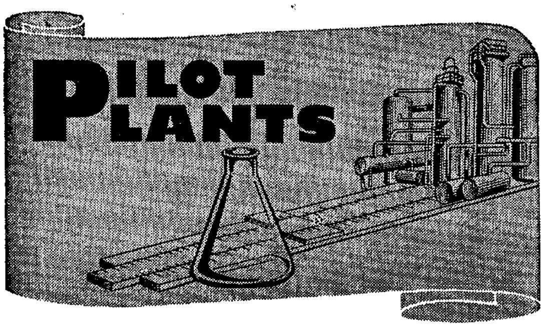

Ethylene and Acetylene Production

KOPPERS-HASCHE FURNACE

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THE successful production of acetylene by regenerative thermal cracking of hydrocarbons over a mass of hot refractory requires high reaction temperature, short contact time, rapid quenching of make gases, efficient heat exchange and recovery, low pressure drop, and automatic burnoff of any carbon deposited during cracking. These requirements are met by the use of regenerative masses composed of special patented tile (*3*). The Koppers-Hasche pilot plant at Verona, Pa., is based on a furnace which embodies some modifications of previous practice (*1, 2, 4, 5*), but which, like the previously reported furnaces, is essentially of Hasche's design. This article includes a description of the pilot plant and its operation, a discussion of some of the problems involved in its design, and experimental data on the production of acetylene from natural gas; acetylene, ethylene, or both from propane; ethylene from ethane; and ethylene from ethane-propane mixtures. Previously reported results are confirmed and extended. In addition, the results first reported here illustrate the adaptability of the furnace to a rather wide range of experimental conditions.

Inner core of furnace is essentially two alumina regenerators separated by a combustion space

The reaction zone in this "heat-make" process consists essentially of a hot mass of refractory which, in separate and alternating steps, absorbs heat from a stream of flame gases and pyrolyzes a stream of hydrocarbon feed gases to form the desired products. The reaction zone is in effect bounded on either side by two regenerative masses of refractory for preheat of combustion air and feed gases, quenching of reaction products, and heat conservation. The over-all process is a cyclic one in which the periodic switch from heating to pyrolysis is accompanied by simultaneous reversal of flow direction.

A schematic diagram of the Koppers-Hasche furnace (Figure 1) shows a long horizontal core of alumina refractory, approximately square in cross section, and encased successively in layers of refractory and insulating brick, the whole being contained in a steel shell. The inner core of the furnace consists essentially of two long regenerators of alumina separated by a central combustion space. The left end of the furnace is alternately the site of entry of combustion air and of exit of quenched product gases; stack gases alternately leave the furnace and feed gases enter the furnace at the right end. Fuel gas enters the combustion space directly. In normal operation the hottest part of each regenerator is adjacent to the combustion space, the temperature falling approximately linearly towards the ends of the furnace. The temperature profile is not quite symmetrical about the combustion space. In the air preheat regenerator (on the left) the temperature rises from about 300° F. at the air inlet end to a maximum of 1500° to 1900° F., depending on the reaction temperature. In the reaction regenerator (on the right) the temperature rises from about 300° F. at the feed inlet end to a maximum of 1600° to 2600° F.; this maximum is taken as the reaction temperature. The reaction zone consists chiefly of the hottest portion of the reaction regenerator.

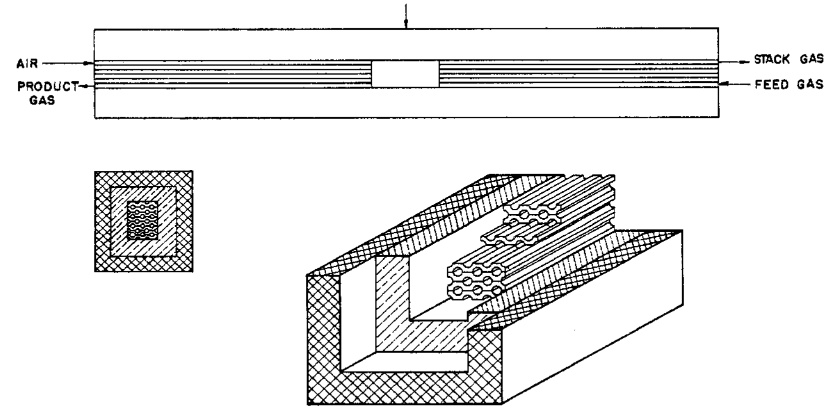

Figure 1. Schematic diagram of Koppers-Hasche furnace

To describe the operating cycle let us arbitrarily start with the heating step. Air and fuel gas enter the furnace simultaneously; fuel gas combines with preheated air in the combustion space. As a consequence of the air preheat the resulting flame temperatures may exceed 3000° F.; it is this preheating that makes it possible to produce acetylene without the use of oxygen. The flame gases give up most of their sensible heat to the reaction regenerator before being vented to the stack. The "heat," typically of 30 seconds' duration, is immediately followed by a short steam purge, after which the furnace is ready for the "make." Feed gas, with or without added steam, now enters the feed inlet end and is preheated and pyrolyzed as it passes through the progressively hotter regions of the reaction regenerator. The products of reaction emerging from the reaction regenerator are rapidly quenched in passing through the preheat section on their way out of the furnace. The heat given up by the quenched gases is the source of preheat for combustion air at the subsequent heat, which follows the make immediately after another short steam purge. Excess air supplied at the heat keeps

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the furnace clear by burning off any carbon deposited during the make.

Flat, grooved tiles, stacked in place, form the regenerators

The regenerators consist of flat, grooved tile of 99+% alumina, which are simply stacked in place without any bonding. When laid face to face the tiles form what is in effect a long continuous mass of alumina of rectangular cross section, containing a multiplicity of parallel, uniform, internal flues of circular cross section that extend throughout its length. The location of the centers of the flues in the cross section of the furnace is very closely approximated by the location of the centers of circles of $^{3}/_{4}$-inch diameter arranged in a close-packed system; the flue diameter is $^{3}/_{8}$ inch.

The success of the process depends on a proper choice both of regenerator material and its spatial configuration. Obviously, the refractory must withstand the severe reaction conditions. In addition, the heat storage capacity per unit volume of regenerator free space should be high, in order that the rapid endothermic reactions can proceed for a practical length of time before subsequent heating. This requires not only that the bulk volume should contain a limited fraction of void space, but also that most or all of the regenerator mass be close to the internal surface, so that it be available for heat exchange. The heat-transfer coefficient between gas and solid should suffice for efficient heat recovery and for rapid quenching of make gases. Furthermore, the pressure drop through the furnace should not be excessively high, even at high throughput per unit volume of free space. Finally, the throughput per unit of cross-sectional area of the regenerator as a whole should be favorable for high plant capacity, and the flues should be large enough that they do not plug with carbon before they are burned free at the heat. The foregoing requirements are neither independent nor completely compatible. Hasche's design of the tile, and therefore the interior construction of the regenerators, successfully fulfills the process requirements.

The internal surface area in the regenerators is approximately 30 square feet per cubic foot of bulk volume; over 90% of the total regenerator mass is within $^{3}/_{16}$ inch of the internal surface; and the rate of heat exchange between gas and solid is of the order 300,000 B.t.u. per cubic foot of refractory per hour at a temperature difference of about 150° F. The pressure required for a flow rate of approximately 200 standard cubic feet per minute per square foot of cross section was from 1 to 2 pounds per square inch, with an over-all regenerator length of approximately 17 feet.

Heat recovery is efficient on simple two-part "heat-make" cycle

It is to be emphasized that the flow of heat gases in the Koppers-Hasche furnace was always in the same direction, and the flow of make gases in the opposite direction. This simple two-part cycle is in contrast to the four-part cycle used previously (*1*), in which the sequence is:

$$\longrightarrow \quad \longrightarrow \quad \longleftarrow \quad \longleftarrow$$

make, heat, make, heat

The four-part cycle has been used to maintain heat balance in the furnace. If all other conditions are equal, heat loss as sensible heat of the exit gases is minimized when the combined heat capacities of the gases flowing in each opposing direction are equal. The four-part cycle achieves this result in spite of any unbalance in the heat capacities of heat and make gas. However, operation on a four-part cycle doubles the time interval between reversal of flow direction. Consequently the favorable effect of heat capacity balance is at least partially offset by the concomitant increase of the load on the regenerators. When one can operate with approximate balance between heat and make gas the heat recovery in the two-part cycle is even more efficient than in the four-part cycle. The simpler cycle makes it possible to use correspondingly simpler valve arrangements.

Figure 1 shows the cross-section of the furnace and the manner in which the tile are stacked to form the regenerator masses. The rather small ratio of gas passage to over-all cross section in the pilot plant furnace was imposed by the high throughput per unit cross-sectional area of regenerator and the necessity for insulating the reaction zone from the shell. In a commercial size furnace the over-all cross section would consist largely of regenerator.

The furnace shell in the pilot plant was constructed of $^{1}/_{2}$-inch steel plate. The over-all inside dimensions were: length, 18 feet; width, $20^{1}/_{2}$ inches; height, $22^{1}/_{4}$ inches. The regeneration sections were $4^{1}/_{2}$ inches wide and 5 inches high. The tile dimensions were $4^{1}/_{2} \times 4^{1}/_{2} \times {}^{5}/_{8}$ inches; the regenerators were built up by stacking the tile eight units deep. Equipment auxiliary to the furnace consisted of an air compressor, natural gas compressor, mixing chamber, and steam jets for reduced pressure operation. A manifold was provided for feeding hydrocarbons from cylinders.

The traffic of gases through the furnace was automatically controlled to conform to a predetermined cyclic sequence by means of air-operated, solenoid-actuated valves. The switches for the solenoid valves were automatically actuated by an electric timer which could be adjusted to repeat indefinitely any desired schedule of valve actions. The flow rate from each individual line was adjusted to the desired meter reading by a manually operated throttling valve. Temperatures were sensed by thermocouples at eight points in the furnace and automatically recorded. Products of combustion were vented directly to a stack; reaction products went through a knockout pot, a washer-cooler, and in some cases a meter, before being vented to a separate stack. The make gas was sampled from the main gas stream through a solenoid valve under control of the main cycle timer, so that gases were continuously sampled throughout the make. A sample of about 2 cubic feet was collected over a period of about 30 minutes. When operating under reduced pressure a dry-type vacuum pump boosted the gas to atmospheric pressure.

Composite samples were analyzed in an Orsat apparatus. Approximately one half of the samples were also analyzed by Podbielniak distillation. Both methods were checked for acetylene from natural gas by having several duplicate samples sent out for mass spectrometer analysis. The accuracy of the analytical methods was found to suffice for the purposes of the experiments except for a consistent bias in the volume per cent of acetylene in the Orsat method. This bias is taken into account in reporting yields. Results have been calculated on the basis of the gas analyses alone, using carbon and hydrogen balances. This procedure was checked by some laboratory-scale experiments in which exit gas volumes were determined both by calculations from the gas analyses and by direct measurement, and in which good agreement was found.

Natural gas was taken directly from the plant gas header to the inlet of the gas compressor. The specific gravity as recorded varied between 0.59 and 0.62, and the composition was somewhat variable. A typical analysis was:

	Analysis, Vol. %
CH_4	94.8
C_2H_6	3.0
C_3H_8	0.6
N_2	0.8
CO_2	0.5
C_4+	0.3

The carbon number on this gas was always quite close to unity. The ethane and propane were supplied in tanks and led to the

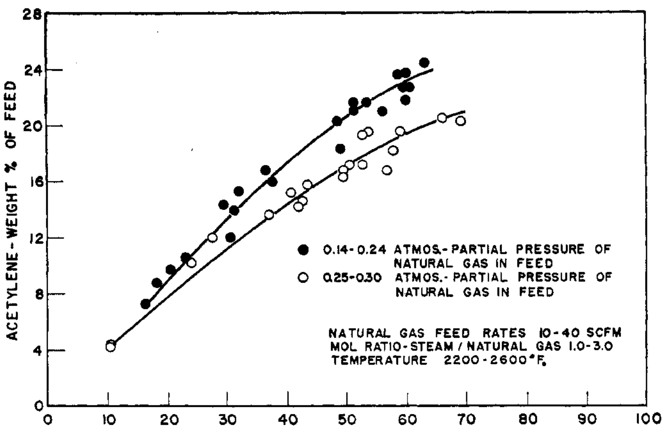

Figure 2

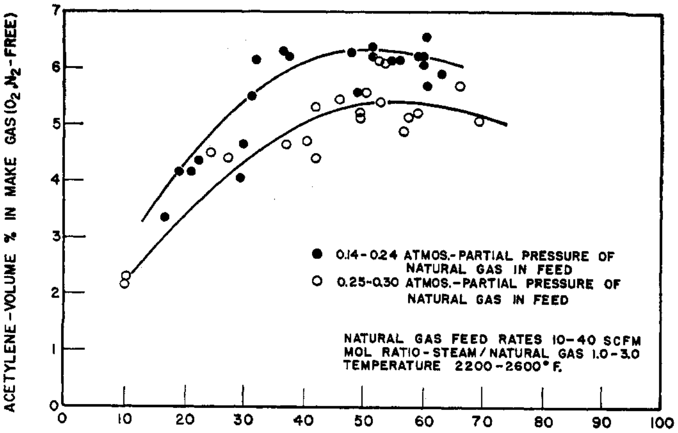

Figure 3

Acetylene from natural gas

furnace through a manifold. The ethane was at least 96% C_2H_6. The propane feed had the following composition:

	Composition, Vol. %
Propane	94.2
Ethane	2.4
C_4 hydrocarbons	1.3
C_4 + hydrocarbons	2.1

Natural gas was used as fuel in all cases as a matter of convenience. A commercial plant would use the exit gas from the product recovery system.

Low partial pressures increase acetylene yields

The yields are given in terms of weight per cent of feed or the number of pounds of a given product emerging from the furnace per hundred pounds of feed entering the furnace. The yields therefore represent the results of single-pass operation with no dilution of feed stock other than with steam. The per cent conversion of feed is defined as the total number of units of feed stock that disappear as the result of any reaction per hundred units of feed stock entering the furnace. Since the feed is assumed to contain only one component, the per cent conversion is the same in either mass or molar units. The yields have been plotted as functions of per cent conversion of feed rather than against the contact time or normal space velocity because the reaction zone is neither at uniform temperature throughout, nor is it sharply separated from the contiguous preheat zone. Moreover, the effective length of reaction zone is not necessarily invariant to changes in experimental conditions; it is a rather sensitive function of the temperature profile in the reaction zone and the temperature dependence of reaction rate, and also of the variation in temperature of the regenerator mass within a cycle. An internal parameter of the system, such as the conversion, therefore turns out to be a much more accurate index of the severity of cracking at a given (maximum) temperature than does the throughput.

The dependence of acetylene yield on per cent conversion of feed is shown in Figure 2 for two ranges of partial pressures of natural gas. A typical run is shown in the first column of Table I. The temperature range is from 2200° to 2600° F. Partial pressure was found to be the most significant factor in increasing acetylene yield at a given conversion; the limitations of the equipment prevented the extension of the investigation to lower partial pressures. Both curves show the acetylene yield increasing with increasing conversion to a maximum in the region of 60 to 75% conversion, after which the acetylene yield may be expected to decrease by secondary decomposition of acetylene. The appearance of the curves in Figure 2 and the succeeding figures is characteristic of consecutive reactions. In addition to the secondary decomposition of acetylene there undoubtedly are parallel reactions such as the direct reaction of methane with steam and the decomposition of methane to carbon and hydrogen through some mechanism other than the direct decomposition of acetylene.

In all cases the improved yields characteristic of low partial pressures of methane were achieved by combination of steam addition with reduced pressure. It has not been demonstrated that either factor alone is as effective as the combination, even at equal partial pressures. Runs were made with high steam-to-feed mole ratios, but the results were inconclusive. Moreover, since the overall pressure could not be reduced much

Table I. Operating Data and Results for Some Representative Runs

Feed gas Desired product(s)	Natural Gas Acetylene	Propane Ethylene	Propane Ethylene + acetylene	Propane Acetylene + ethylene	Ethane Ethylene
Temp., °F.	2440	1850	2265	2450	1750
Pressure, lb./sq. inch	10	15	15	9	15
Steam, mole/mole feed	2.2	0	4.4	6.2	0
Make gas compn. (Podbielniak, air-free), vol. %					
CO_2	2.5	0.3	1.4	2.0	0.5
CO	9.1	0.3	3.6	6.8	0.3
H_2	57.2	25.8	40.0	44.8	42.5
N_2	5.9	1.8	2.3	11.5	1.4
CH_4	18.9	30.6	26.0	15.6	10.8
C_2H_6	...	1.9	...	...	8.9
C_2H_4	0.8	25.6	16.8	5.2	30.0
C_2H_2	5.4	1.7	8.9	11.7	2.6
C_3H_8	...	5.8	...	...	...
C_3H_6	...	4.2	...	...	...
C_3+	0.2	...	...	0.9	3.0
C_4+	...	1.1	1.0	1.5	...
C_5+	...	0.9	...	...	...
Conversion, %	57.2	87.8	99–100[a]	98–100[a]	83.9
Yields, wt. % of feed					
C_2H_4	...	34.3	32.6	13.4	50.7
C_2H_2	20.0	2.1	16.1	28.3	4.1
C_3H_6	...	8.4	...	...	...

[a] Analysis did not distinguish between propane and propylene.

below $^1/_2$ atmosphere, owing to the limitations of the equipment, there is no information on maximum yields attainable by operation at low total pressures without steam addition. Exploratory experiments with high mole ratios of steam at atmospheric pressure indicated low yields of acetylene and unusually high yields of carbon monoxide plus carbon dioxide. This suggests that the direct reaction of steam with natural gas competes with the formation of acetylene and that the relative increase in the rate of the steam-methane reaction with increasing concentration of steam tends to outweigh the favorable effect of dilution of the natural gas. One of the reasons for the favorable results of combining reduced pressures with steam dilution may be that the rate of the methane-steam reaction is more sensitive to pressure than the pyrolysis reactions.

Pyrolysis of propane

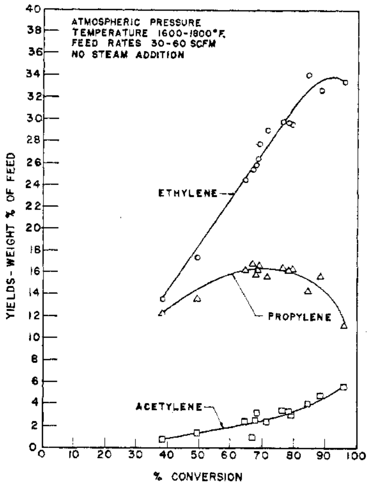

Figure 4

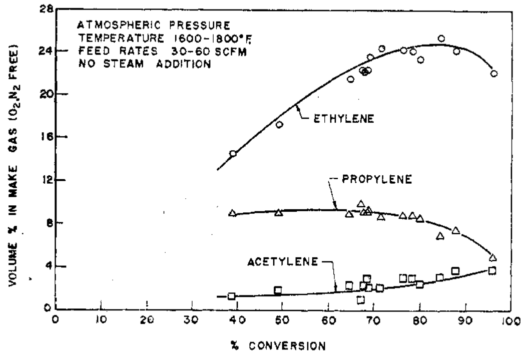

Figure 5

The operating data for all the runs with natural gas were examined in order to determine the effects of partial pressure on throughput (for a given conversion) and also the effect of temperature on both the acetylene yield and on the attainable throughput. The conclusions are approximate, since the furnace is less than ideally suited for kinetics studies. At any given temperature profile and conversion in the range studied the mass throughput is proportional to the partial pressure of natural gas in the feed. This is equivalent to the statement that the decomposition of natural gas is approximately first order. It must be emphasized that this generalization applies only to the rather restricted range of conditions in which the furnace was operated and is not intended for general application. At any given conversions within the ranges encountered and at constant partial pressure the throughput increases by the factor of 1.5 to 2 with every 100° F. increase in temperature from 2200° to 2600° F. (The usual plot against reciprocal temperature is not justified by the precision of the measurements.) All other conditions being equal, increased yields of acetylene appear to be favored by higher temperature, which is a not-unexpected result. However, above 2300° F. the yield is not especially sensitive to temperature. It is not expected that the acetylene yield would be materially increased by any increases in reaction temperature within the safe operating limit of the refractory.

Pyrolysis of propane

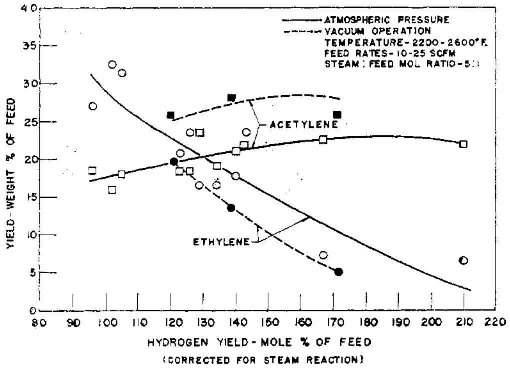

Figure 6

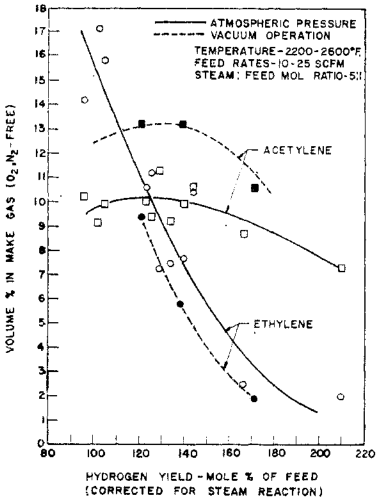

Figure 7

The maximum calculated yields of acetylene are 24% by weight of feed according to Orsat analysis and 21% by Podbielniak analysis, the lower figure probably being more accurate. (Acetylene forms azeotropic mixtures with ethylene; consequently acetylene was determined titrimetrically by precipitation with silver nitrate.) Figure 2 contains results by Orsat analysis, simply because there were more of such data available. The reported results should be corrected for the analytical bias of the Orsat analysis; thus, the maximum of 24% by weight of acetylene thus far observed is closer to 21%.

Figure 3 gives the volume per cent of acetylene in the make gas as a function of the per cent conversion. The concentrations of acetylene were determined by Orsat analysis and are reported on a nitrogen- and oxygen-free basis. As in Figure 2, the reported figures reflect the bias of the analytical method; the true values are approximately 85% of the ones shown in Figure 3. The effect of low partial pressure in increasing the acetylene yield is to increase the acetylene concentration in the make gas, which is consistent with the idea that the decomposition of acetylene is kinetically of a higher order in partial pressure than the pyrolysis of methane. The relatively broad maxima in the curves indicate that the increase in acetylene yield with increasing conversion is more a matter of volume expansion than of increase in the acetylene concentrations. The relatively low concentrations of acetylene at relatively good yields is also a consequence of the increase in gas volume with increasing decomposition; the ratio of make gas to feed gas volumes (at standard conditions) is approximately 2.5 at 65% conversion.

The previously mentioned mass spectrometer analyses showed the presence of methylacetylene in concentrations of the order 0.2% by volume when the corresponding acetylene concentration was approximately 5%. Since the error of analysis is

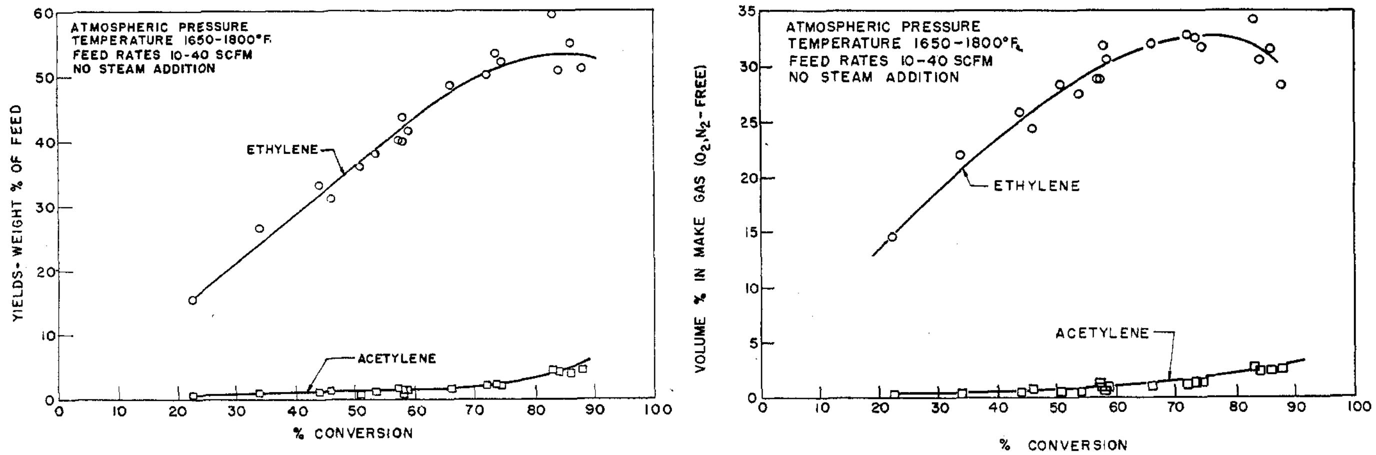

Figure 8

Figure 9

Pyrolysis of ethane

approximately 0.1%, the ratio of methylacetylene to acetylene is not known with precision but may be estimated as approximately 4% on a molar basis or 6% on a weight basis.

Propane yields ethylene, acetylene, or both, depending on reaction conditions

Propane can be pyrolyzed to yield either ethylene or acetylene as the principal product by suitable adjustment of reaction conditions, and one can also obtain both ethylene and acetylene in commercially significant yields. Reaction temperature is the most important factor in determining the nature and relative yields of the products at any given conversion. In the temperature range 1600° to 2000° F. ethylene is obtained in yields up to 34 weight % of feed at 85 to 90% conversion; within this temperature range the dependence of yield on conversion is quite insensitive to variation in reaction temperature. Neither steam nor reduced pressure is necessary. A typical run is illustrated in column 2 of Table I, and the dependence of yields on conversion is shown in Figure 4. Figure 5 shows the dependence on conversion of the concentration in the make gas of each of the products for which yields are shown in Figure 4. As in Figures 2 and 3, the reported results were obtained from Orsat analysis; they contain an upward bias for acetylene and propylene but are reliable for ethylene, which is the principal product of interest. The yield of acetylene may be expected to rise sharply with increasing temperature. However, in the temperature range 1600° to 2000° F. it is still quite low. The best ethylene yield from propane is approximately 34 weight %, and the maximum propylene yield (corrected for bias) is 14%, but the maximum does not coincide with the maximum yield of ethylene.

In order to make acetylene from propane it is necessary to operate above 2200° F. As in the production of acetylene from natural gas, the reaction conditions favoring high acetylene yield include steam dilution and reduced pressure operation. In contrast to methane, maximum acetylene yields coincide with complete, or nearly complete conversion of propane. Since propane decomposes more rapidly than methane, one would expect the maximum yield of acetylene to occur at some conversion higher than the corresponding conversion of methane, but the more rapid decomposition of propane does not explain the occurrence of maximum acetylene yields at complete conversion of propane. However, since the reaction conditions are favorable for the production of acetylene from methane as well as from propane and since methane is one of the decomposition products of the propane and is present in significant amounts when all of the propane has decomposed, the formation of acetylene can continue from what is in effect a new feed.

Figure 6 shows yields of ethylene and acetylene in the temperature range 2200° to 2400° F. as a function of the severity of cracking, and Figure 7 gives corresponding concentrations of ethylene and acetylene in the make gas by Podbielniak analysis. The conversion of propane could not be used as an abscissa in this graph because it was always equal or close to 100%. The yield of hydrogen was considered as a possible internal parameter of the system, since it increases monotonically with increased severity of cracking and continues to increase after all the propane has disappeared. However, the yield of hydrogen is also increased by reaction of steam with either hydrocarbons or carbon. Hydrogen yields were therefore corrected for reaction with steam, and the corrected yields were plotted as the abscissa in Figure 6. The resulting plot shows how acetylene and ethylene may be obtained simultaneously. The individual yields are smaller than the best yields that can be obtained for each product alone. However, the combined yield is higher than the best one for each product alone. Further increase in severity of cracking increases the acetylene yield but at the expense of a much larger amount of ethylene. The sharp drop in ethylene yield as compared with the rather gradual increase in acetylene may be taken as evidence that most of the ethylene is not forming acetylene. Figure 6 also shows the pronounced favorable effect of reduced pressure operation on the acetylene yield, and Figure 7 shows that this effect is primarily an increase in acetylene concentration in the make gas. The decomposition of acetylene would appear to be strongly pressure dependent and the major factor in determining maximum acetylene yield. The best reliable acetylene yield is 27 weight % of feed, at which the ethylene yield is 13%. The combined yields of ethylene and acetylene can reach 45%, of which 15 to 25% (by weight of feed) could be acetylene.

Maximum yields of ethylene from ethane occur at 75 to 85% conversion

Ethane was pyrolyzed for the production of ethylene under the following conditions: temperature, 1650° to 1800° F.; atmospheric pressure; no addition of steam; and throughput of 10 to 40 standard cubic feet per minute. In some runs a special heat cycle (split heat cycle) was employed, in which the fuel gas was turned off for the latter part of the heat period, leaving air alone to the furnace for the remainder of the heating portion of the cycle.

A typical run is illustrated in column 5 of Table I. The dependence of ethylene yield on conversion is shown in Figure 8, and the dependence of ethylene concentration is shown in Figure 9. Maximum yields of ethylene occur in the conversion range 75 to 85%. A reliable value for the maximum ethylene yield is $52\frac{1}{2}\%$

by weight of feed. The acetylene yield is approximately 5% by weight of feed.

Two sets of runs were carried out with a feed stock containing approximately equal parts by volume of ethane and propane, at 1810° to 1885° F., atmospheric pressure, and without steam addition. As expected, the propane was more reactive than ethane—for example, the ethane conversion was 48% in one run as compared with the propane conversion of 80.7%. The observed yields were not significantly different from the values calculated on the assumption that each component reacted independently. It is expected that the best yields obtainable from ethane-propane mixtures will be about 37 to 39% by weight of combined feed or within 1 or 2% of the combined maximum yields when ethane and propane react individually.

All yields reported here are for single-pass operation. With natural gas, where maximum acetylene yields occur in the region of 60% conversion, significant amounts of unconverted feed are found in the make gas; this suggests the possibility of recycle operation. However, the volume expansion associated with the reaction results in dilution of the unreacted methane with permanent gases from which the methane is not easily separable. The introduction of these diluents into the reaction zone by the recycling of scrubbed product gas would result in a sharp reduction of acetylene concentration for only modest increases in over-all yield. With the other gases, by far the greatest part of the feed gas can be efficiently converted in a single pass.

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Coal Gasification at Louisiana, Missouri

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THE Synthetic Fuels Demonstration Plant at the Louisiana, Mo., station of the Bureau of Mines was built to study and demonstrate the production of synthesis gas from coal and the conversion of this gas to liquid fuels. This plant has been described (*3*), and the results of the work on the Koppers coal gasification unit have been published (*1*). These results indicated that a change in the geometry of the gasifier would be beneficial, and, after preliminary tests at the Morgantown, W. Va., station of the Bureau of Mines had supported this belief, a new unit was constructed at Louisiana. This article describes the gasification unit and its subsequent modifications and discusses the results obtained to the time that the Demonstration Plant was closed (June 1953).

The work reported in this article was the result of the coordinated efforts of the personnel of the operating, engineering, and planning sections and is in no sense a personal accomplishment of any one individual or group. A complete description of the original gasification plant has been given in a previous report (*1*).

The new gasifier was constructed for the following purposes:

1. Eliminating "short-circuiting" within the gasifier
2. Feeding finely ground coal without premixing with oxygen
3. Using a refractory less sensitive to temperature variations encountered during operation
4. Removing part of the ash in liquid form

Severe erosion is encountered with modified Koppers unit using coal-oxygen feed system

Preliminary experiments at Morgantown had been conducted in a vertical cylindrical unit, in which the reactants were introduced tangentially near the bottom and the product gases were removed at the top of the unit. This general design was incorporated with the new unit that was constructed at Louisiana. After some discussion concerning refractories, a "ram mix" of high purity alumina was selected as lining. Under the terms of a cooperative agreement with the Bureau of Mines, the Aluminum Co. of America offered technical assistance and much of the necessary material. At the time, the Alcoa engineers were not willing to recommend construction of a unit more than 6 feet in outside diameter, nor more than a 9-inch lining thickness. These limits, with the decision to keep the volume about equal to that of the Koppers unit, led to the design shown in Figure 1.

Originally, it had been planned to pump a slurry of coal in water through a heated coil to produce a suspension of heated coal in superheated steam. This system was similar to the one that was described by Eastman (*2*), except that the coil discharge was to be at substantially atmospheric pressure. Because of difficulties encountered in this feed system, the gasifier was ready for operation before any promise of satisfactory performance of the slurry heater had been obtained. Accordingly, the coal feed system of the Koppers unit, in which coal was conveyed by process oxygen, was adapted for use in the new unit, and the slurry coil was used for superheating steam. All of the coal was delivered to the gasifier by one set of screw feeders, instead of two sets, as was formerly used. This required the screws to operate at twice the normal speed. Preliminary tests indicated that this could be done, but considerable operating difficulty was encountered during the runs.

A horizontal, three-port water-jacketed burner was installed at *A* in Figure 1, tangent to a 42-inch-diameter circle, and the steam nozzle was installed at *B*, tangent to the same circle and 60° from the burner. A flow diagram of the system is shown in Figure 2.

Preweighed coal was dumped at intervals into the feed hopper, from which it was fed by three screws in parallel into three equal

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