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EXPERIMENTAL PRODUCTION OF STRAW GAS.

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INTRODUCTION.

In 1921 the Bureau of Chemistry of the United States Department of Agriculture undertook a study of the production of gas from straw and similar material now often wasted on American farms.[1]

Only one of the types of equipment available for straw-gas production, and that not the most improved one, and only a few of the many kinds of material which may be carbonized were used in these tests. The experiments, however, were extensive enough to show that the type of equipment employed in these tests is not practicable as a farm unit, even though the gas produced can be satisfactorily used for heating, lighting, and stationary power purposes.

STRAW-GAS PRODUCING PLANT.

Straw-gas equipment was installed at the Arlington Experimental Farm, Va. It consisted of a cylindrical steel retort, a steel scrubber and condenser combined, and a steel water-seal gasometer (figs. 1, 2, 3).

The retort, 3 feet in diameter and 8 feet in length, with a volumetric capacity of approximately 50 cubic feet, was equipped with a central return flue and rested on its horizontal axis. Walls and an arch of brick retained the heat produced in the fire box beneath the retort. Eight gas burners (1-inch pipes, each equipped with a single row of holes, and a mixing valve), arranged transversely in the fire

[1] Roethe, H. E. The Production of Gas by the Destructive Distillation of Straw. Power, vol. 52 (1920), pp. 853–854.

box to burn gas from the gasometer, were later removed. A set of slotted bar grates was installed, so that straw, wood, etc., could be effectively burned as fuel for carbonizing the charge.

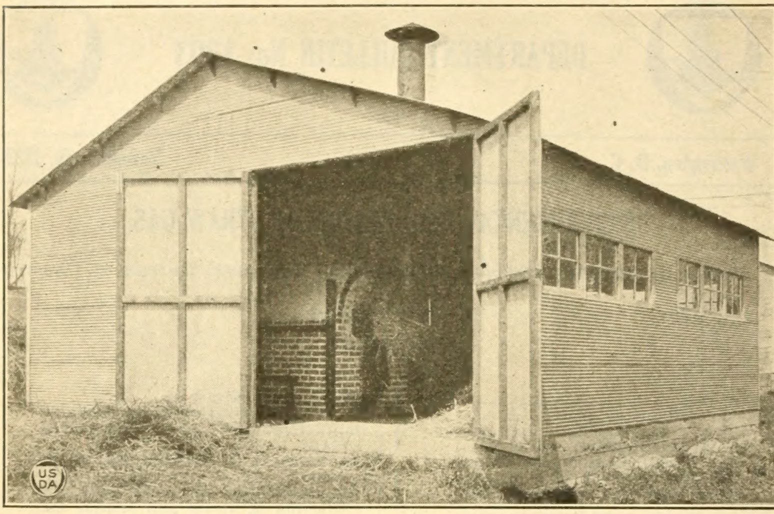

FIG. 1.—Experimental straw-gas plant at the Arlington Experimental Farm, Va.

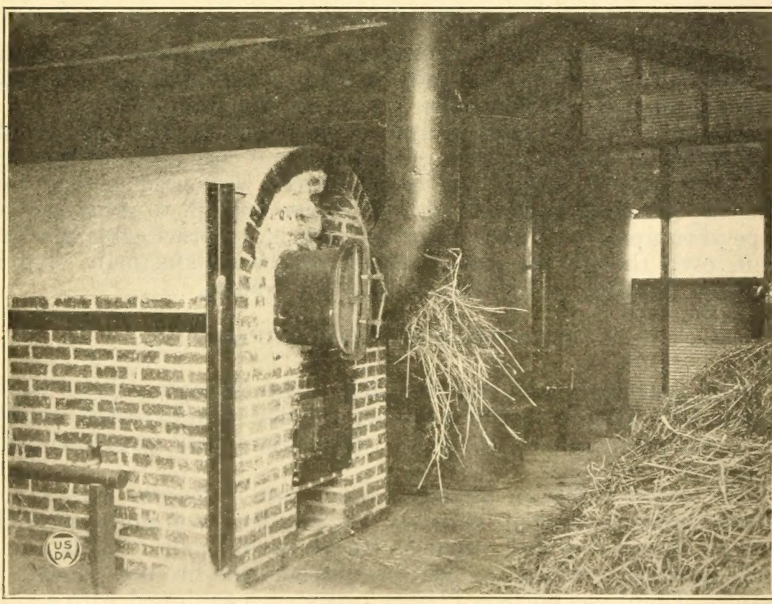

FIG. 2.—Retort, scrubber, and gasometer.

The upright scrubber and condenser, 7 feet high and 2 feet in diameter, contained a quantity of water, above which were placed several fine-mesh screens and charcoal or coke. The cleaning cham-

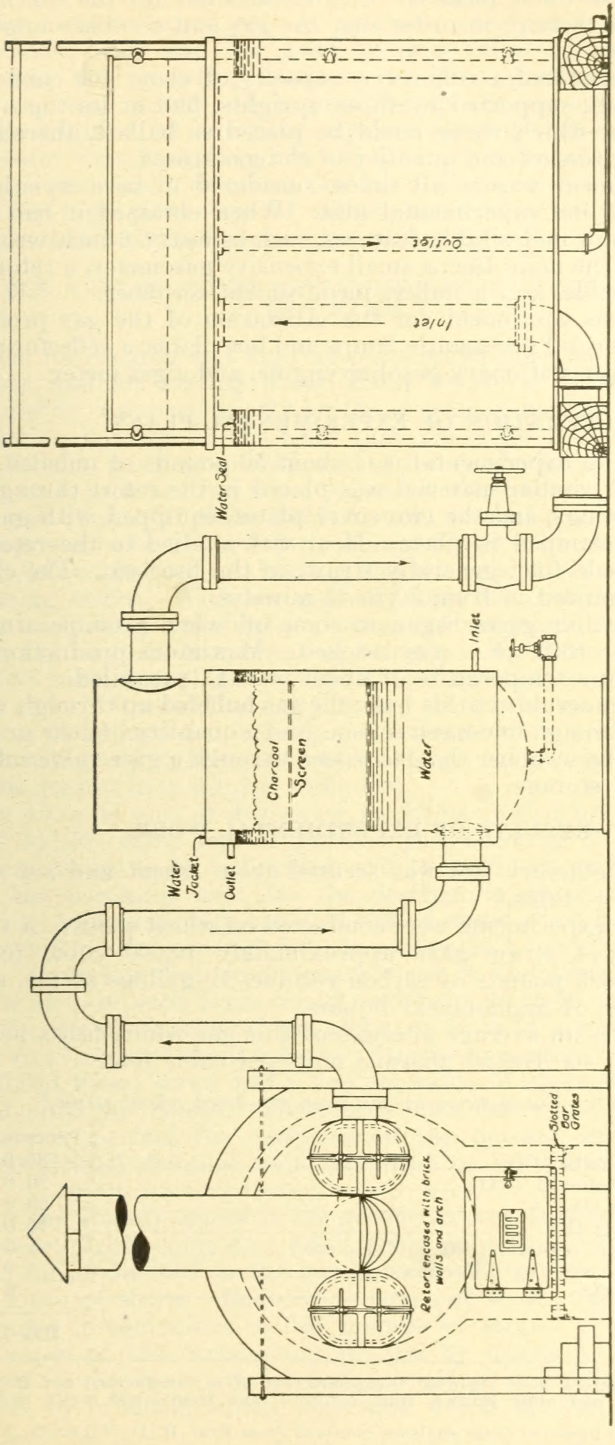

FIG. 3.—Front elevation of straw-gas equipment shown in Figure 2.

ber proper was water jacketed, with connections for the continuous flow of water therein, in order that the gas and scrubber might be properly cooled.

The gasometer had a volumetric capacity of about 100 cubic feet. The upper bell, supported by three uprights, had at its top an extended rim in which water could be placed as ballast, thereby increasing the pressure and quantity of the gas stored.

This equipment was at all times considered to be a strictly demonstrational and experimental unit. When obtained it had some unnecessary and undesirable features, such as heavy 6-inch wrought-iron pipe for the main line, a small expensive gasometer, a retort not readily accessible, and a bulky, inconvenient scrubber.

Miscellaneous equipment for the utilization of the gas produced consisted of several gas-mantle lamps and hot plates, a reflector stove, a 1½-horsepower stationary gasoline engine, and a gas meter.

OPERATION OF EXPERIMENTAL PLANT.

In making an experimental run, about 50 pounds of unbaled, sun-dried straw or similar material was placed in the retort through the two oval openings, and the two cover plates, equipped with gaskets, were tightly clamped in place. Heat was applied to the retort by burning suitable fuel, generally straw, in the fire box. The charge could be carbonized in from 30 to 45 minutes.

The combustible gases began to come off when a temperature of about 200° C. (392° F.) was reached. Maximum production was obtained when a temperature of about 500° C. prevailed.

Entering the scrubber at its base, the gas bubbled up through water, then passed through fine-mesh screens and a quantity of coke or charcoal. From the scrubber the gas passed through a gate valve into the gasometer for storage.

RESULTS OF EXPERIMENTAL WORK.

A very satisfactory gas was secured from wheat and oat straw and from corn stalks.[2]

Most of the experiments were conducted on wheat straw. A ton of sun-dried wheat straw gave approximately 10,000 cubic feet of purified gas, 625 pounds of carbon residue, 10 gallons of tar, and a large quantity of ammoniacal liquors.

Table 1 gives an average analysis of this gas which has a heating value of about 400 British thermal units per cubic foot.

TABLE 1.—*Composition of gas from sun-dried wheat straw.*[3]

	Per cent.
Carbon dioxid (CO_2)	30.0
Carbon monoxid (CO)	26.0
Hydrogen (H_2)	26.0
Methane (CH_4)	15.0
Illuminants (ethylene, etc.) (C_2H_4, etc.)	1.5
Nitrogen (N_2) (by difference)	1.0
Oxygen (O_2)	.5
	100.0

[2] Other investigators have reported the production of a satisfactory gas from flax, barley, rye, rice, and other straws, from corncobs, and from wood waste and other cellulose material.

[3] This table was prepared from analyses obtained from Prof. R. D. McLaurin, formerly of the University of Saskatchewan, Saskatoon, Canada.

Straw gas burns with a beautiful blue flame in a Bunsen burner, hot plate, reflector stove, etc. It produces a very satisfactory light in a mantle lamp and has good heating value. It is also very satisfactory for operating stationary internal-combustion engines, giving the best results when admitted to the explosion chamber with the addition of but little air and ignited under a compression greater than that found in the ordinary type of farm engine. The gas is practically colorless, but has a slight odor. The presence of a fairly high percentage of carbon monoxid (highly poisonous) in the gas makes advisable some care in its production and utilization.

PROBABLE ANNUAL CONSUMPTION OF GAS ON AVERAGE NORTHERN FARM.

As fuel for cooking and lighting purposes in the home, for heating the house, and for heating water, about 300,000 cubic feet of straw gas would be consumed yearly on the average northern farm. This computation is made on the basis that 150 cubic feet of gas is required for the daily preparation of three meals, each mantle lamp consuming 4, each heating stove 20, and a water heater 50 cubic feet of gas per hour. Of these 300,000 cubic feet of gas, about 55,000 cubic feet would be utilized for cooking, 17,000 cubic feet for lighting, 201,000 cubic feet for heating the home, and 27,000 cubic feet for heating water. With the quantity used for cooking and water heating remaining practically constant throughout the year and that for lighting and home heating being greatest during the winter, about 235 cubic feet of gas would be used daily during the summer months and 1,750 cubic feet daily during the winter months. In case the gas is to be used for ironing and for stationary power purposes or for heating and lighting several buildings, the yearly requirement would be greater than 300,000 cubic feet.

From 45 to 50 tons of dry straw would be needed for the production of 300,000 cubic feet of purified gas, allowing 30 tons as the aggregate charge to be carbonized, and 15 to 20 tons as fuel for supplying the necessary heat for the destructive distillation of that quantity. Approximately one-half ton of straw when burned in the fire box will produce enough heat to carbonize 1 ton of straw in the retort. Assuming that small grains yield on the average 1.14 tons of straw an acre, each farm would need from 40 to 45 acres in small grains for the production of gas alone, or 19 to 21 acres of corn, allowing an average of about 2.4 tons of stover an acre.

Air-dried wheat straw has a heating value of about 6,000 British thermal units per pound. Therefore, when this straw is burned in the fire box as fuel for carrying on the process, approximately 6,000,000 British thermal units are used in carbonizing 1 ton of straw.

Using gas already stored in the gasometer as a fuel for continuing the process, 3,000 cubic feet of it (representing 1,200,000 British thermal units) burned in the gas burners of the fire box will carbonize 1 ton of straw. Reduced to terms of straw, this 3,000 cubic feet of gas is equivalent to 600 pounds of straw. Therefore, the continuation of the carbonizing process by means of gas already produced results in a material saving in straw and at the same time conserves by-products which otherwise would be lost. Also, it is

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more convenient and requires less labor than the burning of straw. However, burning straw apparently gives a greater yield of the desired gases, owing to the fact that a high temperature can be obtained in a shorter time, the length of time for carbonization is shortened, and the added expense for piping, burners, and mixers is made unnecessary. On the other hand, a greater quantity of heat is lost when straw is burned as fuel than when gas is used.

LIQUEFYING AND COMPRESSING STRAW GAS.

The liquefaction of straw gas (as a simple gas) by means of compression and a very low temperature is not successful in the laboratory on account of the different gases involved. Hydrogen must be liquefied separately, and several of the other gases freeze during the process. Obviously, the liquefying of straw gas, as either a simple or a complex gas, is not feasible, least of all on the farm.

Straw gas can be compressed at ordinary temperatures for storage as a gas in suitable tanks. The compression of this gas on the farm is not practicable, however, on account of the added expense and the necessity of securing the services of a person thoroughly familiar with the technique of compressing operations and with the many precautions which must be observed. For example, care must be taken to compress the gas to its ultimate pressure only in a suitable number of operations, to properly cool the gas and compressors, and to maintain the proper lubrication of the compressor.

STRAW GAS FOR AUTOMOTIVE POWER.

Straw gas has possibilities as a fuel for propelling automotive vehicles, but under present conditions it is improbable that it will be used to any extent in such a manner. Automobiles have been operated on this gas carried in a flexible, impervious bag attached to the car. A bag containing 300 cubic feet of gas held a supply sufficient to run the car for 15 miles. This method, however, is unsatisfactory and impracticable.

USE OF BALED STRAW.

Charging the retort with baled straw would facilitate its handling, expedite several operations, and make possible a more compact retort. On the other hand, baling would doubtless cost from $2 to $3.50 per ton of straw, more time would be required to completely carbonize baled straw, and the quality of the gas produced would probably be lower, owing to the fact that the heat penetration would not be as uniform as when loose straw was carbonized. The maximum production of the desired inflammable gases seems to prevail when the temperature of distillation is rapidly raised.

VALUE AND UTILIZATION OF BY-PRODUCTS.

At present the by-products from the destructive distillation of straw and similar material apparently have no commercial value.

Although the carbon residue, which can be readily powdered to a fine consistency, can be used satisfactorily in the manufacture of lampblack, it is doubtful whether a market for this residue or the other by-products would yield a profit to the farmer. The cost of collecting, hauling, and shipping, as compared with the prices these products command, would make such a procedure unprofitable.

The most advantageous utilization of the by-products probably is on the farm where the grain is produced. As a fuel the carbon residue has a heating value of approximately 10,000 British thermal units per pound, while as a fertilizer its average composition is about 5 per cent potassium oxid (K_2O), 1.5 per cent ammonia (NH_3), and 0.3 per cent phosphoric acid (H_3PO_4). The tar can be used satisfactorily as a wood preservative and disinfectant.

IMPRACTICABILITY OF EXPERIMENTAL PLANT.

The results of the tests here reported indicate that the type of straw-gas producing plant used is not practicable as a unit for farms, chiefly on account of its initial cost and upkeep, the length of time required to produce suitable quantities of gas, and certain inconvenient features of the retort and scrubber.

In conducting an average run on the production of gas, about 75 pounds of unbaled straw can be placed in the retort as a maximum single charge. Considering the time necessary for charging the retort, carbonizing, cooling, and removing the charge, approximately 1¼ hours are required for the distillation of this quantity of straw, yielding about 375 cubic feet of purified gas. The complete cost of the plant as installed, exclusive of building, was $1,500.

The annual cost of producing gas in this plant is shown in Table 2.

TABLE 2.—*Cost of producing straw gas in experimental plant.*[4]

Interest on investment (6 per cent on $1,500)	$90.00
Depreciation (8 per cent)	120.00
Labor for producing gas (1,000 man-hours at $0.50 per hour)	500.00
Total	710.00

On this basis, 4.22 cubic feet of gas can be produced for 1 cent, or 1,000 cubic feet for $2.36. In terms of heating units, the gas produced for 1 cent represents 1,688 British thermal units.

In the foregoing computations no charge has been made against the straw consumed, no monetary value has been given the by-products, and no consideration has been given to hauling charges, or to the cost of a building for housing the equipment. The heat for carbonizing the charge was supplied by straw burned in the fire box. Straw, generally wasted in many sections, has a distinct potential value by virtue of the fertilizing constituents which it contains. According to figures[5] taken from accurate analyses, with nitrogen selling for 25 cents, phosphoric acid for 8 cents, and potash for 15 cents a pound, oat straw has a value of $7.73, barley straw one of $6.68, wheat straw one of $4.95, and rye straw one of $5.25 a ton. It would be necessary to pay these prices to obtain the same quantity of fertilizing constituents in commercial fertilizers. Accordingly, straw when returned to the soil for the addition of plant food elements is very valuable.

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[4] Yearly production of gas, 300,000 cubic feet.

[5] Fertilizing Value of Straw. Farm Implement News, vol. 40, no. 46 (Nov. 13, 1919), p. 27.

A general comparison can be made with the cost of the ordinary fuels with which the straw gas produced in this plant would have to compete. The number of British thermal units per unit for each fuel or source of energy considered forms the basis of comparison. The approximate heating value (in British thermal units) of straw gas is considered to be 400 per cubic foot; that of gasoline, 108,000 per gallon; that of kerosene, 128,000 per gallon; that of anthracite coal, 15,100 per pound of combustible, or 12,250 per pound of coal; that of bituminous coal (high grade), 15,200 per pound of combustible, or 13,600 per pound of coal; that of wood (air dried), 6,000 per pound; and that of electricity, 3,415 per kilowatt hour.

On the basis of heating units produced, straw gas, as a fuel for heating, cooking, and stationary power purposes, costs at least 1 cent per 1,690 British thermal units.[6] Wood selling for $10 a cord, sawed and split, costs 1 cent per 18,000 British thermal units; anthracite coal at $15 a short ton costs 1 cent per 16,335 British thermal units; bituminous coal (high grade) at $14 a short ton costs 1 cent per 19,430 British thermal units; gasoline at 25 cents a gallon costs 1 cent per 4,320 British thermal units; and kerosene at 18 cents a gallon costs 1 cent per 7,110 British thermal units.

When wood and coal are burned for home-heating purposes a large quantity of heat is lost and wasted. It has been estimated that in the neighborhood of 30 per cent of the heating units pass up the chimney with the flue gases. The aggregate loss is still greater when these fuels are used for cooking purposes, since much heat is also wasted during the preparation of a hot fire and after the completion of the cooking. These losses do not occur when gas is burned. Considering these heat losses, wood selling at $10 per cord would cost 1 cent per 12,600 British thermal units, anthracite coal at $15 a ton, 1 cent per 11,435 British thermal units, and bituminous coal at $14 a ton, 1 cent per 13,600 British thermal units, when used for heating the home. These figures would be somewhat higher when these fuels were used for cooking purposes. The cost of straw gas produced in the experimental plant, then, is very high as compared with the cost of ordinary fuels.

The cost of straw gas as a source of light for farms is about half again as great as that of electricity supplied by an individual electric lighting plant. Assuming the yearly consumption to be 432 kilowatt hours, the cost of electricity produced by a good farm electric plant of approximately one kilowatt output for the average farm varies from $0.36 to $0.46 per kilowatt hour.[7] For the sake of comparison, a cost of $0.40 per kilowatt hour will be taken. When burned in an inverted gas-mantle lamp at the rate of 4 cubic feet per hour, straw gas produces a light of about 14.4 candlepower. Considering a tungsten incandescent (vacuum) electric lamp to average about 1 candlepower for each watt, and allowing appropriate charges for the necessary gas pipe and gas-lighting fixtures, straw gas would cost about 67 cents per 1,000 candlepower hours, or 1 kilowatt hour.

[6] Round numbers are used in all these calculations.

[7] Fogle, F. E. The Farm Electric Plant. Michigan Agricultural College Quarterly Bulletin 4 (1921), pp. 119–121.

IMPROVEMENT OF EXPERIMENTAL EQUIPMENT.

Much could be done to lower the cost of, simplify, and improve the experimental equipment used.

The brick arch and walls incasing the retort are effective in conserving heat, but their initial cost is high, as well as their cost of upkeep in case it is necessary to repair or replace the retort. The retort would probably last for four or five years when used to produce 300,000 cubic feet of gas per year and subjected to the heat of straw burned in the fire box. The retort is very inaccessible under the present arrangement. A sheet-iron casing, similarly shaped and covered with heavy layers of asbestos, inclosing a readily replaceable retort or baking chamber, would be more practicable from every standpoint. The main gas line could be 2-inch piping, with attachment to the retort on top at its center.

The front end of the retort should be equipped at the top with a single large gas-tight charging door which can be readily opened and closed. A similar door should be placed at the bottom to permit easy and rapid removal of the carbon residue after the charge has been carbonized. For the exclusive burning of straw, the fire box should be equipped with a regular straw-firing door.

The return flue, while increasing the cost of the retort, slightly decreasing its volumetric capacity, and making the charging operation more laborious, permits a more even and rapid carbonization of the charge.

Everything considered, the gas burners, as arranged in the fire box, were not entirely successful, and the burning of straw in the fire box seemed to be more satisfactory.

While effective, the scrubber is bulky and expensive, with an interior not readily accessible. A better arrangement would be a separate, compact water-cooled condenser, and a separate scrubber which could be much smaller than the one used. Such equipment would cost less and at the same time result in a more effective and satisfactory recovery of tar, heavy oils, and ammoniacal liquors. On account of the size and thickness of the main gas line, there is a tendency for the tar to condense and collect in the gas outlet and elbow at the front of the retort.

A retort the size of that in the experimental unit would require a gasometer having a capacity of at least 400 cubic feet. It could be constructed of lighter material than that used and could be made more compact by making the lower bell upright instead of inverted. Gasometers are expensive, bulky, and somewhat troublesome, especially during the winter when antifreezing solution must be kept in the water compartment. The question arises as to the most satisfactory method of storing the gas, for which several other devices suggest themselves. A steel tank in which the gas could be stored at a pressure of, say, 75 to 100 pounds per square inch, or an impervious canvas-rubber bag, similar to those used in England during the World War on motor busses driven by coal gas, might be more practicable.

IMPRACTICABILITY OF DESTRUCTIVE DISTILLATION OF STRAW AND SIMILAR MATERIAL ON FARMS.

Gas produced from straw may be used successfully for lighting and heating and as a motor fuel. The question of the feasibility of a straw-gas plant on the farm, then, depends primarily upon the cost of production and ease of operation. The estimated cost of the gas as produced under the conditions here outlined is prohibitive. This cost is dependent upon a number of factors, the most important of which are the initial cost of the equipment, cost of upkeep, length of time necessary for carbonizing individual charges, and the total quantity of gas required. Any conditions which tend to decrease the expense of manufacture or enhance the value of the main product and by-products would, of course, increase the attractiveness of the proposition, but that such conditions would be of a magnitude to make it a financial success is doubtful. On the other hand, the use of this gas would afford many advantages and conveniences which can not be measured in dollars and cents.

Considering the proposition impartially from every angle, it appears that the destructive distillation of straw and similar material for the production of gas on the farm is not practicable.

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