] of the respective generators

	Ordinary water gas	Carbureted water gas	Lurgi high-pressure gas (20 atmospheres pressure)			
	Coke fuel	Coke fuel	Raw gas	Purified gas	Purified gas, CO_2-free	Purified gas at rated generator capacity
Percent:						
$CO_2 + H_2S$	5.5	4.4	33.7	9.1	0.0	9.1
Illuminants	.2	10.0	.7	.6	.7	.6
O_2	.0	.0	.2	.2	.2	.2
CO	40.0	32.0	12.1	16.7	18.4	16.7
H_2	50.0	35.0	37.5	52.3	57.5	52.3
CH_4	.8	14.8	14.5	20.0	22.0	20.0
N_2	3.5	3.8	1.3	1.1	1.2	1.1
	100.0	100.0	100.0	100.0	100.0	100.0
B.t.u.[b] dry gas	303	570	333	438	483	438
Mean hourly capacity[a]:						
Cubic feet per square foot of equivalent grate area	2,290	2,890	2,100	1,532	1,392	1,810
Therms per square foot of equivalent grate area	6.96	16.45	-	6.73	6.73	7.93

a/ The above capacities are based upon results attainable with generators having an internal diameter of approximately 9 feet; that of the Lurgi generator is 8.85 feet.

b/ B.t.u. per cubic foot, high value 60° F., 30 inches Hg.

Note-Since the initial preparation of this publication, Dr. Hubmann has advised the Bureau of Mines that it is his recollection that results of tests made at Brüx (Most), Czechoslovakia, indicated a much higher production per hour per square foot of equivalent grate area than the 7.93 therms given in column 6 above.

At first it may seem inconsistent that the gas-making capacity of the Lurgi generator, making gas continuously as described, is not appreciably greater than that of a modern water-gas set; the elimination of the cyclic system common to water-gas practice and the use of pressure both favor the Lurgi process. The use of fine coal, the high moisture content of the coal heretofore used; and the thinness of the hot zone (reaction zone of the fuel bed), all tend to influence capacity adversely. The rate at which the gas reactions occur at the relatively low temperatures that usually prevail in most of the fuel bed (below 1,800° F.) in the Lurgi process are not compatible with high rates of flow through the fuel bed. If higher temperatures are employed, conditions are less favorable for the production of CH_4, and more O_2 is required per 1,000 cubic feet of gas made.

Braunkohle Used in Germany

In certain sections of Germany, a technique for making gas has developed that is radically different from that employed in this country, largely for two reasons, viz., (a) the coals available are much like lignite and therefore are ill-suited for use in the ordinary water-gas generator; and (b) the lack of ample supply of petroleum makes it highly desirable that the oil and tar content of their coal be recovered, either before its use in making gas or in the gasification steps.

It was necessary to use a coal, initially containing up to 50 percent of moisture, which does not form coke but which slacks upon being heated. Advantage was taken of the property which the low-grade lignitic fuels have of being more reactive than the higher-grade coals. Thus, the Lurgi process was developed to use a particular fuel under a prescribed set of conditions. A representative composition of the German Braunkohle (brown coal) is as follows:

	As mined	Partly dried	Dry
Moisture.....percent	52.0	10.0	0.0
Volatile matter Fixed carbon...do.	42.1	79.0	87.8
Ash.....do.	5.9	11.0	12.2
	100.0	100.0	100.0
Calorific value.....B.t.u. per lb.	5,120	9,600	10,660
Ash-softening temperature.....°F.	1832	to	2012...
Total sulfur.....percent	1.81	3.4	3.78
Combustible sulfur.....do.	1.06	2.0	2.22
Sulfur in ash.....do.	.75	1.4	1.56
Tar (by Fischer assay).....do.	6.93	13.0	14.44

To recover as much tar and oil as possible in gasifying the above, it was found to be desirable to remove the gas from the fuel bed at a relatively low temperature (approximately 300° C.), and this can best be accomplished when the fuel charged into the generator contains an appreciable amount of moisture. Coal containing 18 to 25 percent of moisture is preferred to dry coal when gasification is carried on in the Lurgi generator.

Other Reported Data on the Lurgi Gas-making Process

Although other lines of research were directed to high-temperature gasification of coal, even to the slagging-type producer, the Lurgi process was developed along a different line, i.e., gasification at relatively low temperatures was of most concern. The difficulties experienced in the early stages of experiments to make gas with oxygen were largely due to excessively high temperatures and resultant clinker troubles. It was evident that the amount of oxygen used per unit volume of gas made must be reduced to a minimum, even though it was anticipated that the cost of oxygen would be lowered in due time. Furthermore, the low ash-softening temperature of the available coals also dictated operations should be conducted at low temperatures. Two other important factors appear to have been uppermost in the minds of those responsible for the development of the Lurgi process, namely, the conservation and

production of oil. In that process, not only were oil and tar recovered, but when operating at about 20 atmospheres pressure the methane formed was sufficient so that the purified gas could be used as city gas without enrichment. Still another important factor is the difference in volumetric ratio of H_2 to CO in the gas made at low temperatures; the latter temperatures favor a higher H_2 to CO ratio and the production of more CO_2. A gas with a high H_2 to CO ratio is desirable for the synthesis of certain liquid fuels:

Experiments with brown coal containing 18 percent of moisture, using 110 cubic feet of O_2 per 1,000 cubic feet of dry, crude gas made, gave results reported as follows:

Gasification at moderate pressure below 10 atmospheres of a lignitic coal of low tar content:

		Raw gas	CO_2-free gas
CO_2	percent	28.0	0.0
CO	do.	16.0	22.2
H_2	do.	50.0	69.4
CH_4	do.	3.0	4.2
N_2	do.	3.0	4.2
		100.0	100.0
O_2 used per 1,000 cubic feet of gas made	cu.ft.	110	153
B.t.u. per cubic foot of dry gas at 60° F., and 30 inches of Hg., calculated		244.5	340.0
B.t.u. per cubic foot of saturated gas at 60° F., and 30 inches of Hg., calculated		240.2	334.0

It was estimated that the oxygen, costing 2 Pf. per cubic meter (22.6 cents per 1,000 cubic feet), increased the cost of the CO_2-free gas by 3.3 cents per 1,000 cubic feet.

The influence of pressure on the composition of gas made in a Lurgi generator has been discussed, but the data of table 2 are presented to show the compositions of gases, raw and CO_2-free, made at low temperatures when equilibrium conditions prevail.

TABLE 2. - Gasification of carbon at different pressures at 1,340° F. (theoretical values).

Gasifying pressure	1 atmos.	10 atmos.	20 atmos.
Composition of raw gas, volume percent:			
CO_2	11.3	27.5	31.8
CO	49.0	25.8	20.2
H_2	37.0	30.4	25.8
CH_4	2.7	16.3	22.2
	100.0	100.0	100.0
Composition of CO_2-free gas, volume percent:			
CO_2	0.0	0.0	0.0
CO	55.2	35.6	29.7
H_2	41.7	42.0	37.8
CH_4	3.1	22.4	32.5
	100.0	100.0	100.0
High calorific value of the dry raw gas at 60° F. ....B.t.u. per cu.ft.	308	348	375
High calorific value of the dry CO_2-free gas at 60° F. ....do.	347	480	550
O_2 used per 1,000 cubic feet of dry CO_2-free gas....cu.ft.	164	124	102

Actual tests made on a moderate scale for a number of different fuels gave results as shown in table 3:

TABLE 3. - Results obtained in a small generator with an internal sectional area of approximately 10.765 square feet and using different fuels[a]

Fuel used	Semi-coke (breeze)[b]		Anthracite, 6% vol.[c]	Brown coal (Saxony)[d]		Brown coal[e]
Test number	1	2	3	4	5	6
Absolute pressure.....atmospheres	1	18	26	26	30	26
Fuel charged per square foot sectional area per hour.....lb.	22.5	20.5	72.8	106.6	104.5	94.3
Raw gas composition:						
CO_2 H_2S.....percent	25.5	35.2	35.2	31.9	38.2	32.1
Illuminants.....do.	.2	.3	.3	.6	.9	.4
O_2.....do.	.1	.2	.2	.3	.1	.2
CO.....do.	21.0	17.0	9.7	17.2	10.9	15.5
H_2.....do.	51.4	34.0	43.1	36.3	37.2	39.0
CH_4.....do.	1.8	13.3	11.5	13.7	12.7	12.8
	100.0	100.0	100.0	100.0	100.0	100.0
Scrubbed gas composition:						
CO_2 H_2S.....percent	3.0	3.0	3.0	3.0	3.0	3.0
Illuminants.....do.	.3	.4	.4	.8	1.3	.6
O_2.....do.	.1	.3	.1	.4	.2	.3
CO.....do.	27.3	25.6	14.5	24.5	17.4	22.1
H_2.....do.	66.9	50.9	64.7	51.8	58.2	55.7
CH_4.....do.	2.4	19.8	17.3	19.5	19.9	18.3
	100.0	100.0	100.0	100.0	100.0	100.0
Calculated heating value of the scrubbed dry gas, 60° F., 30 inches Hg., ...B.t.u. per cu.ft.	336	457	441	461	473	450

a/ Results according to the German engineer, Otto Hubmann.
b/ Tests 1 and 2 were made with "Grudekoks," which is carbonized brown coal.
c/ Test 3 was made with a noncoking coal of higher rank than brown coal.
d/ Tests 4 and 5 employed Saxony brown coal.
e/ Test 6 was with German brown coal.

These tests indicated that using a dust-free coal, size 0.12- to 0.31-inch, moderately high gas-making rates could be obtained at 20 or more atmospheres pressure, and that the drop in pressure through the fuel bed was not high, being of the order of 2 inches of water with a bed 9 feet deep.

Results obtained under test conditions on the small generator having an internal diameter of approximately 4 feet, which are said to be "average results", are as follows:

Fuel used, dried and screened brown coal.

Distillation (carbonization) yields:	
Tar.....weight percent	10.2
Water of distillation.....do.	7.4
Water (moisture in coal).....do.	27.4
Coke (char).....do.	44.9
Gas and remainder.....do.	10.1
	100.0

Proximate analysis of coal:

Moisture	percent	27.4
Volatile, plus fixed carbon	do.	67.5
Ash	do.	5.1
		100.0

Elementary analysis of coal:

Carbon	percent	49.0
Hydrogen	do.	3.4
Sulfur (combustible)	do.	0.7
Oxygen and nitrogen	do.	14.4
Ash	do.	5.1
Moisture	do.	27.4
		100.0

Screen analysis (converted from original data, which was given in metric units):

Size		
Through 0.315-inch on 0.197-inch	percent	39.2
Through 0.197-inch on 0.079-inch	do.	56.8
Through 0.079-inch on 0.039-inch	do.	2.5
Through 0.039-inch on 0.020-inch	do.	0.7
Through 0.020-inch	do.	0.8
		100.0

Calorific value of the coal:		
High value	B.t.u. per lb.	8530
Low value	do.	7910
Coal gasified per 24 hours	lb.	47,390
Coal gasified per hour per square foot of internal sectional area of the generator	lb.	183

Composition of gas made:

		Raw gas	Scrubbed gas
$CO_2 + H_2S$	volume percent	30.6	3.0
Illuminants	do.	0.6	0.7
Oxygen	do.	.1	.1
Carbon monoxide	do.	16.5	23.1
Hydrogen	do.	34.0	47.7
Methane	do.	16.3	22.8
Nitrogen	do.	1.9	2.6
		100.0	100.0

Calorific value, dry gas at 60° F. and 30 inches mercury	B.t.u. per cu.ft.	351 / 474
Specific gravity, dry gas		0.765 / 0.463
Hydrogen sulfide, grains per 100 cubic feet		287 / 0.0
Ammonia, per 100 cubic feet scrubbed gas produced	grains	0.0074
Oxygen used per 1,000 cubic feet of dry scrubbed gas made	cu.ft.	150
Steam used per 1,000 cubic feet of dry scrubbed gas made	lb.	60

Tar recovered - 72 percent of the total tar content of the coal.

A reported heat balance in gasifying brown coal in the test generator is shown as follows:

Heat balance of pressure gas operation of a small test generator using screened, partly dried, brown coal containing 27 percent moisture

	Percent
Input:	
Heat in the coal	89.9
Heat in the steam	10.1
	100.0
Out:	
Heat of combustion of the scrubbed gas	62.2
Heat of combustion of the tar and benzine	14.3
Combustible matter with the ash	0.4
Phenol in the wash waters	0.9
Steam produced in water jacket	0.6
Sensible heat of the gases and heat lost	16.2
Heat lost in steam superheater ventilation lines	5.4
	100.0

Heat of combustion of the gas, tar, and oil represents 76.5 percent of the heat input as coal and steam. Although the tests were made under conditions not readily obtainable in average plant operation, the results are presented to indicate that under favorable conditions high conversion efficiency may be obtained.

Subsequent to the experiments of Dr. Otto Hubmann in Germany, Dr. Friedrich Danulat of Frankfurt, a representative of the Lurgi Co., reported on the pressure gasification of coal in a Lurgi generator at a time when first-hand data on full-scale operations were available to him; some of the data reported by the latter are presented as follows:

Operations with various coals at 20 atmospheres absolute pressure:

Fuel	Brown coal (Lausitz)	Brown coal (middle Germany)	Hard coal (noncoking coal from the Ruhr)
Composition:			
Moisture, weight percent	27.4	16.9	6.6
Volatile and fixed carbon, do.	67.5	72.5	88.4
Ash, do.	5.1	10.6	5.0
	100.0	100.0	100.0
Tar content, percent by weight	10.2	14.8	0.0
Calorific value, high value, B.t.u. per lb.	8520	9060	13,680
Size, inches	0.08-0.39	0.08-0.39	0.12-0.39
Composition scrubbed, purified gas:			
CO_2, volume percent	3.0	2.3	1.0
Illuminants, do.	0.5	0.9	0.3
O_2, do.	0.1	0.2	0.0
CO, do.	22.8	22.0	27.9
H_2, do.	48.7	50.7	52.4
CH_4, do.	22.6	21.8	16.9
N_2, do.	2.3	2.1	1.5
	100.0	100.0	100.0