ashes of many fuels soften at 1,900° to 2,100° F. (1,038° to 1,149° C.), and in this range problems arise. The duration of contact of the gas-making fluids is very short at the necessary high rates of flow, and there is the natural tendency for steam to pass through the fuel bed unreacted, and for the CO_2 content of the gas to be excessively high when relatively low temperatures prevail.

(c) Reactivity of the fuel. - In the use of fuels having low ash-softening temperatures, it is desirable that they be reactive in order to promote suitably complete gas reactions. Brown coal, lignite, and subbituminous coals, or, rather, the char resulting from heating them, are highly reactive and therefore suited for use in a Winkler generator. The author believes that serious difficulties may be experienced in using fuels of low ash-softening temperatures that are not very reactive at the lower temperatures, such as a high consumption but low conversion of steam per unit of gas made, poor quality of the gas made, and a high content of carbon in the ash. Progress in the development of this process may alter these conditions; definite and accurate limitations cannot be made at this time because of lack of complete information based upon experience.

(d) Tar content of the fuel. - In a somewhat minor degree, the tar content of the fuel fed to the generator affects results. The fuel in the feeding mechanism becomes heated appreciably before it is discharged into the generator, and hence if considerable amounts of tar are evolved by such preheating, clogging may occur, or resistance to flow may be so great that extra power will be required to propel the charge into the generator.

When a finely divided coal that evolves tar upon being heated is used as generator fuel, there will be a tendency for agglomeration of the particles as the tar is expelled; and it will be difficult to obtain uniform or satisfactory results. Little information is available on this phase of the subject at present.

Some Results of Operation of the Winkler Process

The results given below are based upon operations, as reported, at Zeitz, Germany. The plant is basically a hydrogenation plant, the raw gas being made in Winkler generators. There were three generators, one of which was used as a spare. The inside diameter of each generator was 8.2 feet. The grates comprised fire brick placed on edge but spaced apart 1/8 to 3/8 inch. A water-cooled scraper arm just above the grate rotated slowly during the operation. The depth of the fluidized fuel was 3.3 to 4.9 feet. Oxygen and steam were admitted above the fuel bed as well as beneath it. The internal diameter of each generator in the widest portion above the grate was 8.2 feet; the section area was 52.8 square feet.

Fuel used ....Carbonized brown coal known as "Grudekoks."	
Size of fuel fed to generator ....inches	0.12-0.16
Generator fuel used per day ....short tons	650.2
Composition of the "Grudekoks":	
Carbon ....weight percent	62.0
Hydrogen ....do.	2.0
Sulfur ....do.	5.8
O_2, N_2, and ash ....do.	30.2
	100.0
Softening temperature of the ash ....° C.	1,000-1,100
Calorific value ....B.t.u. per pound	10,190
Raw gas made daily with two generators, dry at 60° F., and 30 inches Hg ....cubic feet	27,656,000
Raw gas made daily with two generators, saturated at 60° F., and 30 inches Hg ....do.	28,145,000
Generator fuel used per 1,000 cubic feet of raw dry gas ....pounds	47.04
Generator fuel used per 1,000 cubic feet of raw saturated gas ....do.	46.15
Steam used per day at 2.5 atmospheres pressure:	
To two generators (process) ....short tons	402.3
Total ....do.	483.8
Total per 1,000 cubic feet of dry gas at 60° F., and 30 inches Hg ....pounds	35.0
Total per 1,000 cubic feet of gas saturated at 60° F., and 30 inches Hg ....do.	34.4
Generated, per 1,000 cubic feet of dry gas at 60° F., and 30 inches Hg ....do.	42.5
Oxygen used (basis pure O_2):	
Daily supply to two generators, dry at 60° F., and 30 inches Hg ....cubic feet	6,721,000
Dry O_2 per 1,000 cubic feet of raw dry gas made...do.	243
Composition of raw gas:	
$CO_2 + H_2S$ a/ ....percent by volume	24.4
CO ....do.	29.1
H_2 ....do.	44.2
CH_4 ....do.	0.7
N_2 ....do.	1.6
	100.0
Calculated high heating value, dry at 60° F., 30 inches Hg ....B.t.u. per cubic foot	252
Calculated high heating value, saturated at 60° F., 30 inches Hg ....do.	248
Total dust removed from the gas by the dust separators per day ....short tons	299.2
(About 80 to 85 percent of this dust was removed in the multiclone separators)	

a/ The H_2S content was 1.3 percent, leaving 23.1 percent of CO_2.

Composition of the dust:		
Carbon	percent by weight	54.01
Hydrogen	do.	0.89
Ash	do.	45.10
		100.00
Calculated calorific value	B.t.u. per pound	8,200
Composition of the ash collected at base of generator:		
Carbon	percent by weight	25.8
Hydrogen	do.	0.0
Residue	do.	74.2
		100.0
Calculated calorific value	B.t.u. per pound	3,650
Total carbon (combined) in the gas as CO_2, CO, and CH_4, per 1,000 cubic feet of dry gas, computed	pounds	16.80
Actual carbon in the fuel used per 1,000 cubic feet of dry gas, according to the fuel analysis	do.	29.16
Carbon in the dust, per 1,000 cubic feet dry gas	pounds	11.70
Carbon in ash and not accounted for above	do.	0.66
Steam generated (per 1,000 cubic feet of dry gas) at 18 atmospheres pressure	do.	42.5

Calculations based upon the above data but computed with reference to the dry gas free from CO_2 and H_2S, herein designated as "rich gas":

Rich gas composition:		
CO_2	percent by volume	0.0
CO	do.	38.5
H_2	do.	58.5
CH_4	do.	0.9
N_2	do.	2.1
		100.0
Specific gravity		0.438
Calorific value of the dry rich gas	B.t.u. per cubic foot	324
Rich gas made per day (equivalent)	cubic feet	20,908,000
Materials used and yields per 1,000 cubic feet of dry rich gas as above:		
Process steam	pounds	38.7
Other steam	do.	7.8
Total steam	do.	46.5
Generator fuel	do.	62.2
Oxygen (basis pure dry O_2)	cubic feet	321
Steam generated at 18 atmospheres pressure	pounds	56.2
Rich gas (324 B.t.u.) made per square foot of sectional area of generator per hour, dry gas basis	cubic feet	8,250

Miscellaneous Notes on Operation at Zeitz

Of the total O_2 and steam supplied to the generator, 90 percent of each was introduced beneath the grate, and the remainder was introduced 6.5 feet above the fuel bed. Although it was stated that the generators were not operated at capacity because it was found that erosion occurred in the waste-heat boiler at maximum capacity, and hence lower linear velocities were maintained in the gas stream passing through the heat exchanger to protect it,

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it is noted that the blown-over fuel, called dust, is a rather high percentage of the total fuel used, hence for all practical purposes it appears that the production given above is close to maximum rate of make. Sufficient information is not available at this time to make a more positive statement as to capacity. The limits of capacity reported are: Minimum 335,000 and maximum 744,000 cubic feet of dry gas per hour measured at 60° F. and 30 inches of mercury pressure. The latter figures correspond to 6,340 to 14,050 cubic feet of gas per hour per square foot of generator sectional area.

The gas from the generators passes through waste heat boilers, dust separators, coolers, and water scrubbers. Gas entering the dust separators is said to contain 17.8 pounds of dust per 1,000 cubic feet of gas; leaving the separators it contains 3.56 pounds; at the outlet of the cooler-scrubbers it contains 1.9 avoirdupois ounces; and at the outlet of the Thiesen scrubbers the dust content of the gas is 1.2 to 1.6 grains per 1,000 cubic feet. The water used for scrubbing the gas absorbs considerable H_2S and CO_2, and these gases are expelled by air blowing before the water is conducted to a settling pond.

The dust collected, which is approximately half carbon, is used as powdered coal for steam generation. This is done usually without grinding, although extra pulverization was practiced for awhile. Dust particles recovered for fuel use are 0.1 to 0.5 mm. (0.004 to 0.020 inch) in size and are adaptable for use as powdered fuel in spite of the high ash content, largely because they are very reactive; this applies to the dust made when gasifying such fuel as "Grudekoks," as described above. Besides the dust carried overhead in the gas, there is approximately 1.89 pounds of ash, removed in a fine granular form, per 1,000 cubic feet of dry raw gas made.

Operation of Winkler Process at Leuna, Germany

At the chemical plant (Merceberg Ammoniakwerke) at Leuna, there were five Winkler generators - four large and one small one. Considerable development work was done at Leuna on this process. The generators, initially designed for gasification with mixtures of air and steam, were subsequently used with mixtures of O_2 and steam, substantially as described in the foregoing.

The large generators had an internal diameter of approximately 18.0 feet and corresponding sectional area of 255 square feet and a rated hourly capacity of approximately 2,676,000 cubic feet of raw dry gas measured at 60° F. and 30 inches of mercury pressure. This is equivalent to 10,494 cubic feet of gas per square foot of sectional area per hour. The small generator had an internal sectional area and capacity half that of the large generators. These generators were operated in much the same manner as the generators at Zeitz. The steam-oxygen mixture introduced below the grate was 40 to 50 percent O_2 and 60 to 50 percent steam (percent by volume), whereas at a level 10 feet above the grate an O_2-steam mixture was introduced comprising 80 percent O_2 and 20 percent steam. This is different from the procedure at Zeitz. The linear velocity of the gases in the generator was said to be approximately 9.84 feet per second at the prevailing temperature. Another figure relating to the limits of generator capacity was given as 3,100 to 9,315 cubic feet per hour per square foot of sectional area, the gas volumes being corrected to 60° F. dry at 30 inches of mercury.

An example of operating results obtained with the small generator is as follows:

Raw gas made per hour, dry and at 60° F., 30 inches Hg. ....cubic feet	1,338,000
Fuel used..........carbonized brown coal.	
Size of the fuel chiefly used..........inches (but ranging from 0.118 to 0.394 inches)	0.197
Gas made per square foot of internal sectional area of generator, dry gas at 60° F. 30 inches Hg..........cubic feet	10,500
Composition of the raw gas:	
CO_2..........percent by volume	20.0
CO..........do.	38.0
H_2..........do.	40.0
CH_4..........do.	1.5
N_2..........do.	0.5
	100.0
Calculated high heating value dry gas, 60° F. and 30 inches Hg..........B.t.u. per cubic foot	268
Calculated high heating value saturated gas, 60° F. and 30 inches Hg..........do.	263
Specific gravity dry raw gas..........	0.714
Drop in pressure through 1 meter (39 inches) depth of fluidized fuel in generator..........inches of water	19.5
O_2 used (pure dry O_2) per 1,000 cubic feet of dry raw gas..........cubic feet	250
Total steam used per 1,000 cubic feet of dry raw gas..........pounds	19
Temperature in fluidized bed of solid fuel..........° F.	1652
Temperature in zone above fuel bed..........° F.	2012
Coal used per 1,000 cubic feet of dry gas made, measured at 60° F. and 30 inches Hg..........pounds	33

Variation in composition of gas with variations in steam-oxygen ratio and other factors:

CO_2..........percent	20.0	to	25.0
CO..........do.	38.0	to	28.0
H_2..........do.	40.0	to	44.5
CH_4..........do.	1.5	to	2.0
N_2..........do.	0.5	to	0.5
	100.0		100.0

Total O_2 used ranged from 240 to 300 cubic feet per 1,000 cubic feet of raw gas made.

Total O_2 used per 1,000 cubic feet of CO_2-free gas was 320 to 375 cubic feet.

Notes on the Use of Air Instead of Oxygen in Making Gas in a Winkler Generator

The Winkler generator was initially designed for use with air and steam in making producer gas and was in operation for that purpose until rather recently, making power gas in Germany. When the results making the latter gas are compared with those using O_2, the difference is at first somewhat surprising. The calorific value of the raw producer gas is about 45 percent of the value of the raw gas made using O_2, and the volume made per unit of time using air is 40 percent of that made with O_2. Thus, the thermal output per hour is $\frac{40 \times 45}{100}$, or 18 percent of that made with O_2. In other words, the use of O_2 increases the output of heat energy as combustible gas 5.5-fold. The composition of the producer gas made by blasting with air, along with the required steam, is or may be much the same as ordinary producer gas, although there is a tendency for the CO_2 content to be high and the H_2 low. As in the instances described above, the reactivity of the fuel used has important bearing on the results attained.

It is noteworthy that the Winkler process is used with satisfaction in Germany in making gas for the hydrogenation of tar and for generating power gas for use in internal-combustion engines. Although the process has not yet been developed to the stage wherein all types of solid fuel can be used, it definitely can be used with the reactive solid fuels that are available in the United States.

In figure 8 are shown comparatively the costs of gas-making materials for the Winkler and water-gas processes. The line representing costs for the Winkler process is based upon gas having the same calorific value as water gas, namely, 300 B.t.u. per cubic foot. In this comparison no credit is allowed for the blown-over fuel in making calculations of costs of materials used in generating Winkler gas. With allowance for such a credit, the cost line for the latter gas would be more favorably located in figure 8. The net amount of steam consumed in making water gas is considered to be 50 pounds per 1,000 cubic feet of gas, and this includes the steam for generating gas and for operating air blowers when waste heat economizers are employed. In certain sections of the country where carbonized fuel suitable for use in a Winkler gas generator conceivably might be obtainable at $2.50 per ton, good coke for generating water gas is not obtainable at present at $6 per ton. Under such conditions, other factors remaining the same, there would be a marked saving in making synthesis gas in a Winkler instead of a water-gas generator when the cost of oxygen is 10 cents per 1,000 cubic feet.

THE SLAGGING-TYPE GAS PRODUCER

In times past, various engineers engaged in the manufacture of combustible gas in this county have expressed interest in the production of gas in a slagging-type gas producer. Experimental work in this field is costly and perhaps this is one reason why it has been limited. Considerable work was done on a large scale at the ammonia works at Leuna. There were six generators of this type in the latter plant, one was known as a "Pintsch generator" and the others were built by the "I.G." and were thus designated. A sectional drawing of one of the latter is shown in figure 9.

In the initial attempts to gasify solid fuel, including the step of slagging the ash, fuels of low ash-softening temperatures were selected, and air was used as the chief gas-making fluid. It was found that this operation could be successful, but that it was extremely sensitive to variations in the ash-softening temperature, amount of ash in the fuel used, and the rate of making

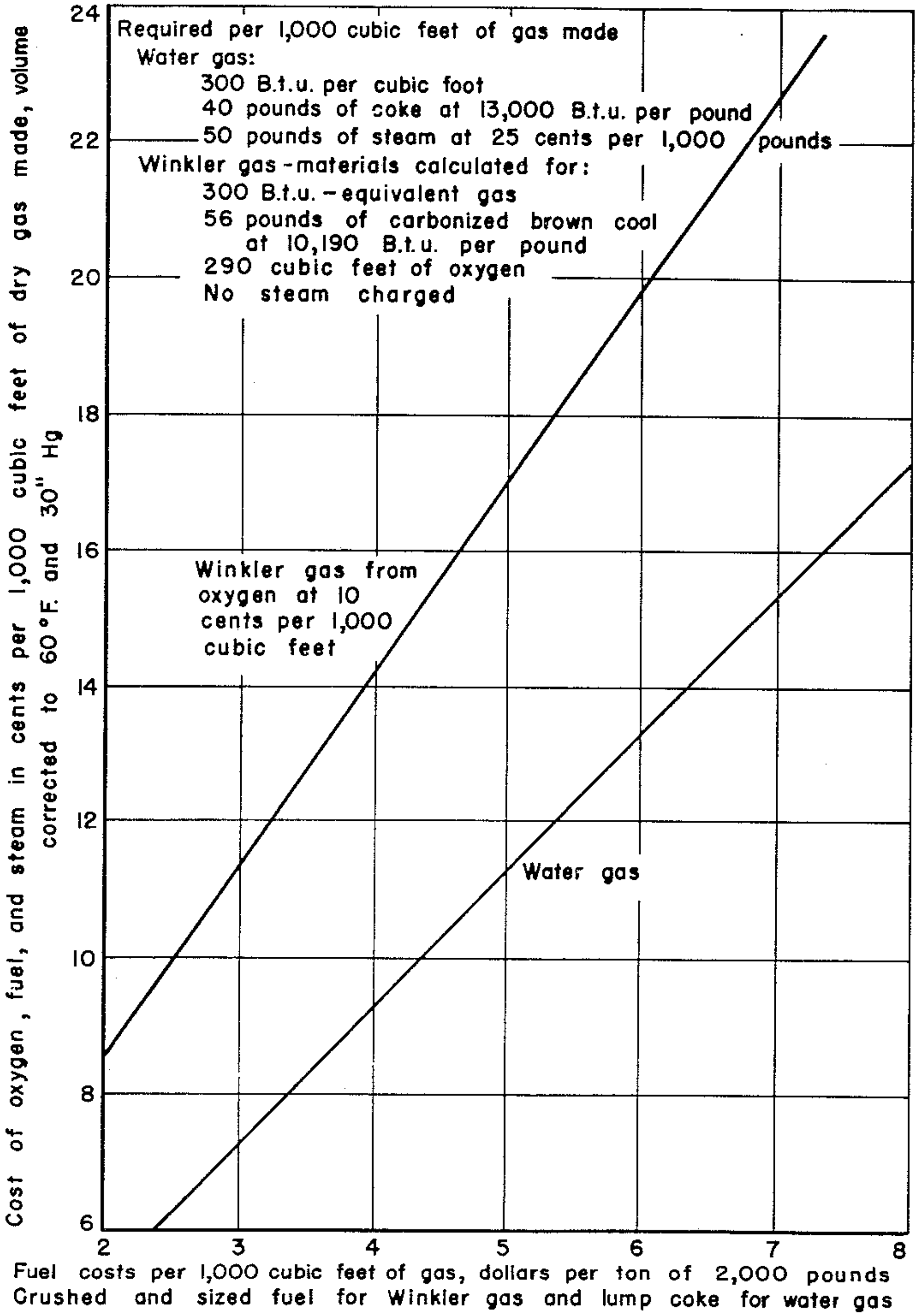

Figure 8. - Comparative costs of materials required in making ordinary water gas and Winkler gas with solid fuel costing $ 2 to $ 8 per ton.

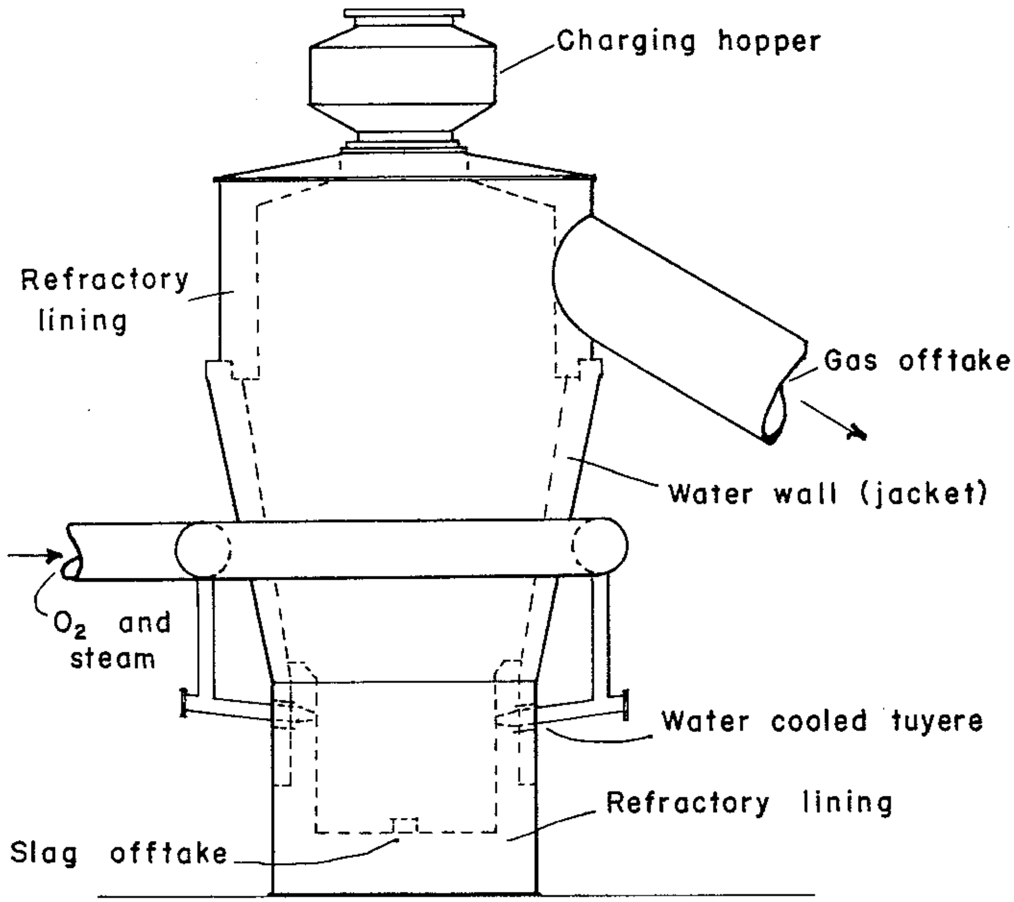

Figure 9.– Diagram of a slagging-type gas producer.

gas, temperature and moisture content of the air and other variables; the danger of serious trouble from freezing was ever present. Quite satisfactory results are attainable when O_2 instead of air is used along with a controlled amount of steam. The generator as at present developed has an internal diameter of 9.87 feet at the tuyeres and a corresponding sectional area of 76.5 square feet. Experience has shown that a complete refractory lining is not required, although as initially built the generator was not only completely lined but steam-jacketed as well.

In the operation of the generator, a fuel-bed depth of about 11.5 feet was maintained. It is, of course, necessary that the composition of the ash be such that it will readily flow as a liquid at the operating temperature. To provide this condition, it is common practice in this particular case to introduce lime into the generator along with the fuel and also to recirculate some of the crushed slag previously withdrawn from the generator. The amounts of lime and slag thus used will vary with different fuels, but in this instance the amount of lime used (introduced as calcium carbonate) was 3 percent of the fuel, and the recirculated slag amounted, with some variation, to as much as 20 percent of the total fuel used. The fuel normally charged to the generator was high-grade furnace coke, sized 1-1/2 inches and larger, free of fines. With this fuel, the capacity of the generator was 468,500 to 502,000 cubic feet of gas per hour, measured dry at 30 inches of mercury and 60° F., and this is equivalent to 6,140 to 6,570 cubic feet per hour per square foot of sectional area at the tuyeres. Thus, one generator of 9.87 feet internal diameter (at tuyeres) has a daily capacity of 11,244,000 to 12,048,000 cubic feet of gas. A representative composition of the generator gas is as follows:

Composition of producer gas from coke:	
CO_2........................percent by volume	3.5
CO........................do.	68.0
H_2........................do.	28.0
N_2........................do.	0.5
	100.0
Specific gravity........................	0.735
Calculated high heating value dry gas at 60° F. and 30 inches Hg........................B.t.u. per cubic foot	311
Calculated high heating value saturated gas at 60° F. and 30 inches Hg........................do.	306

In producing this gas, the ignited bed of coke confined in the generator is blasted with a mixture of steam and O_2 in proportions adapted to provide a temperature of 1,700° C. in the fuel bed adjacent the tuyeres. Using furnace coke as fuel, the proportions of steam and O_2 employed are:

O_2........................percent by volume	35	to	40
Steam........................do.	65	to	60
	100		100

The materials used per 1,000 cubic feet of gas made, measured dry at 60° F., and 30 inches of mercury, were:

Oxygen	cubic feet	250
Steam	cubic feet	470
Coke	pounds	26.7
Actual carbon combined as CO and CO_2 in 1,000 cubic feet of the gas	pounds	22.72
O_2 in the gas, calculated from the analysis per 1,000 cubic feet of gas	cubic feet	248
(Coke used was furnace grade, larger than 1-1/2 inches)		
Interval between slag draw-off periods	minutes	20
Temperature of gas at generator offtake	° C.	400

The gas thus made was found to be quite satisfactory as fuel and power gas, but the belief was expressed that it was essential for best results to use high-grade coke over 1-1/2 inches in size, free of fines. It was reported that the use of the water jacket as initially planned was not necessary; the preferred method of cooling of the generator wall was to spray water against the outside of the inner wall.

In one experimental run, carbon dioxide was used instead of steam, along with the O_2 supplied to the generator, as a temperature-controlling medium. This operation was successful, and the resulting gas contained 94 percent of carbon monoxide. Approximately the same amount of O_2 is required per 1,000 cubic feet of this gas as when making gas from steam-oxygen mixtures. On this basis, it follows that out of every 1,000 cubic feet of gas made, about 500 feet of carbon monoxide comes from reaction of O_2 with carbon, and about 400 cubic feet of it comes from the reaction of carbon dioxide with carbon. Accordingly, the materials required per 1,000 cubic feet of this gas are approximately 250 cubic feet of O_2, 260 cubic feet of CO_2, and about the same amount of coke as above (26.7 pounds), varying somewhat with the inlet temperatures of the CO_2 and steam.

In making gas by either of the foregoing procedures, slagging the ash and withdrawing it as a liquid, the carbon-gasification efficiency is high. All of the carbon of the fuel used appears in the gas, which gas contains only a small amount of CO_2 or other inert matter. It is noteworthy that although the gas is designated "producer gas," it has a high calorific value and is in effect much the same as water gas, the difference being in its lower H_2 to CO ratio, which difference is occasioned by the use of O_2 in gasification.

One interesting experiment was performed with satisfactory results that appreciably increased the production of hydrogen at the Ammoniawerke at Leuna. The water-gas generators used for making gas for the synthesis of ammonia were modified Pintsch generators with automatic grates; their combined capacity was too small to satisfy the demands for gas. The capacity was increased by forcing the maximum amounts of air and steam into the fuel bed during the respective portions of the cycle, meanwhile operating the automatic grate at a greater rate for the purpose of keeping the fuel bed "loose and open," so that the amounts of steam and air used are appreciably greater than when the grate is in normal operation. The triple effects of these changes were:

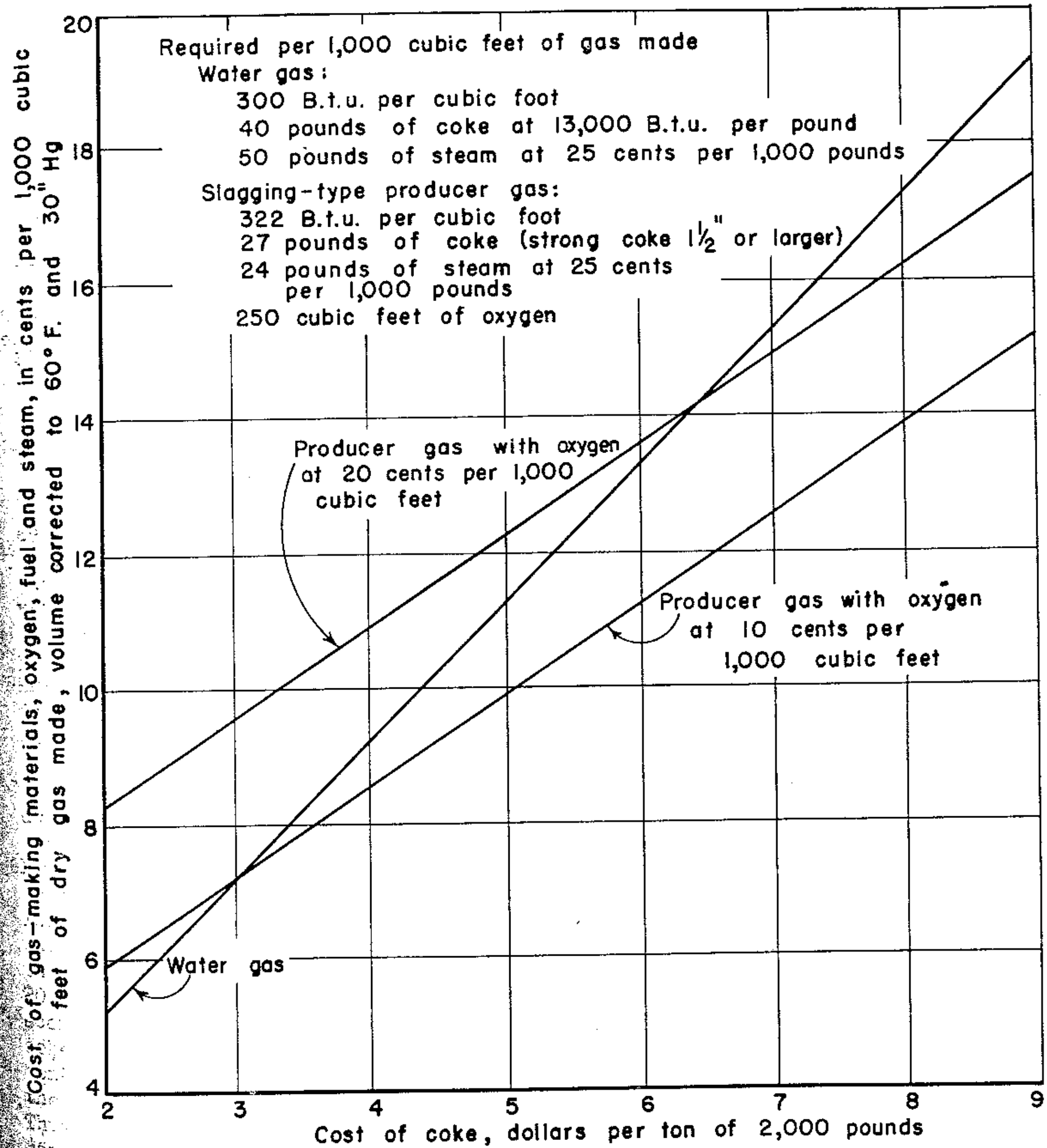

Figure 10.– Comparitive costs of materials required in making ordinary water gas and slagging-type producer gas.