



ESSENTIALS OF A SUCCESSFUL CONSTANT-COMPRESSION ENGINE

Author(s): C E Sargent

Source: *SAE Transactions*, 1924, Vol. 19, PART I (1924), pp. 193-219

Published by: SAE International

Stable URL: <https://www.jstor.org/stable/44723703>

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at <https://about.jstor.org/terms>



JSTOR

SAE International is collaborating with JSTOR to digitize, preserve and extend access to *SAE Transactions*

ESSENTIALS OF A SUCCESSFUL CONSTANT-COMPRESSION ENGINE¹

BY C E SARGENT²

ABSTRACT

The efficiency of internal-combustion engines increases with the pressure of the charge at the time of ignition. Therefore, a compression at full load just below that of premature ignition is ordinarily maintained. But when such an engine is controlled by throttling, the efficiency drops as the compression is reduced, and as automobile engines use less than one-quarter of their available power the greater part of the time, the fuel consumption is necessarily high for the horsepower output.

On account, also, of the rarefaction due to throttling, more power must be developed than is necessary to drive the car; automobile engines in which the fuel is introduced during the induction stroke, would be more efficient, therefore, if the maximum compression were constant during all ranges of load. In the design under consideration this feature is accomplished by allowing free air, or the products of combustion, when the engine is running at less than full load, to enter the cylinder first, and the gas charge last so that it will be adjacent to the spark-plugs at the ignition time. By designing the combustion-chamber so that it will maintain a stratified charge during compression, ignition is effective, irrespective of the number of heat units introduced or the mean effective pressure desired. In the gasoline fuel at present available the induced charge is composed mostly of air with liquid spheres floating in it, so that violent agitation during the heat of compression is necessary to convert the liquid particles into gas; but the time is so short that, even with the maximum amount of perturbation, a considerable part of the fuel content is unconsumed.

While turbulence seems necessary for ordinary variable-compression prime-movers, it would be fatal to a constant-compression engine the cycle of which depends upon stratification. To operate such an engine successfully, the fuel, before admission, must be converted into a fixed gas without raising the temperature of the air above the dew-point.

¹ Annual Meeting paper.

² M.S.A.E.—Research engineer, Bryan, Ohio.

When accomplished in the manner shown, a constant-compression engine is entirely feasible. It may be constructed with a distributing-valve that varies the time during which air and gas are admitted or with poppet-valves that control the intake gases in the same way. While such an engine should have practically the same efficiency at full load as engines of standard construction, the fuel consumption per car-mile on less than full load should be considerably less.

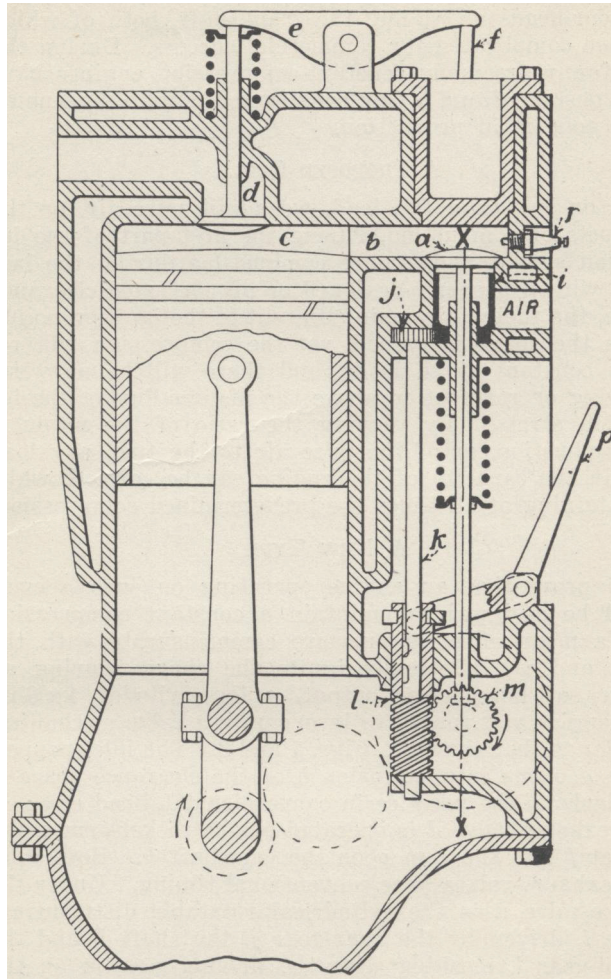
The only method now employed for controlling the speed of an automobile engine is throttling the intake, thereby reducing the quantity of explosive mixture admitted to the cylinders. While this method could hardly be improved upon for simplicity, it has two serious disadvantages that are recognized by the engineering profession.

Throttling the mixture to reduce the speed and load lowers the compression, a condition conducive to inefficiency, and reduces the absolute pressure above the piston during the induction stroke, materially increasing the fuel consumption. If, in running on less than full load the absolute pressure in the intake is 7.5 lb., the mean effective pressure during the corresponding working stroke would have to be 7.5 lb. higher than if this braking effect were eliminated. The desirability then of a constant-compression engine, in which the compression is just below the critical point of preignition at all loads and speeds, is apparent, especially in automobile engines, which run at less than one-quarter load about 90 per cent of the time.

THE DIESEL TYPE

The ultimate solution of the problem will, no doubt, be an engine of the Diesel type, in which the compression is inherently constant; but, for the present, an engine using available fuel, with normal but constant compression irrespective of the mean effective pressure, seems greatly to be desired. Reducing the fuel but not the air would solve the problem, if the attenuated mixture would ignite; but if there is less than 50 B.t.u. per cu. ft. of air at atmospheric pressure there will be no flame propagation; such a mixture, if the engine ran at all, would cause irregular and spasmodic firing, and much of the fuel would pass out unconsumed.

Decreasing the clearance as the induced charge is throttled will maintain a constant compression, but will



not overcome the loss caused by manifold rarefaction. Engines have been built in which the clearance volume can be changed with the load, either by lowering the cylinder-heads or raising the crankshaft, both of which are too complicated for commercial success. During the last few years many constant-compression engines have been described and a few constructed, but to my knowledge none is in production.

A PROPOSED CYCLE

If, on less than full load, we admit pure air, or the products of combustion, during the first part of the induction stroke, and a pure combustible during the last part, with a properly designed or proportioned clearance space, the fuel will remain adjacent to the ignition points when the spark is passed, yet the compression will remain constant at all loads, and there will be no wire-drawing or rarefaction above the pistons during the induction stroke. By varying the ratio of the products of combustion, or of the pure air to the fuel, any load within the capacity of the engine can be carried, while maintaining at all times the predetermined compression.

A NEW TYPE

To prove that an engine operating on such a cycle could be designed to maintain a constant compression and a mean effective pressure commensurate with the load, and yet effectually ignite the charge during all ranges of horsepower output, a four-cylinder 4 x 6-in. Erd engine was rebuilt to incorporate a valve mechanism similar to that shown in Figs. 1 and 2. The inlet poppet-valve *a* opens into extension *b* of the clearance space *c*, similarly to the practice in conventional L-head engines. The exhaust-valve *d* is operated by the rocker-arm *e*, the tappet *f* and the cam *g* on the camshaft *h*. Both inlet and exhaust-valves have conventional timing. Under the intake-valve *a* is the cylindrical rotatable distributing-valve *i*, driven by the spur-gear *j*, the shaft *k* and the spiral-gear *l*, meshing with the driving-gear *m* on the camshaft *h*. At full load the distributing-valve port *n* registers with the gas port *o* during the lift of the intake poppet-valve *a*, delivering only a pure mixture to the combustion-chamber.

As the load gets lighter and less mean effective pressure is required to maintain the speed desired, the distributing valve *i* is retarded in time with reference to

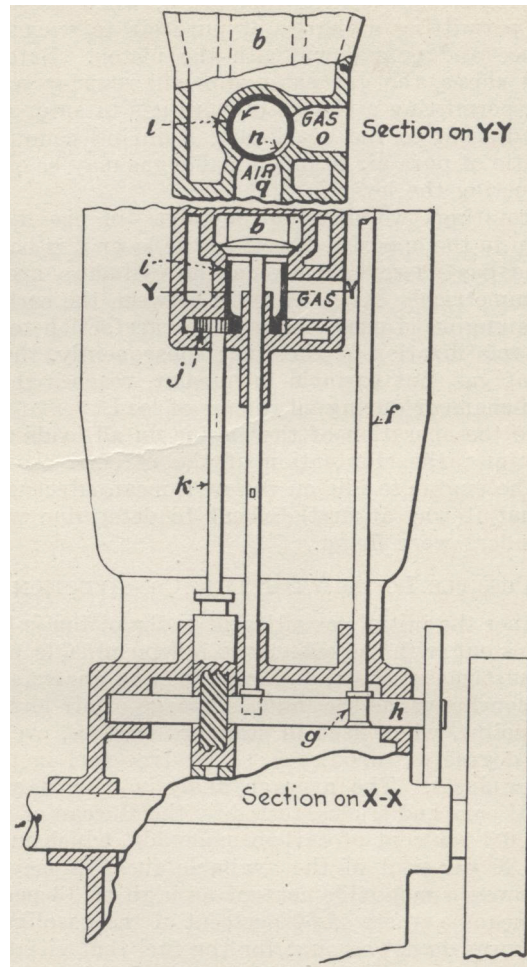


FIG. 2—SECTIONAL ELEVATION THROUGH THE VALVE AND THE DRIVING MECHANISM WITH A HORIZONTAL SECTION THROUGH THE DISTRIBUTING-VALVE AND THE GAS AND AIR PASSAGES ABOVE

the opening of the poppet-valve *a* by the control handle *k*, raising and rotating the spiral-gear *l* until the port *n* partly registers with the air-port *q*, when the valve *a* opens, permitting a charge of pure air to scavenge the clearance and pass down with the piston. Before the valve *a* closes, the gas passage *o* will register with the port *n*, permitting a charge of pure gas to enter and remain adjacent to the spark-plug *r* during compression. Any ratio of pure air to inflammable gas may be obtained by adjusting the lever *k*.

By rotating two distributing-valves in one direction and two in the opposite direction, the lever *k* is balanced, and the gas passages between the cylinders are short and symmetrical. As no throttle between the carbureter and the engine is used, there is no rarefaction to assist in the volatilization of the fuel; consequently, the same grade of gas, but variable in amount, reaches the combustion-chamber during all ranges of load.

While the operation of the engine on all loads seemed satisfactory, the elimination of the rarefied charge allowed the engine to idle on so low a mean effective pressure that it was at first difficult to determine whether all cylinders were firing.

POSSIBLE LOSSES WITH THIS CONSTRUCTION

Whether the initial gas adjacent to the piston is burned or passes out with the exhaust is indeterminable without an exhaust-gas analysis, and even such an analysis would not be conclusive, as the induced charge of air and available gasoline, when used in standard engines, even with a high degree of turbulence, shows free fuel in the exhaust products. The average analysis of exhaust gas from 101 cars and trucks, tested by the Bureau of Mines, showed 6.5 per cent of carbon monoxide, which means a loss of 30 per cent of the available fuel. Some of the cars showed a monoxide content as high as 13 per cent, which means a waste of 50 per cent of the gasoline; and these figures do not account for the fuel that vitiates the lubricating oil when, in liquid form, it reaches the combustion-chamber and passes down to the crankcase.

As practically all present-day fuel available requires 500 deg. fahr. to volatilize the heavy ends, and as such a temperature of the intake air is fatal to the volumetric efficiency of an engine, a large proportion of the fuel passes to the combustion-chamber in the form of little liquid spheres floating in pure air. As every fuel sphere

requires 10,000 times its volume of pure air for perfect combustion, and as liquid spheres, no matter how small, cannot burn before they are converted into gas, we see the desirability of violently agitating the air and the liquid particles, during the fractional part of the second that the heat of compression is available, to break up these liquid spheres by attrition into a mixture approaching a fixed gas.

Turbulence increases the thermal efficiency in an internal-combustion engine, except when natural or a fixed gas is used for fuel; yet no matter how violently the in-

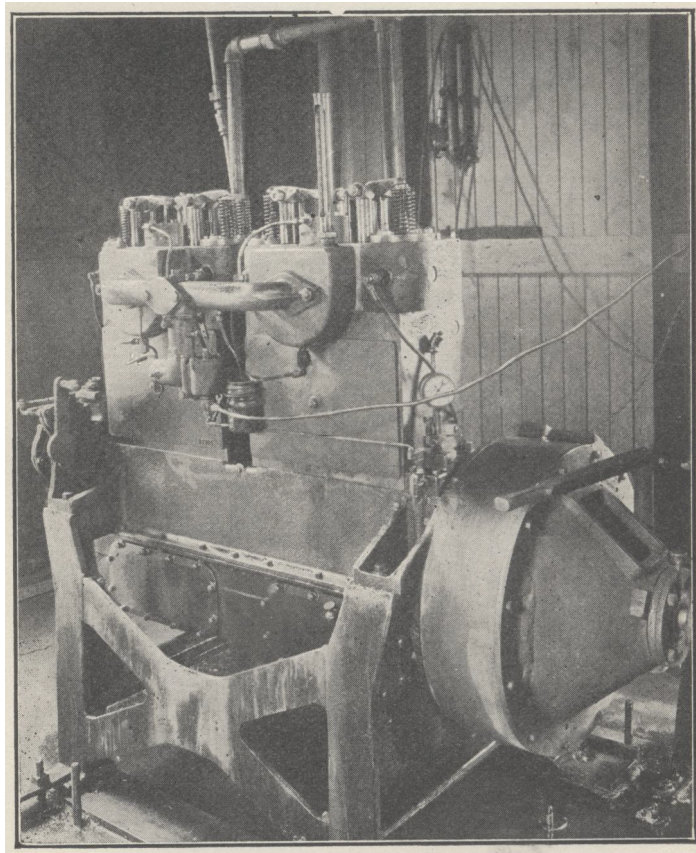


FIG. 3—THE EXTERIOR OF THE CONSTANT-COMPRESSION ENGINE USING POPPET-VALVES FOR THE ADMISSION OF THE AIR AND THE FUEL

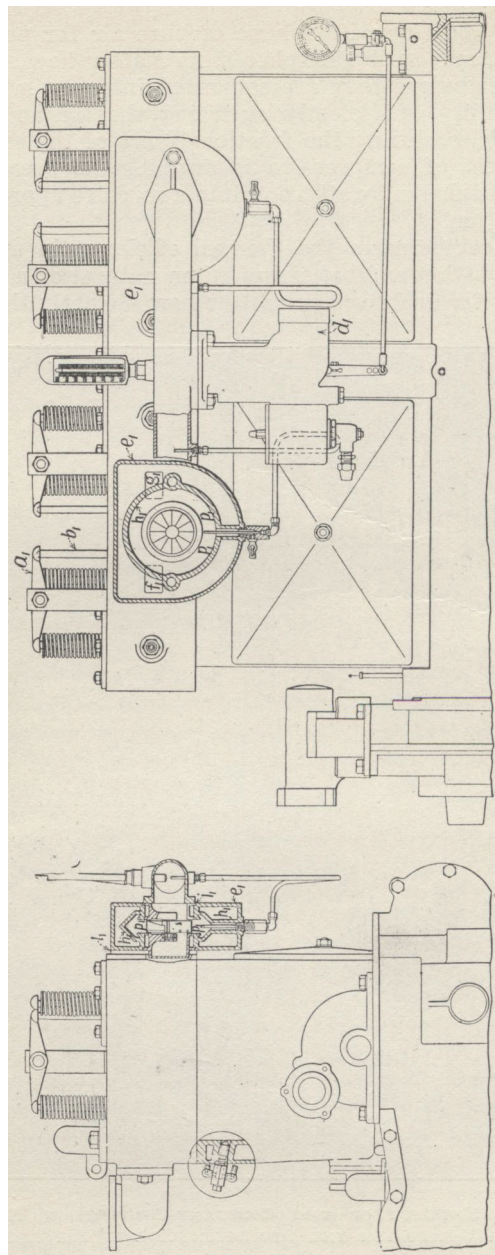


FIG. 4—END ELEVATION AT THE LEFT, AND AT THE RIGHT A SIDE ELEVATION OF THE CONSTANT-COMPRESSION ENGINE SHOWN IN FIG. 3

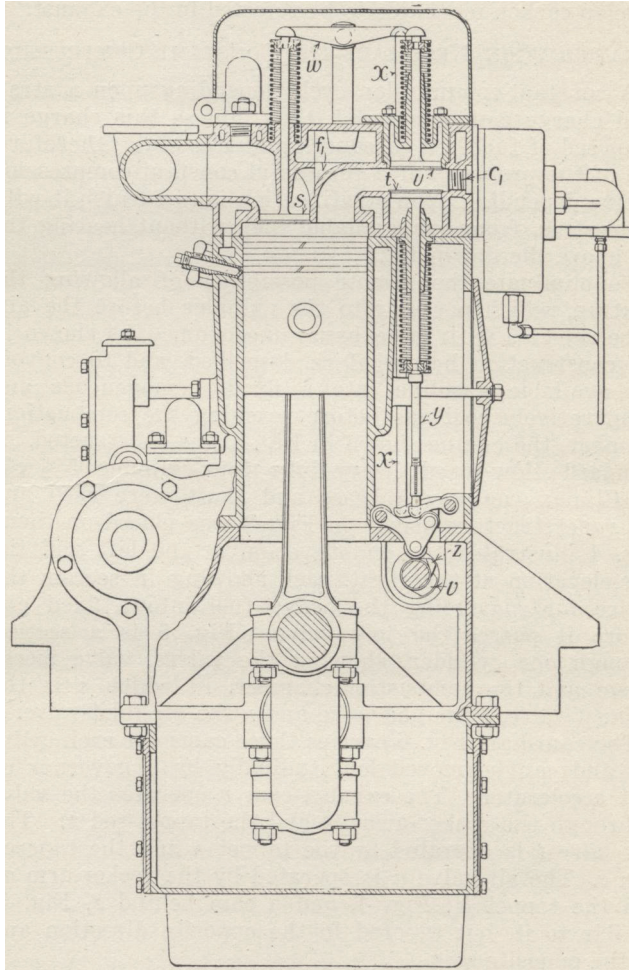


FIG. 5—SECTION THROUGH THE CYLINDER AND THE COMBUSTION-CHAMBER OF THE ENGINE

duced charge is agitated, when it is composed of liquid fuel and air, the time of gasification is so short that there will still be unburnt liquid at the end of the combustion stroke to contaminate the crankcase oil and develop carbon monoxide to be rejected in the exhaust.

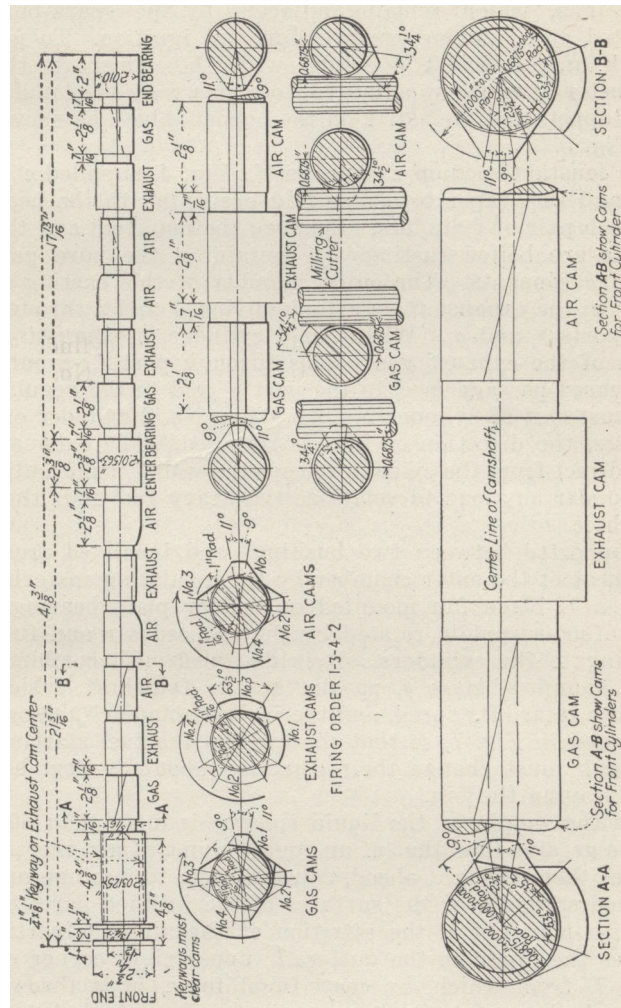
STRATIFICATION NECESSARY FOR CONSTANT COMPRESSION

A constant-compression cycle depending upon a stratified charge cannot succeed, then, unless this charge is composed of fuel in a gaseous, liquid-free state; therefore, one of the problems of a successful constant-compression engine depending upon stratification is to furnish it with a pure gas, from our available fuel, without heating the air above the dew-point.

To eliminate the remote possibility of allowing the mixture, which passes into the cylinder before the air, to be rejected with the exhaust unconsumed, as shown in the construction hereinbefore described, and to convert the available gasoline into a fixed, homogeneous and comparatively cool gas before reaching the combustion-chamber, the engine shown in Fig. 3 was constructed. A standard slow-speed heavy-duty four-cylinder $5\frac{1}{2} \times 7$ -in. Climax engine crankcase and shaft were used and the superstructure shown in Fig. 3 was placed on them. Fig. 4 illustrates the end-elevation at the left and the side-elevation at the right, each showing in section the device for converting the heavy fuel into a fixed gas before it passes the inlet-valve. Fig. 5 is a section through one cylinder, showing the valves, valve mechanism and the combustion-chamber, in which *s* is the exhaust-valve, *t* the gas-valve and *u* the air inlet-valve.

The camshaft Fig. 6 carries three cams for each cylinder and can be moved longitudinally by a governor or foot accelerator. The exhaust-cam *v* operates the valve *s* through the rocker-arm *w* and the tappet-rod *x*. The gas-valve *t* is operated by the tappet *y* and the tapered cam *z*. The air-valve *u* is operated by the rocker-arm *a*, and the tappet *b*, Fig. 4, and a cam behind *z*, Fig. 5, similar to it, but tapered in the opposite direction and on the opposite side.

The exhaust-valve has standard timing. The gas-valve at full load has standard timing, but as the camshaft is moved endwise, the time of opening the gas-valve becomes later as the load gets lighter. The air-valve does not open at full load, but as the load decreases and the camshaft is moved to give less gas, the air-valve opens



at the beginning of the induction stroke and closes shortly after the gas-valve has opened.

At less than full load pure air enters the combustion space first, then, for an instant, air and gas, and finally pure gas, which remains adjacent to the spark-plug located at c , during compression and ignition. To get quick and sufficient openings with the camshaft, the diameter of which was limited, toe cams were used under the tappets and the skirts on the poppet-valves, as shown in Fig. 5.

A constant-vacuum carbureter d , Fig. 4, supplied cold air and fuel vapor to a manifold branching to the head of each pair of cylinders. Between the manifold and the heads are bolted castings e , containing the pure gas-making elements. The outer chamber of this casting is open to the exhaust from cylinders Nos. 1 and 2 through the ports f and g . When No. 1 cylinder is exhausting, part of the exhaust gas passes through port f , around the cored passage in e to the port g and to the regular exhaust exit of cylinder No. 2. When No. 2 cylinder exhausts, the direction of flow is reversed. The exhaust-gas direct from the cylinders keeps the wall h sufficiently hot under any load to volatilize the heavy fuel-ends that reach it.

Supported between two bushings and insulated from the heat of the outer chamber by the insulating material i , is a 12-blade fan mounted on ball or plain bearings. This fan is rapidly rotated by the induced air and fuel flowing to the cylinders. It is designed with combination damping-blades j , parallel to the fan-shaft, which tend to retard its speed, and the inclined blades k , shown enlarged in Fig. 7, so that the air and the fuel starting through must change their direction about 30 deg. before leaving the fan.

As the weight of the liquid spheres is more than 600 times greater than that of an equal volume of air, inertia drives them straight ahead, causing them to impinge upon and spread over the surfaces of the inclined parts of the fan-blades, and the attrition of the air and inertia drives the liquid to the gutters l , upper right corner of Fig. 7, from which, by centrifugal force, it is thrown through the registered openings m , against the hot surface of the wall h , where the liquid fuel is converted into fixed gas.

If the liquid fuel reaches the inside of the fan-housing n , before it reaches the gutters, the lip o , will guide it to

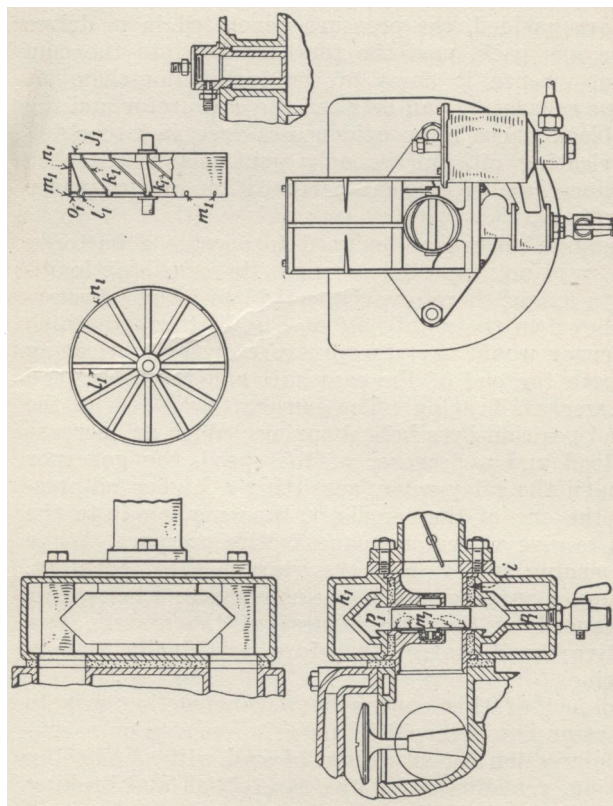


FIG. 7—THE FUEL-SEPARATING FAN USED ON THE ENGINE
 Details of the Vanes or Blades Are Given in the Upper Right Corner, While
 the Application of the Fan to the Engine Cylinder Is Shown in the Re-
 maining Views, a Section Being Reproduced in the Lower Left Corner

the holes m_1 , where it will mingle with the gutter fuel and fly to the insulating chamber. As the heat of the exhaust, insulated from the airstream, affects only the liquid fuel that reaches the wall h_1 , it would have no deleterious effect on the engine power if the fuel used were petroleum ether.

When the heavy ends of liquid fuel reach the hot wall h_1 and are gasified, the pressure generated in p_1 drives the pure gas back, past the fan-housing, into the cold airstream, whence it flows to the combustion-chamber. With this separating fan between the carbureter and the engine block, there is no evidence of free fuel reaching the lubricating oil, and as only pure gas reaches the combustion-chamber, violent perturbation or turbulence is superfluous.

The engine governor, designed to operate a butterfly throttle, was not expected to move the camshaft longitudinally; it was, therefore, connected to a balanced relay-valve, shown in the right half of Fig. 4, through which the governor would vary the pressure of the lubricating oil between the end of the camshaft and the closed end of the camshaft bearing. The camshaft was held in the light-load position by a helical spring. With an increase of the load and a decrease of the speed, the governor would open the relay-valve, admitting a higher oil-pressure to the end of the camshaft, thus moving it to the position to give a greater mean effective pressure. While this governing system held the average speed constant, the racing or surging of the engine above and below this speed, caused by the sluggishness of the system, was prohibitive; hand control, therefore, was finally used in this engine.

The object of this experimental construction was to show that an engine could be made to operate on a constant compression for all ranges of load without missing in ignition, yet eliminating the rarefaction and braking effect found in standard engines using throttling control. At full load, the efficiency of such a cycle should be no better than that of the ordinary engine, other things being equal, but at light loads, at which the automobile more often operates, a saving in fuel should be effected. Compared with a standard 4 x 6-in. throttling engine of the same make as was used in constructing the engine shown in Fig. 1, the constant-compression engine, when idling at the same speed, ran 17 per cent more revolutions per unit of fuel.

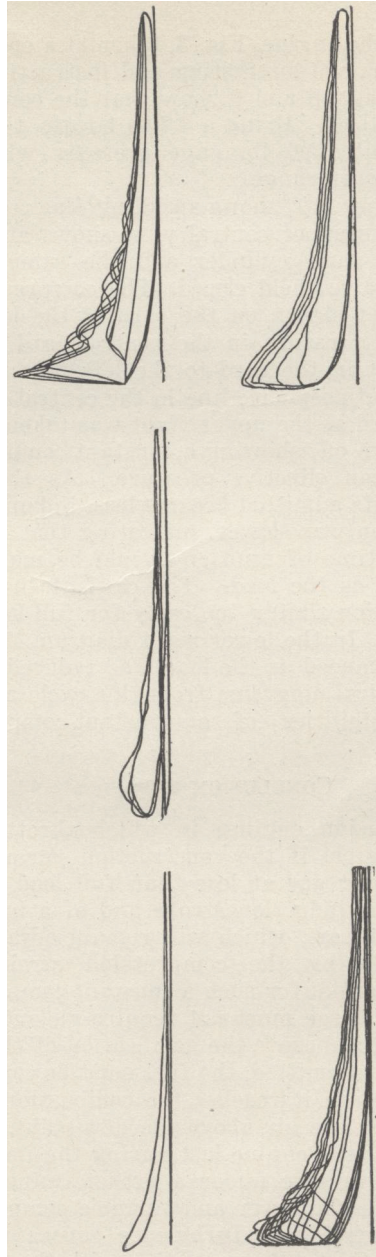


FIG. 8—REPRODUCTIONS OF INDICATOR-CARDS OBTAINED FROM THE CONSTANT-COMPRESSION ENGINE AT DIFFERENT LOADS. The Indicator-Card at the Upper Left Is an Idling Diagram from Cylinder No. 1, the Middle Card in the Upper Row Is Another Idling Diagram from Cylinder No. 1 with the Air-Valves Held Closed, and the Card at the Upper Right Was Taken as the Full Load Was Thrown Off and Shows a Constant Compression but a Variable Mean Effective Pressure. The Indicator-Card Reproduced in the Lower Left Corner Shows an Ignition Timing That Is Too Early for Full Load and Too Late for Idling, While in the Card at the Lower Right the Time of Ignition Was Advanced as the Load Was Reduced.

Diagrams from the engine, Fig. 3, taken at a speed not to exceed 600 r.p.m., are interesting and instructive, and as reproduced in Figs. 8 and 9 show that the conditions anticipated are realized. Using a 4.7 to 1 ratio, the compression approximates 90 lb. gage pressure with full mean-effective-pressure range.

Fig. 8, at the upper left, shows an idling diagram from cylinder No. 1. The upper central view shows an idling diagram from the same cylinder and the same idling load with the air-valves held closed. The compression is about one-third that shown on the card at the left and the mean effective pressure in the central card equals, approximately, that in the card to the left plus that of the loop below the atmospheric line in the central card.

The indicator-card at the upper right was taken as the full load was thrown off, showing a constant compression but a variable mean effective pressure. As the total number of heat-units admitted became less, inflammation or flame-propagation was slower, indicating that for the best efficiency the time of ignition should be materially advanced inversely as the load. The card at the lower left shows an ignition timing too early for full load and too late for idling. In the lower right diagram the time of ignition was advanced as the load was reduced.

Fig. 9 shows typical diagrams from this cycle and emphasizes the possibilities of a constant-compression engine.

CONCLUSION

Constant-compression engines in which throttling is eliminated are feasible if the construction permits the admitting of an inert gas at less than full load during the first part of the induction stroke and of a burnable gas during the last part, which will remain adjacent to the spark-plugs during the compression stroke. As stratification is essential for such a constant-compression cycle, the induced charge must not require violent agitation or turbulence to improve the gasification of the fuel. If turbulence is not permitted, the fuel must be converted into a fixed gas before it reaches the combustion-chamber, without heating the air above the dew-point. With a fixed gas entering the engine last during the induction stroke, ignition is as sure under a predetermined high compression as with the lower and variable compression of throttling engines, when turbulence causes a commingling of the products of combustion with the gas.

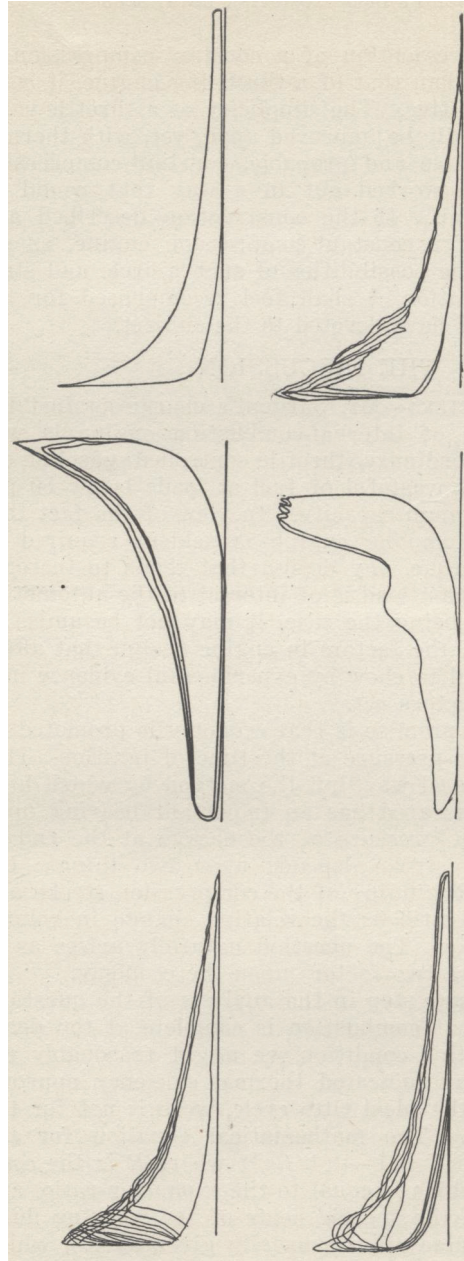


FIG. 9—ANOTHER SET OF TYPICAL DIAGRAMS OBTAINED WITH THIS ENGINE

The Indicator-Card Reproduced in the Upper Left Corner Was Taken at a Speed of 550 R.P.M. and a Variable Load; in the Upper Central Card, the Speed Was Increased to 600 R.P.M. and the Engine Was Fully Loaded; the Card in the Upper Right Corner Was Taken at a Speed of 500 R.P.M. and a Three-Quarter Load. The Diagram Reproduced in the Lower Left Corner Was Taken at a Speed of 500 R.P.M. and a Variable Load and the Lower Central Card, Like the One above It, Was Taken at Full Load and 600 R.P.M. The Card in the Lower Right Corner Was Taken at a Speed of 600 R.P.M. with Fixed Ignition Which Was Too Late at Light Load and Too Early at Full Load

While the valve motion of a constant-compression is more expensive than that of a throttling engine, it is by no means prohibitive. The simplicity of a throttle-valve engine could hardly be improved upon, yet, with thermal advantages possible and probable, constant-compression control could be worked out in a way that would be satisfactory to all. If the construction described and the essentials of a constant-compression engine, as set forth, open up the possibilities of such a cycle and start further investigation, I shall feel recompensed for the time and study I have devoted to the subject.

THE DISCUSSION

H. A. HUEBOTTER:—Mr. Sargent's charge against the automotive type of internal-combustion engine is well founded. The ordinary throttle-controlled gasoline-engine is decidedly wasteful of fuel at loads below 50 per cent of its maximum capacity. In view of the fact that the average automobile engine is seldom required to exert its full torque, any design that tends to increase the economy at part load is of interest to the automotive engineer. This being the case, it may not be amiss to consider some of the factors in engine design that affect fuel economy and to show by experimental evidence how some of these factors act.

Mr. Sargent's premise is that economy is promoted by high compression-pressure at the time of ignition. This is true in a general way, but the method by which high compression is secured has an important bearing upon the results. The pressure of the charge at the end of the compression stroke depends upon two things: the pressure at the beginning of the compression stroke and the compression-ratio or the relative change in volume during the stroke. The question naturally arises as to the effect of these two factors upon the economy.

As a preliminary step in the analysis of the question, let us assume that combustion is complete at top dead-center. Under this condition we might reasonably expect to realize an indicated thermal efficiency approximating that of the ideal Otto cycle, were it not for the radiation losses. The mathematical equation for the ideal efficiency is $E = 1 - (1/R^{n-1})$ where R is the compression-ratio, which is equal to the expansion-ratio, and n is the ratio of the specific heats of the working fluid. The empirical value of n is usually given as 1.3, which is not far from the average gas constant at the working

temperatures of the engine. The above equation simply states in quantitative terms that the more the gas is expanded in the cylinder after combustion, the greater is the proportion of its thermal energy that can be converted into work. It is worthy of note that this equation does not recognize the effect of compression pressure, but is based upon the assumption of combustion at constant volume. Rapid combustion is assisted by high compression-pressure, proper fuel-air proportion, turbulence, and the absence of diluent gases in the charge.

To what extent the ideal thermal-efficiency is obtained in practice can be learned by laboratory investigation. In Fig. 10 are plotted the values of the indicated thermal-efficiency of an engine running at a constant speed on the same quality of fuel-air mixture. The engine had originally been built with a compression-ratio of 4.45, which gave a compression pressure of from 75 to 80 lb. per sq. in. gage. The compression-ratio was later raised to 6.75 and the compression pressure went to 120 lb. per sq. in. gage. Neither of the efficiency curves shows an alarming variation within the upper two-thirds of the indicated-horsepower range. It seems probable that, over this range, the change in the combustion rate due to the change in the compression pressure and in the proportion of inert gas from the preceding cycle was compensated for almost entirely by the variation of the spark-advance. The percentage of heat radiated to the water-jacket is, however, much greater at light loads than at heavy loads, which fact would account for the slight drop in efficiency. For example, at 14 i.hp., with the high-compression ratio, the jacket loss was 900 B.t.u. per min.; whereas, at 28 i.hp., it was 1250 B.t.u. per min., this being a 40-per cent increase in radiation for a 100-per cent increase in load. The compression pressure at the lightest load in the upper curve was about 50 lb. per sq. in. gage. The greatest variation in efficiency between 50 and 120 lb. per sq. in. gage from the full-load efficiency was less than 10 per cent of the latter value. The compression pressure at the point *a* on the upper curve was slightly less than that at point *b* on the lower curve. The greater expansion of the burned charge, however, increased the thermal efficiency 28 per cent at the same compression-pressure and from 20 to 30 per cent at the same loads. Unfortunately for the present discussion, the load on the high-compression engine was not carried below 25 per cent of the maximum

brake-load. On the low-compression engine, the point *c* corresponds to 25 per cent brake-load, below which the efficiency drops rapidly. The effect of low compression-pressure is very pronounced at the light loads.

The curves in Fig. 10 illustrate two facts very clearly. These facts should be kept in mind as fundamental in any attempt at improving the economy of an internal-combustion engine. They are that (*a*) the indicated thermal-efficiency of an engine is a function of its expansion-ratio and (*b*) the indicated efficiency is a function of the time required for combustion.

To obtain a high brake-thermal-efficiency, the friction losses in the engine must be reduced to a minimum. It is interesting to note that Mr. Sargent's engine eliminates the high pumping-loss of the throttled engine at light load.

I wish to call attention to the fact that the highest point of each curve in Fig. 10 represents an efficiency of 58 per cent of that given by the equation for the ideal efficiency of the gasoline-air cycle. The fuel-air mixture-ratio was 0.08, or 12.5 lb. of air per lb. of gasoline. With a 0.0625 or 16 to 1 ratio, the efficiencies were 70 per cent of the ideal.

C. H. SCHWEITZER:—Mr. Sargent has made some interesting and valuable experiments; however, the data presented do not prove the feasibility of a constant-compression engine of the type described for automotive use. Mr. Sargent's proposed cycle is known in gas-engine design as "mixture or quality regulation," thus differing from the "charge or quantity regulation" that corresponds to the throttling of the gasoline engine. This mixture regulation has certain decided disadvantages such as (*a*) ignition is possible only within the limits of certain mixture-ratios and only one among them gives the best fuel-economy and (*b*) too lean mixtures, as used at light loads, cause missing or after-burning. Mr. Sargent tried to eliminate this disadvantage by a stratification of the charge, to get a quick ignition in the rich mixture adjacent to the spark-plug. To reach this result, he partly eliminates the turbulence in the cylinder and replaces it with an outside turbulence produced by fans. He says, "as only pure gas reaches the combustion-chamber, violent perturbation or turbulence is superfluous."

This is a mistake. Mr. Sargent has misunderstood the part that turbulence plays in the combustion. The most important effect of the turbulence is the speeding-

up of the combustion. I recall the striking experiments of Dugald Clerk with a gas engine. He ran the engine under normal conditions and obtained a regular diagram; then he shut off the ignition and, a little later, the intake and the exhaust-valve were shut. In this way, the turbulence in the cylinder was damped and then came to rest. When he turned on the ignition again, he obtained a much lower and an entirely undesirable diagram that showed considerable after-burning. Prof. G. B. Upton, in a paper entitled Spark-Advance in Internal-Combustion Engines,³ concluded from Hopkin-

³ See TRANSACTIONS, vol. 18, part 2, p. 98.

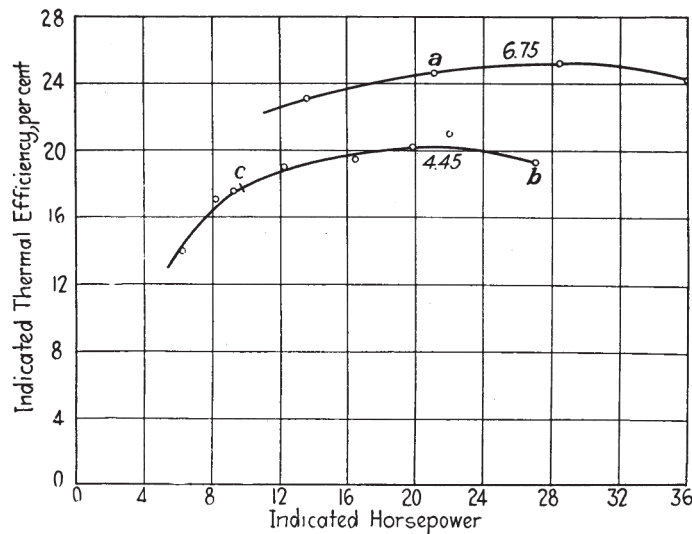


FIG. 10—EFFECT OF THE COMPRESSION-RATIO AND THE LOAD UPON THE THERMAL EFFICIENCY

The Curves Give the Values of the Indicated Thermal Efficiency of an Engine Running at a Constant Speed on the Same Quality of Air-Fuel Mixture. The Lower Curve Was Obtained at the Original Compression-Ratio of 4.45 to 1, Which Gave a Compression Pressure of from 75 to 80 Lb. per Sq. In. The Compression-Ratio Was Subsequently Raised to 6.75 to 1, Which Increased the Compression Pressure to 120 Lb. per Sq. In. The Upper Curve Was Obtained at This Ratio. Neither of the Curves Shows a Great Variation within the Upper Two-Thirds of the Indicated-Horsepower Range. Over This Range the Change in the Combustion Rate Due to the Change in the Compression Pressure and in the Proportion of the Inert Gas from the Preceding Cycle Was Probably Compensated for Almost Entirely by the Variation in the Spark-Advance. These Curves Illustrate Two Facts That Should Be Kept in Mind as Fundamental in Any Attempt To Improve the Economy of an Internal-Combustion Engine. They Are That (a) the Indicated Thermal Efficiency of an Engine Is a Function of Its Expansion-Ratio and (b) the Indicated Thermal Efficiency Is a Function of the Time Required for Combustion

son's experiments that "turbulence cuts the explosion time in two at 1000 r.p.m., divides it by 3 at 2000 r.p.m., and so on. In racing engines the explosion times drop to 1/5, and in engines with small cylinders they drop perhaps to 1/10." Thus, the elimination of turbulence is a poor way to increase the economy and is probably inapplicable to high-speed engines. This is proved also by Mr. Sargent's indicator-diagrams. I have analyzed the second one in Fig. 9 of his paper, which looks the best, by the exponential method, and found considerable after-burning. Even in the case of an absence of turbulence, the stratification of the cylinder content would be incomplete. The spent gases at the beginning of the induction stroke have a higher pressure and temperature than has the mixture sucked in later. This accelerates the mixing and decreases the inflammability of the mixture, as shown also by Mr. Sargent's diagrams taken at part load with unchanged ignition-timing.

In the engine described, a decrease of turbulence is obtained by allowing a full-area air-passage, thus decreasing the air velocity. This has another undesirable effect. Successive mixtures for the same load conditions will not be of uniform composition at the ignition points. This will cause variable explosions, resulting in variable torque and fluctuating speed in multi-cylinder engines. This conclusion is borne out by the spreading diagrams obtained by Mr. Sargent. Another disadvantage in an automobile engine of the type described would be that it would have full compression at starting, making cranking more difficult. I should like to ask Mr. Sargent if the hot surface of the wall *h* is hot enough to vaporize all the fuel at light load and cool exhaust when there is no rarefaction to assist vaporization.

I agree with Mr. Sargent's opinion that "the ultimate solution of the problem will, no doubt, be an engine of the Diesel type." This will eliminate the justifiable criticism Mr. Sargent has made of the present type of automotive engine without adding most of the deficiencies mentioned.

C. E. SARGENT:—Dugald Clerk's experiments referred to, of cutting out the ignition and keeping all valves closed for several engine revolutions before firing the mixture, in which a lower mean effective pressure is obtained, do not prove that turbulence is necessary for a high thermal-efficiency. In fact, churning the mixture

back and forth during several piston strokes ought to cause a better commingling of the confined gases. The cause of the lower mean effective pressure might have been leakage and loss of heat to the cylinder-walls.

As to the importance of turbulence in speeding-up combustion, a dry homogeneous mixture does not need turbulence; you cannot get out of the gas any more heat than there is in it, in spite of unlimited stirring. If the exhaust shows no carbon-monoxide content or no unburnt mixture, good combustion will be obtained.

Rapid inflammation, caused by turbulence, Mr. Schweitzer claims, means high thermal-efficiency. It can be too rapid. If we burn hydrogen without retarding the ignition, we get an initial pressure that is five or six times the compression pressure, permitting the heat to be absorbed by the walls before the piston starts. Consequently, we get very poor thermal-efficiency when the inflammation is too quick. From experiments made 20 years ago, it was found that the highest thermal-efficiencies were obtained when the angle of inflammation was about 15 deg. past the vertical. With such timing the piston is moving as the volume increases, thereby preventing a loss of heat to the cylinder walls.

My experience as regards starting with constant compression has been that we get full compression in cranking a cold engine, no matter how much it may be throttled. Yet, with the throttle wide-open, a starter will crank the engine with full compression about as quickly as it will without it.

QUESTION:—Is the heat at idling loads sufficient to gasify the fuel when there is no rarefaction?

MR. SARGENT:—I presume that, ordinarily, rarefaction materially assists gasification if sufficient heat is not available, but with the device I described the liquid fuel, away from the air, is heated by the exhaust gases, so that rarefaction is superfluous.

QUESTION:—What is the total friction and pumping-loss at approximately one-quarter load on constant-compression engines as compared with that of throttling types under the same conditions?

MR. SARGENT:—I do not know. Experimenting in a machine shop is different from experimenting in a research laboratory. The only comparable result that I obtained was that on light loads the revolutions per unit of fuel with the constant-compression engine were 17

per cent more than with the same engine throttling, which is not enough to make much difference.

QUESTION:—Did you note any carbon due to the cracking of the fuel in the exhaust heating-chamber?

MR. SARGENT:—No. I have examined the exhaust heating-chamber after making a long tour, and have found a considerable quantity of the same kind of stuff that you find in the explosion-chamber, a sort of brown dust and dirt. I have never seen enough carbon accumulation to require cleaning or to insulate the fuel from the exhaust. Upon examining the fan, after driving on the road, I found that the front side was scoured and polished; and upon investigation it appeared that much of the dirt that went into the air was caught in the film of oil and delivered to the heating-chamber, in the same way as with the heavy fuel.

QUESTION:—Do the extra cam-gears present unusual difficulties in making quiet operation?

MR. SARGENT:—The engine was very noisy before it was changed over to constant compression and the change did not improve it. The camshaft presented a problem to its makers. They made two and shipped them before they found out exactly how to make them; and after they learned that the tapered cam was a warped surface and could easily be made with a milling cutter, they said they could make a camshaft nearly as cheaply as they could the ordinary typical camshaft.

QUESTION:—Is not the wear on the cams and the followers considerable, due to localized contact on the tapered cams?

MR. SARGENT:—I thought that it would be. The roller, of course, is crowned, so that it will follow the tapered cam and always travels on the center. After a long series of experimental runs, it was examined very carefully; the roller showed no evidence of wear. The theoretical line of contact was about $3/32$ in. wide and highly polished, showing that its elasticity gave it considerable bearing.

QUESTION:—Is not a 17-per cent gain in fuel economy at light load much below that expected or possible?

MR. SARGENT:—I think it is. I gave that only because it was all the recorded evidence I had on the subject. I think we can get better results than that under the proper conditions.

QUESTION:—In the so-called "Dempsey cycle," air being admitted near the outer center of the piston through

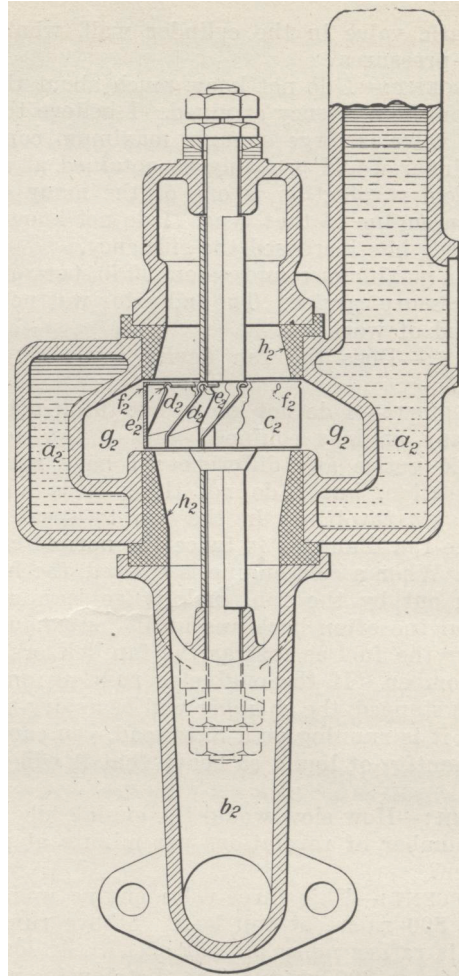


FIG. 11—ENLARGED TRANSVERSE SECTION OF THE GASIFYING DEVICE

The Function of This Device Is To Separate the Particles of Liquid Fuel from the Air Stream and Convert Them into a Dry Gas before They Enter the Cylinders. The Temperature of the Exhaust Passage a_2 Is Maintained Practically Constant throughout All Ranges of Load for, although the Exhaust Passage Becomes Hotter as the Load Increases, More Air Flows Through

an automatic valve in the cylinder wall, what are the maximum pressures?

MR. SARGENT:—I do not know much about the Dempsey cycle or the efficiency attained. I believe that if the automatic valve is large enough, maximum compression in the cylinder would probably be obtained at all loads; but manifold rarefaction is one of the many disadvantages of an engine of that type. I do not know whether Mr. Dempsey has increased the efficiency.

As to the maximum compression, 90 lb. per sq. in. gage was the pressure carried. The indicator was not adapted to this kind of work.

QUESTION:—Does the fan device cause sluggish acceleration?

MR. SARGENT:—I do not know, but think not. I have driven many engines equipped with a fan device and never could notice any difference; I have never timed the acceleration, but I do not think it is appreciably sluggish. No throttling in the fan to speak of takes place. The fan diameter is twice the normal carbureter diameter. When a cold engine is started, the heavy fuel is thrown out by the fan, making so lean a mixture that the engine often backfires until the exhaust begins to vaporize the fuel as fast as the fan delivers it to the heated chamber. If the engine is running on a heavy load and is stopped, the chamber will be as dry as a bone; but, when it is running on a light load, you can draw off a small quantity of liquid so heavy that it will put out a match.

QUESTION:—How slow would the engine idle and what was the number of revolutions per minute at maximum horsepower?

MR. SARGENT:—This three-valve engine was supposed to run at 800 r.p.m. at full load. I have run it up to 1000. It is rather noisy at that speed. At low load, it idled as low as 300 r.p.m. The distributing-valve type of engine would run very low indeed; it would idle down to 100 r.p.m. with a heavy flywheel.

QUESTION:—Does fuel dispelled by the fan return to the carbureter?

MR. SARGENT:—Under normal conditions the fuel dispelled by the fan does not return to the carbureter but is converted into gas and returns to the airstream from which it came. To explain the action of the fan or the liquid separator, I refer to Fig. 11, which is an enlarged transverse section of the device. Liquid fuel floating in

or carried along by the airstream consists of little spheres, only the surfaces of which can burn but not until they have been converted into gas. Coal, pulverized until it will pass through holes so small that the combined area of 40,000 of them is less than 1 sq. in., is composed of irregular flakes having probably 10 times as much surface per unit of volume as have liquid spheres, travels 50 ft. and requires several seconds of time before it is consumed. We see then that liquid fuel passing toward the combustion-chamber must be separated from the air and changed into a dry gas before it enters the cylinders, if complete combustion is to be realized. In Fig. 11, *a*, represents the exhaust passage and *b*, the air and fuel leaving the carbureter. As the air carrying the fuel flows toward the combustion-chamber, it drives the fan *c*, at a high velocity. This fan is designed so that the air must change its direction in passing through, about 30 deg., while the liquid spheres, which are about 600 times as heavy as the air per unit of volume, going straight ahead, impinge on the inclined blades *d*, and by inertia flow to the gutters *e*, from which by centrifugal force they are thrown through the housing holes *f*, to the chamber *g*, surrounded by the exhaust passage *a*. If the heat in the exhaust is sufficient to convert the liquid into gas, a pressure is generated in *g*, and it works back past the fan edges to the airstream. As the air should not be heated above the dew-point, its temperature is controlled by the thickness of the Bakelite insulators *h*. When the load increases the exhaust passage gets hotter but, as more air flows through, its temperature is maintained practically constant through all ranges of load. As the constant-compression engine described has an abnormally cold exhaust at light load, provision was made for returning the heavy fuel to the airstream as it leaves the carbureter. An overflow pipe located $\frac{1}{4}$ in. below the lower edge of the fan returned the accumulated fuel to the manifold during idling loads, but is unnecessary in standard engines, as the exhaust has sufficient heat even at light loads to vaporize the heavy ends.