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No. 356

THE FUNDAMENTAL PRINCIPLES OF HIGH-SPEED SEMI-DIESEL ENGINES

By Dr. Büchner

PART I

A GENERAL DISCUSSION OF THE SUBJECT OF FUEL INJECTION IN DIESEL ENGINES AND DETAILED DESCRIPTIONS OF MANY TYPES OF INJECTION NOZZLES

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PART I.

A General Discussion of the Subject of Fuel Injection in Diesel Engines and Detailed Descriptions of Many Types of Injection Nozzles.

In today's lecture I will more fully develop a few ideas which I could only briefly allude to at last year's session of the "Brennkrafttechnischen Gesellschaft," since they were but loosely related to the subject ("The Combustion of Heavy Oils in Carburetor Engines") then under consideration.

At that time I raised three fundamental questions, which should indicate the direction to follow (aside from carburetor engines) for technical progress in the utilization of heavy oils.

The first question was "How much longer shall it be before solid injection shall receive in Germany the consideration due it not only for stationary and marine Diesel engines, but also for high-speed automobile engines?" I reminded you of a recent remarkable invention, the Deutz VM engine. The exceed-

* From "Jahrbuch der Brennkrafttechnischen Gesellschaft," Volume V (1924), pp. 59-75. Parts II and III will be issued as Technical Memorandums Nos. 357 and 358.

ingly small fuel consumption of 166 grams (5.8 ounces), obtained by Professor Maier in Stuttgart for an effective power of 320 HP., indicated something extraordinary and demonstrated the need of a thorough revision of the prevailing views on fuel injection by means of compressed air (Fig. 1).

The second question was "How long will the hot-bulb engine be treated in Germany as an obsolete link in the development of internal combustion engines, although the firm of Heinrich Lanz, of Mannheim, with its "Bulldog", has shown how well the hot-bulb engine can be adapted to the severe requirements of vehicular traffic?" (Fig. 2).

The third, and indeed the most comprehensive question, I clothed in the following language: "Is it not time to investigate more thoroughly than heretofore (along with the heat losses inside internal combustion engines) the processes on which the formation of combustible, rapidly-burning mixtures depends?" Much-divided combustion chambers, as now often constructed (e.g., Dr. Heidelberg's combustion chamber, Fig. 3), may appear of doubtful advantage from the viewpoint of heat losses, but raise the question as to whether the active side of the heat balance of the internal combustion engine does not merit more consideration along with the passive side. In fact, the task of obtaining as complete a mixture as possible must supersede, or at least equal in importance, the question of heat losses. I consider this one of the most important requirements, even

for the special type of engine we are about to consider.

It has required many years of painstaking work to discover in some degree upon what the completeness of the combustible mixture depends and to invent the mechanical devices for producing a complete mixture of the components (fuel and air) in the short time available. As regards the formation of the mixture, no final conclusion has yet been reached, from either the theoretical or practical viewpoint. It has been found advantageous, however, in addition to measuring the excess of air, to devote more attention than hitherto to the separation of the fuel into its smallest particles, to the distribution of these particles in the air at different piston speeds and to the many variations in the motion of the fuel vapor, since it has been demonstrated that there is a close connection between the above-mentioned phenomena and the regularity of the engine and its smoothness of operation.

At the railroad session of September, 1924, in the discussion of "Diesel locomotives", the adaptability of the Diesel engine to changes in revolution speed and torque was hardly mentioned, still less the formation of the combustible mixture. In order not to leave a similar gap, but rather to determine, at the outset, the real requirements of vehicular traffic on high-speed semi-Diesel engines, I will discuss briefly a few automobile engines, which will serve as standards of comparison for great flexibility of functioning.

The Maybach crude-oil engine, type G 4a (Fig. 4) (maximum power 150 HP. at 1300 R.P.M., fuel consumption 180-185g (6.35-6.53 oz.) per horsepower-hour at a normal output of 100-120 HP.) functions in the Diesel manner by compressed-air injection and has intake valves with unchangeable needle-lift, but nozzle seats whose free cross-section varies according to the load. At the same time, a pressure regulator is provided, which regulates the injection pressure according to the revolution speed. In this manner a wide range of adaptability of the engine to all combinations of torque and revolution speed is obtained.

This engine also shows that the Diesel process works well with ordinary automobiles, since the engine differs but little in shape and size from a carburetor engine. The same statement will probably apply to future high-speed semi-Diesel engines.

In the second place, we will consider the clutchless and gearless power car, built as an experiment by the Maybach Engine Company shortly after the war. Any one who has sat at the steering wheel of such a car can testify that the carburetor engine is no longer inferior to the steam locomotive, as regards its adaptability to the varying resistances of travel. In this connection I differ somewhat from one of the previous speakers, Professor Nordmann, who discussed the internal combustion engine from the standpoint of a locomotive builder. Maybach's gearless car is started electrically, with the aid of a start-

ing motor, by pressure on a Bosch starter. At the same time, the internal combustion engine is brought to a moderate revolution speed and, after going a few yards, the gas pedal needs to be pressed down only a little for the engine to run on its own power. By continuing to open the throttle, the engine can be brought to full speed in a few seconds.

In order to illustrate the idea of flexibility by still a third example, I wish to call attention to an interesting engine in Berlin, which has reached an advanced experimental stage. Engineer Egersdörffer undertook to convert, with the least possible changes, carburetor engines of the ordinary type, designed for omnibuses, into engines for burning heavy oils (gas-oil and yellow oil). As shown diagrammatically in Fig. 5, the carburetor has been removed and the fuel is sprayed, by means of compressed air, directly into the intake pipe close to the intake valve. Thereby the fuel is delivered to the spraying nozzle through an "Egersdörffer" rotary pump, the air being compressed in a revolving compressor coupled directly to the pump. In order to obtain the remarkable flexibility of functioning, the compressed air and fuel has to be introduced in a satisfactory manner into the inflowing current of air. This does not preclude the possibility of still further improvements, until the very severe requirements of urban omnibus traffic are met satisfactorily in every respect, even with regard to completeness of combustion.

In each of these three engines there is a special mixing device and it would seem at first as though they had no feature in common. By examining, however, the shape of the compartments in which the fuel and air are mixed and from which the mixture flows, we can determine, in all three cases, the phenomena of expansion and contraction which produce satisfactory mixing. It seems to be an opportune time to introduce the term "diffuser" into the vocabulary of internal combustion engines, since the recent researches on the conditions of flow in the tubes designated as diffusers render it possible to obtain data not only for explaining the mixing process, but also for improving it.

In a retrospect on the results of the 1913-1914 benzol-carburetor contest (published in the "Automobil Rundschau," 1914, p. 149), I spoke, in order to express the final result in a simple formula, of the "Victory of the Venturi Tube." This is a diffuser in which the small ends of the frustrums of two cones are connected by a cylindrical portion, whose diameter determines the range of the revolution speed of the engine.

Both the above-mentioned Maybach engines, which are characterized by the broad limits of their revolution speeds, are provided with diffusers of variable cross section.

Semi-Diesel engines are also often provided with diffusers. They are situated inside the cylinders and connect an antechamber, designed for a partial combustion, with the main com-

bustion chamber, in which the piston moves and in which the combustion is completed (Figs. 2-3).

The former conception, according to which the currents in the combustion chambers of Diesel engines, with respect to the resulting fall in the temperature of the air and the increased heat transmission, were to be avoided as far as possible, seems to have been thoroughly shattered. Technical problems cannot be solved by theories alone. There are already a large number of solid injection engines, in which air currents of very decided direction and magnitude are produced, for the express purpose of producing the mixture of the fuel and air in one or more stages, partly before ignition and partly during the combustion. These processes of flow must be investigated, in order to arrange and explain the many flow phenomena. Experiments are the best means for this purpose, although conclusions from analogy, for which the considerable literature on diffusers affords the opportunity, will be found useful in a general way.

Practical technicists must learn, parallel with scientific research, to control the processes of flow in the combustion chambers and to increase the regulatability of solid injection engines for vehicular use to as high a degree as has already been accomplished for carburetor engines.

We will drop this train of thought, however, for the present, and will consider, instead, another line of development,

which is exerting a decisive influence on the appearance of the new solid injection engines and which has finally enabled the construction of high-speed engines with the revolution speeds customary in automobiles. I refer to the so-called "airless-injection" process, i.e., direct fuel injection under very high pressure.

James McKechnie (Technical Director of the Vickers Company, Barrow-in-Furness, Lancashire, England) must be considered as the most prominent inventor of solid-injection Diesel engines with the usual high compression. From the first, he devoted his attention to maintaining the injection pressure at the same level for both large and small quantities of fuel, because he realized that only in this way could he obtain a greater load range of the engine and a low rate of fuel consumption, even with small loads. Since his first attempts (in 1910) were, according to his own statements, unsatisfactory in the direction indicated, they can be omitted here. I will simply mention that a fuel receptacle with a flexible wall (sometimes called "pulsator") was introduced between the fuel pump and the injection nozzle to eliminate the fluctuations in pressure.

Fig. 6 shows one of Mr. McKechnie's more recent improvements. At every stroke, the fuel pump delivers a quantity of fuel beyond the requirements of the maximum engine load. The intake valve is actuated by a cam and closes very gradually during the power stroke, so that the fluid pressure does not

increase too suddenly in all the compartments between the intake and compression valve. The maximum desired compression is reached shortly before the end of the stroke of the pump piston. The compression valve, which also serves as an injection valve, is likewise mechanically operated. With the aid of an axially adjustable cam, the beginning of the injection, its duration and the degree of opening of the valve can be adapted to the engine load. The maximum pressure generated by the pump is governed by a safety valve, which is held under the pressure of an adjustable spring. The fuel displaced by the pump piston is received by a fuel collector with elastic walls until the maximum injection pressure is reached, beyond which point it escapes through the safety valve into the suction side of the pump or into a fuel tank. In Fig. 6, the safety valve and fuel collector are located one above the other. The working cylinder has a combustion chamber, which is made up of a flat circular disk and a spherical section. A spraying nozzle is used, which admits the fuel into the combustion chamber in a bundle of cylindrical streamlets.

Mr. McKechnie has also investigated the atomization processes and since his conclusions on the effect of the shape of the nozzle do not seem to be very well known in Germany, they will be briefly explained here.

When a fuel jet, under such high pressure (2000-6000 lb. per square inch), is injected through a small opening into

compressed air, it forms a cloud at a certain distance from the mouth of the nozzle. This distance, the striking or carrying distance of the spray, depends on the width or diameter of the channel leading to the exit, in relation to its length, and also on the velocity at which the fuel leaves the nozzle. In order, therefore, to increase the carrying distance, the length of the injection channel with respect to its diameter must be as great as possible, or, in other words, the jet must be given a good lead for a long distance. The obtention of the finest possible spray requires, on the contrary, that the injection channel ~~be as short as possible~~ with reference to its cross-section, and that the fuel pressure be kept as great as possible, the same as for obtaining the maximum carrying distance.

Furthermore, according to Mr. McKechnie, the fineness of the spray can be increased by causing the fuel to leave the nozzle as a flat or wedge-shaped film, in such manner that the individual particles must move in different directions and thus overcome the viscosity which tends to hold them together.

With the nozzles shown in Fig. 7, the fuel velocity is small, clear to the mouth of the nozzle, so that the fuel pressure is converted almost entirely into velocity, without any great losses from friction before leaving the nozzle. In all three nozzles the mouth is formed by wedge-shaped lips with sharp edges. The wedge shape can be obtained by tapering either one or both sides of the nozzle opening, but in all cases the

nozzle, outside the mouth, must be so shaped, that the fuel can not cling to the end of it.

In all three of the nozzles shown in Fig. 7, the injection valve is nearer the mouth than in the former types. In the first nozzle, it is close to the mouth; in the second, a little farther away; and in the third, it helps, in conjunction with the valve seat, to form the mouth. With the first and second nozzles, the valves can be operated either mechanically or by fluid pressure, while, with the third nozzle, they can be operated only by fluid pressure. In the first nozzle, both lips are symmetrical, but in the second and third, they are unsymmetrical and the lower lip is undercut, the latter being stationary in case 2 and movable in case 3. In case 2, the distance between the two cuts can be finely adjusted and in case 3 the fuel, before reaching the mouth, is divided into separate streamlets by a series of longitudinal grooves on the inner surface of the valve-stem guide, the valve-lift being very small (0.006-0.01 in.).

McKechnie's conclusions on the relation between the shape of the nozzle and the process of atomization lose nothing in their fundamental significance by the fact that he has recently introduced the fuel into the combustion chamber in the form of a cone-shaped bundle of round streamlets. In this process he employs a short-stem valve, which is coupled with the operating rod. The fuel enters, through a ring-shaped valve-slot,

into a space from which the spraying channels branch (Fig. 8a, center). According to a communication from K. J. E. Hesselman ("Zeitschrift des Vereins deutscher Ingenieure," July 7, 1923, p. 661, col. 2, - See also N.A.C.A. Technical Memorandum No. 312, p. 14), McKechnie, the same as Hesselman himself, had found five to be the best number of holes.

The close connection between the atomization process and the shape of the nozzle seems to justify the introduction of a larger number of nozzles. Figs. 8a and 8b represent several so-called "single" or "multiple" nozzles, i.e., nozzles with one or more round or rectangular openings. The experimental nozzle employed by Dr. Riehm (Fig. 8a, left) (M.A.N. Werke, Augsburg) is an open nozzle with a single round hole ("Z.d.V.D.I.," June 21, 1924, p. 642). Its diameter is 0.305 mm (0.0122 in.); length, 1 mm (0.0394 in.); discharge coefficient (i.e., ratio between actual and theoretical discharge quantity), 0.7; coefficient of velocity, 0.98.

Vollmer's nozzle (Fig. 8a, right) ("Deutsche Automobil-Konstructions-Gesellschaft") has an automatically-operated valve inside the spraying head. Adjoining the valve seat there is a small "antechamber" from which oblique radial channels lead downward to a ring-shaped deflecting surface. From here the fuel is forced out (through a ring-shaped slot, a slot segment or several grooves) into the combustion chamber. Fir injecting large quantities of fuel, two or more such ring slots, or series

of slots, are arranged above one another.

In the injection valve of the "Hannoversche Waggon Fabrik" ("Hawa"), a single round spraying hole is used and the valve needle is exactly in the middle of the opening (Fig. 8b, left). The fuel-intake pipe is tightly and rigidly connected with the valve needle, so that it participates in the lifting motion of the needle. The needle is accurately ground into the nozzle and passes a long distance through it, so that in this way any outward escape of the highly compressed fuel is practically impossible.

In the nozzle of the "Linke-Hofmann-Lauchhammer Aktien-Gesellschaft" (Breslau), the injection valve has a longitudinal bore (Fig. 8b, right). The fuel therefore reaches the spraying holes by two routes and the fluid pressure, acting on the blunt lower end of the valve needle, helps to relieve the fuel needle, so that the fuel pressure in the spraying hole suffers fewer fluctuations from the opening and shutting of the valve and the valve always works very smoothly.

The "Hawa" and "Linke-Hofmann-Lauchhammer" nozzles are transition forms from the simple round-hole nozzles to the more recent ring-slot nozzles with a small apex angle.

In the nozzles of Vollmer, "Hawa" and "Linke-Hofmann-Lauchhammer," a ring-shaped surface for receiving the fuel pressure is created in the usual manner by removing the valve needle.

The "nozzle b," Deutz-Heidelberg (Fig. 19, Part II) may be considered as belonging to the type of nozzles shown in Figs. 8a and 8b.

Fig. 9 shows nozzles of Cross, Benkert, Professor Junkers and Grieve-Livens. The nozzles of Cross (London) and Professor Junkers are open nozzles. A valve is located above the opening in the nozzles of Benkert (Harburg) and Grieve-Livens (Lincoln). They may therefore be regarded to a certain degree as closed nozzles.

The nozzle of Cross reminds us of the well-known acetylene burner, two-fuel jets meeting at an angle of about 90° and forming a fan. Benkert and Prof. Junkers also endeavored to effect the atomization and evaporation of the fuel by causing two-fuel jets to meet at an angle of 180° or 90°. Thereby Benkert provides, at the mouth of the nozzle, a sharp edge, which is produced by the intersection of the two opposite fuel channels with an obtuse hollow cone.

In the nozzle of Professor Junkers, a needle is tightly fitted into the nozzle cylinder, this needle being provided with grooves in its lower conical end. The removal of the needle from the nozzle cylinder leaves the fuel grooves exposed, so that they can be easily cleaned, like all the other fuel-intake channels in the needle.

In the Grieve-Livens nozzle, the axial nozzle bore behind the valve seat opens into a "saw-cut" in the nozzle plate, which

likewise helps to give a fan-shape to the fuel jet.

It is obvious that the consideration of the shape of the corresponding combustion chamber determined the design of the abovementioned nozzles (cf. Figs. 28a and 37, Parts II and III).

The nozzles shown in Figs. 10-13 all help to form more or less flat or conical fuel jets. In the Tartrais-Peugeot nozzle (Fig. 10a), the flat inner surface of the disk valve meets a sharp edge on the body of the nozzle. The spraying effect is increased by the spiral grooves on the outside of the valve stem.

In the Fenyvesi-Levi nozzle (Fig. 10b), the valve stem is bolted to a diaphragm, which is subjected to the fuel pressure, so that the valve head is pressed harder against the outer surface of the body of the nozzle, as the fuel pressure increases.

In the nozzles of the Hannoversche Waggon-Fabrik ("Hawa") (Fig. 11), the nozzle openings are almost all unsymmetrically formed (as in the Tartrais) of sharp edges and flat surfaces. The only exceptions are the last two, in which the fuel is forced through a conical or flat slot. In all the nozzles, an initial tension can be imparted to the valve stem or the nozzle lips and there is no other valve spring.

The nozzles of Harlé & Co., Wineberger, Gebr. Korting Bros. Co. (Fig. 12), as likewise the nozzles of the Heinrich

Kamper Motorenfabrik A.G. in Berlin-Marienfelde (Fig. 13), have valves at their mouths. They all have valve springs and are operated by the fuel pressure, with the exception of the valve of Harlé & Co., which is operated by an exterior cam and is adjusted to the lift limit of the injection valve. Wineberger employs a valve seat, composed of a flatter and a steeper part. Below the portion of the valve head which fits the flatter part of the valve seat, the valve head has a sharp edge, which touches the steeper part. While Harlé & Co. and Wineberger employ disk valves, which are suited to larger combustion chambers, Körting employs a valve needle terminating in a conical tip, which seems to be of more suitable size for smaller engines.

The Heinrich Kämpe Motorenfabrik A.G. makes the contact surfaces of valve and valve seat spherical, so that when the valve is open, there is a tapering circular slot which causes the fuel to attain its maximum velocity at its point of entrance into the combustion chamber. This principle is applied both to valves opening outward and to those opening inward, as shown in Fig. 13.

Rodiger (Vienna) replaces the valve spring by a spiral accordeon sleeve, in which the vertical expansion of the spirals can be regulated by adjusting a long nut so as to vary the pressure of the conical valve head against the valve seat.

The Acro Company in Küssnacht (Switzerland) has proposed nozzles in which a rigid cylindrical or conical spindle fits into a round sharp-edged opening and forms, with the latter, a narrow circular slot. These nozzles represent an attempt (for a given quantity of fuel to be injected) to extend the walls of the opening as much as possible and to make the slot as fine as possible. This applies also to the last nozzle of the Acro Company (Fig. 13), which is produced by the lateral compression of a cylindrical tube and has an opening in the form of a straight line.

Fig. 14 shows a series of needle-valve nozzles. The variously-shaped tips on the lower ends of the valve spindles are intended to prevent incrustation of the nozzle exits. Manifestly such nozzles also serve other purposes. In all cases, the quantity of fuel is limited (independently of the cross-sectional area of the passage at the valve seat) by the slot between the needle tip and the edge of the nozzle opening, or is systematically adjusted to the valve lift. At the same time, the fuel is usually led through a tube of some length, so as to give the jet a correspondingly greater momentum, together with a smaller angle at its apex. The jet can be guided by the needle tip and the wall of the nozzle opening, either on both sides (inner and outer) or on one side (inner or outer).

In the nozzles of Harlé & Co., Kämper, Dr. Heidelberg-"Deutz" (nozzle C) and Suchaneck, the needle tips are usually

cylindrical. In the nozzles of Benz & Co. and Gebr. Sulzer the tips are usually conical. Petersen's nozzle has a cylindrical tip with two opposite flattenings. In the nozzles of Harlé, Kämper, Heidelberg, Petersen and Benz, the walls of the nozzle bore are cylindrical for a considerable distance before reaching the exit, while in Suchaneck's nozzle the tip has a conical taper.

In the Sulzer Bros. nozzle, the idea of giving direction to the fuel flow for some distance before the exit is less prominent, but the regulation of the fuel delivery is especially noteworthy, the aim being to avoid undesirable pressure increases in the working cylinder during the injection period.

It has been found that, with a simple conical injection valve, it is very difficult to control the rate of injection, so as to keep the combustion in the cylinder under constant pressure. Generally, too great a portion of the fuel charge enters the combustion chamber at the very beginning of the opening of the inlet valve, so that the combustion, instead of being gradual, takes place explosively and thus produces undesirable pressure increases. In order to prevent this and to obtain constant-pressure combustion, the valve, below the conical stop-valve, is provided with a conical prolongation extending into the mouth of the nozzle, so that the cross-sectional area of the nozzle exit increases gradually on the opening of the valve and also decreases gradually as the valve closes.

The regular operation of the valve needle is due mainly to the twofold throttling of the fuel in its passage through the stop-valve and the nozzle exit.

All the needle-valve nozzles have more or less of this double-throttling effect and indeed, all the more, the smaller the circular slot between the needle tip and the edge of the nozzle opening. Special attention should perhaps be called to the fact that, in certain needle-valve nozzles (such as the Heidelberg-"Deutz" and Petersen's), the nozzle plates have sharp edges, which cause an eddying of the fuel jet on its outer surface. Needle-valve nozzles are less affected by errors in their manufacture; i.e., all the nozzles in the same lot give the same jet, without great lateral deviations.

Fig. 15 shows a series of centrifugal nozzles. A nozzle of an older type, which Dr. Kuehn used (among other nozzles) in his experiments at the technical high school in Danzig has, like the nozzle of Tartrais, atomizer rods with very long spiral grooves (2 or 3 grooves of 1" or 0.5" pitch). The bore, just above the mouth of the nozzle, has a length which is a multiple of the diameter of 0.53 mm (0.021 in.)*

Recently, the length of the spiral grooves has been reduced as much as possible, in order to avoid unnecessary friction, as exhibited in the nozzles of the firm of Heinrich Lanz,

* Dr. Kuehn, "Ueber die Zerstäubung flüssiger Brennstoffe," in "Der Motorwagen," July 10, 1924, to Feb. 10, 1925. See also N.A.C.A. Technical Memorandums Nos. 329-331.

Mannheim, and still more in the nozzle of the firm of J. and C. H. Bolinders, Stockholm. The nozzle of Bolinders has an injection channel whose length is only a little greater than its diameter.

Many experimenters have felt themselves called to test some centrifugal nozzle in practical engine operation, because the assumption that a more perfect distribution of the fuel in the combustion chamber can be obtained with the aid of centrifugal force, is extremely alluring. The practical results have not always come up to the expectations, so that we cannot yet speak of any increase in the use of such nozzles.

The conclusions of Dr. Kuehn are so instructive, that we will repeat them briefly. The nozzles without atomizer rods gave a conical jet of about 3.5° at the apex and a discharge coefficient $\mu = 0.78$. The measurements of the cone angle and of the discharge coefficient, for the higher atomization pressures (of 40 atm. or more), gave the following fairly constant values for gas-oil:

	Cone angle	Discharge coefficient μ
Nozzle without atomizer	3.5°	0.78
" with old "	26.5°	0.74
" " atomizer II	43.0°	0.54
" " " III	49.0°	0.51

The spiral motion and the cone angle therefore have considerable effect on the discharge coefficient. The old atomizer gives a cone angle of about 27° and μ thereby decreases only a few degrees. With a cone angle of over 27° (43 and 49°), however, μ decreases greatly, thereby indicating the great resistance to the flow of the fuel through the small nozzle opening due to the greater spiral motion imparted to the fuel by atomizers II and III.

An increase in the cone angle at constant atomization pressure causes no noteworthy change in the size of the drops. At the same exit velocity, the motion of the fuel drops is checked more quickly, the greater the apex angle, because the conical film is spread out more and embraces a much larger quantity of air, which in part acquires a whirling motion and in part is carried along with the spray.

The centrifugal nozzles have met with great success when used according to the method of Lanz and Bolinders to change the cone angle in connection with the engine load.

In the nozzles of Lanz (for the "Bulldog" engine shown in Fig. 2), there is interposed in the space above the nozzle outlet (Fig. 15), an adjustable body, with spiral grooves on its cylindrical or conical surface for giving the fuel a spiral motion. The fuel leaves the nozzle with a larger or smaller apex angle, according to the position of this body. This body occupies its lowest position under full load and the

liquid disk between its frontal surface and the nozzle outlet is then so thin that it is set into rapid rotation by the successive fuel charges entering with every stroke of the pump, as a result of which the broadest cone (indicated by the dotted line in Fig. 15) is produced at the lowest position of the adjustable body and with the strongest fuel delivery. Conversely, the narrowest cone is produced at the highest position of the adjustable body and with the weakest fuel delivery. A conical body is used in the improved Lanz nozzle. If it is screwed up high, a ring-shaped passage is formed between it and the wall and the effect of the spiral grooves is practically eliminated. The grooves exert their full effect, however, as soon as the adjustable body is screwed so low that it touches the wall.

An adjustable spindle is likewise provided in the nozzle of Bolinders. It carries at its lower end a reinforced cylindrical head, which has on its frontal surface a disk-shaped space enclosed by a ring. When the spindle is screwed down, the fuel enters this space through two axial and two tangential grooves and acquires a circular motion which generates a cone angle of about 90°. If, on the contrary, the adjustable spindle is screwed up high, the way is left open, outside of the tangential grooves, for the direct entrance of the fuel into the space above the injection hole. This results in a smaller cone angle of about 15°. The pressure losses are very small in

the nozzle of Bolinders, since all the grooves for the passage of the fuel are very short. Herewith I wish to conclude what I have to say on injection nozzles.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

Solid-injection "Deutz VM"(Prof.Maier)

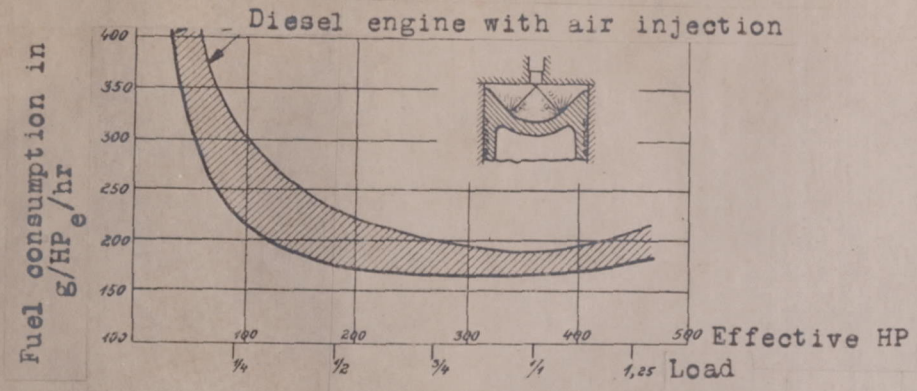


Fig.1

Heinrich Lanz "Bulldog"

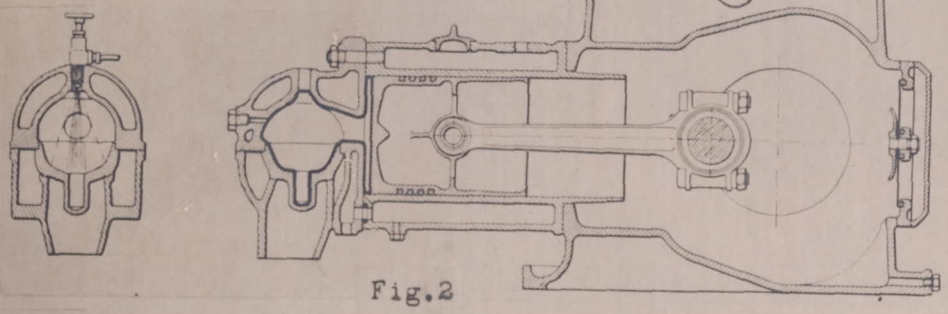
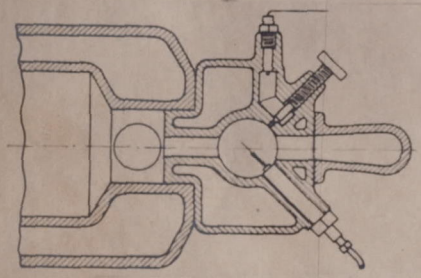


Fig.2



Dr.Heidelberg

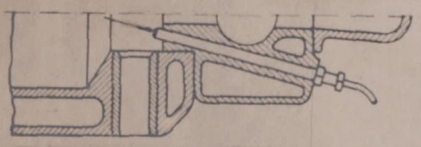


Fig.3

Egersdörffer

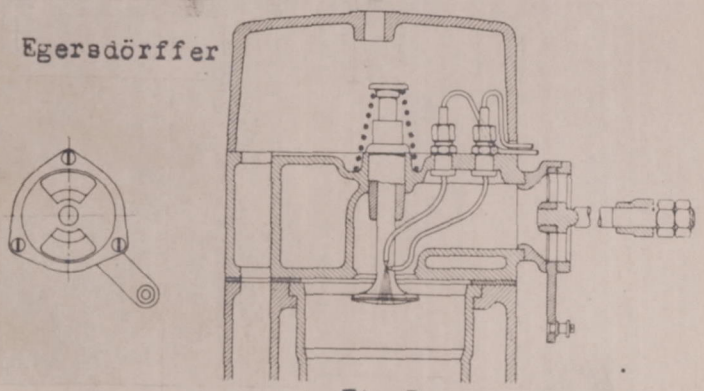
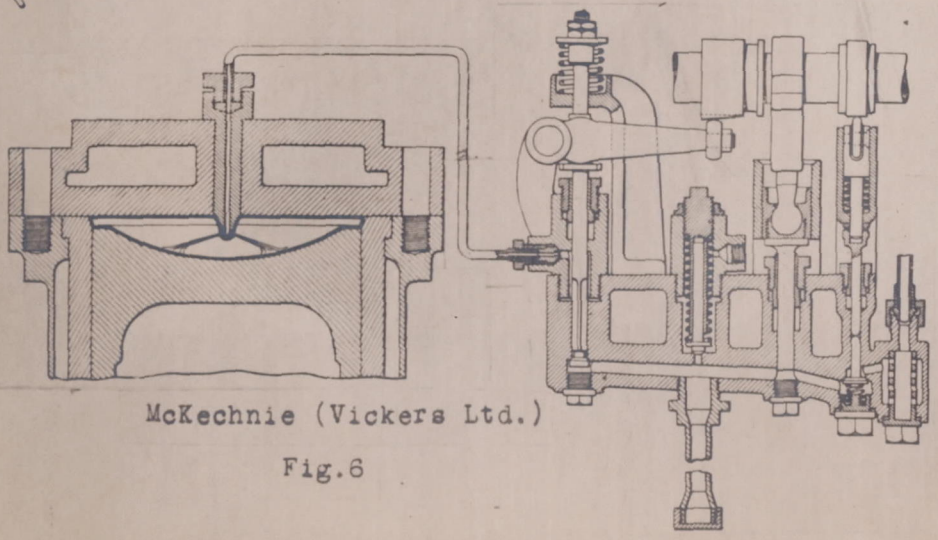


Fig.5



McKechnie (Vickers Ltd.)

Fig.6

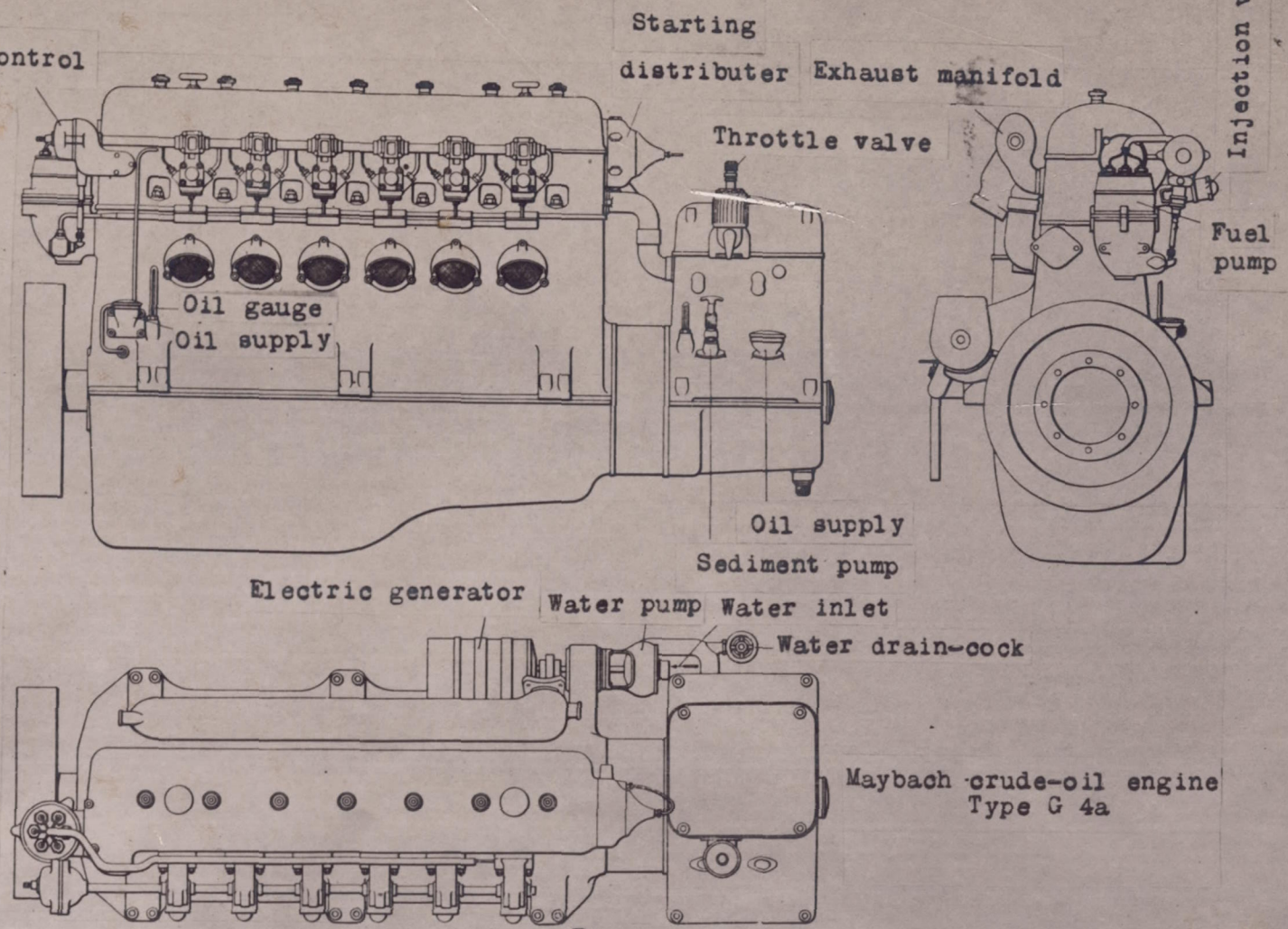

Hand control
Starting distributer
Exhaust manifold
Injection valve
Throttle valve
Fuel pump
Oil gauge
Oil supply
Oil supply
Sediment pump
Electric generator
Water pump
Water inlet
Water drain-cock
Maybach crude-oil engine
Type G 4a

Fig.4

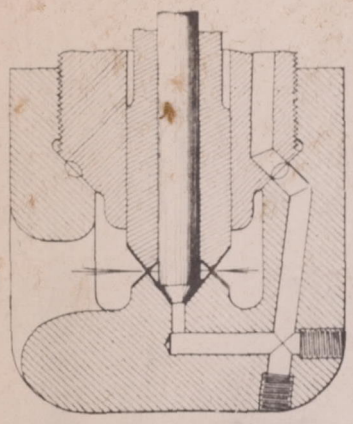
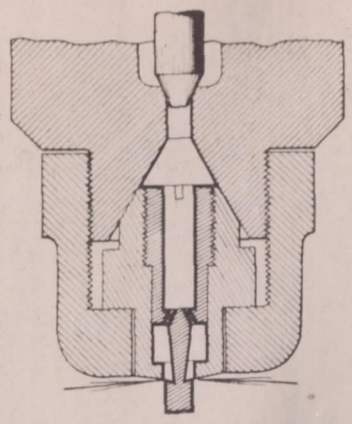


Fig.7



McKechnie (Vickers Ltd.)

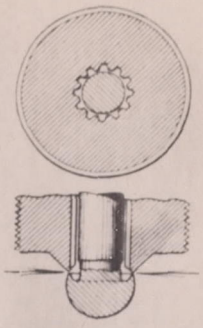
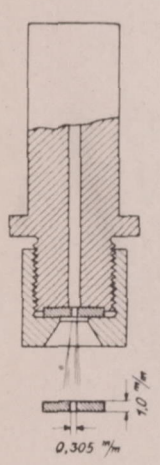
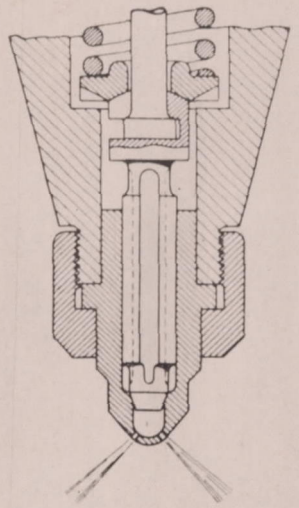


Abb. 7.

'c Kechnie - „Vickers

Dr.Riehm





Vollmer

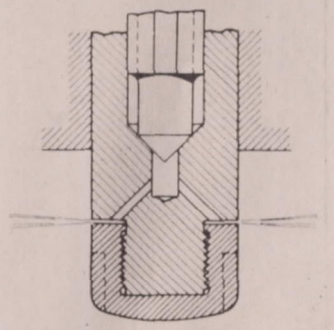
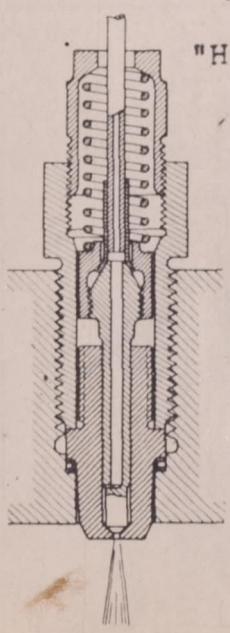


Fig.8a

"Hawa"



"Lauchhammer"

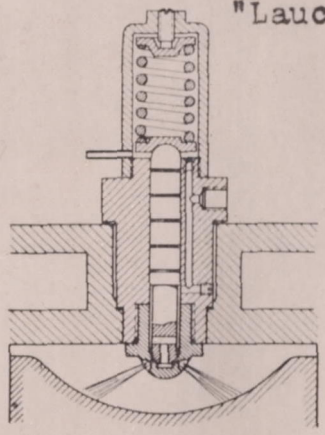


Fig.8b

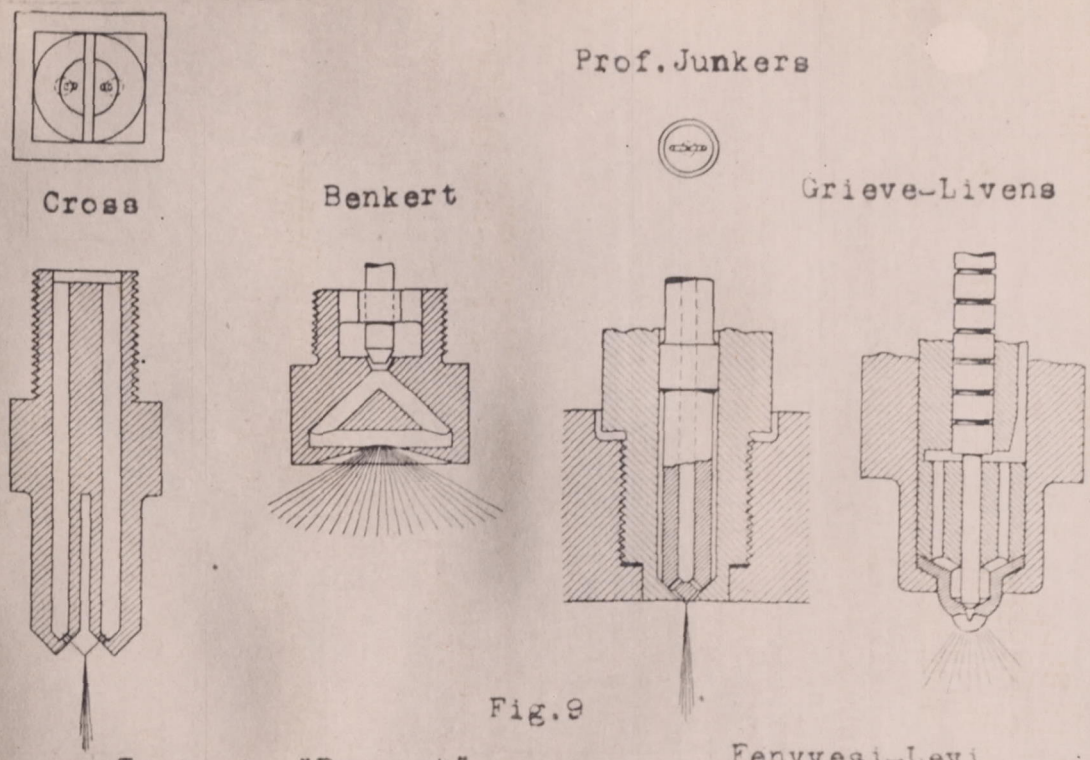


Fig.9

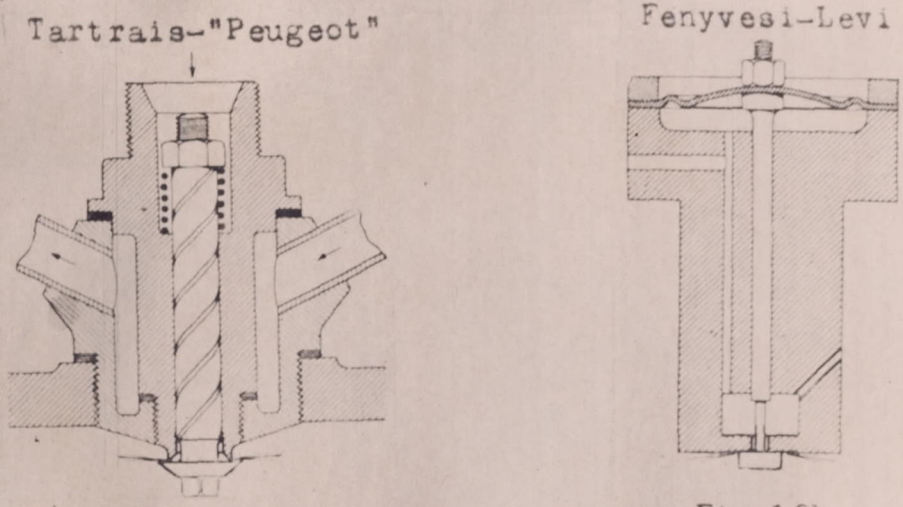


Fig.10a Fig.10b

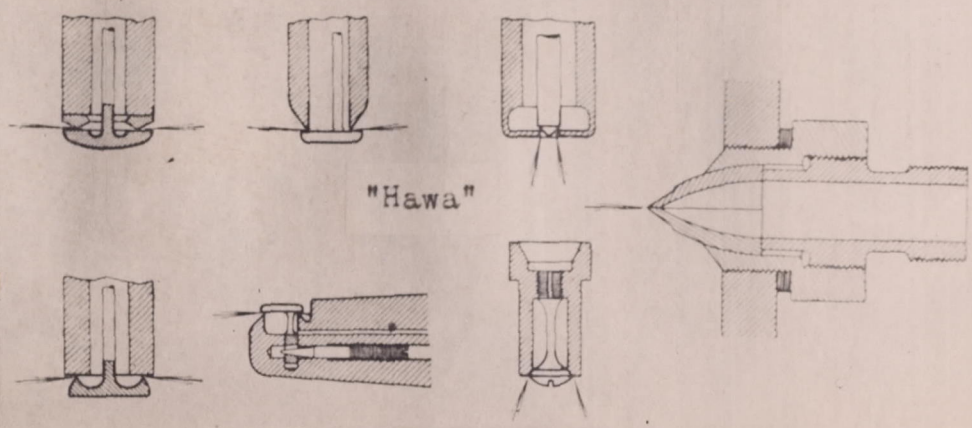


Fig.11

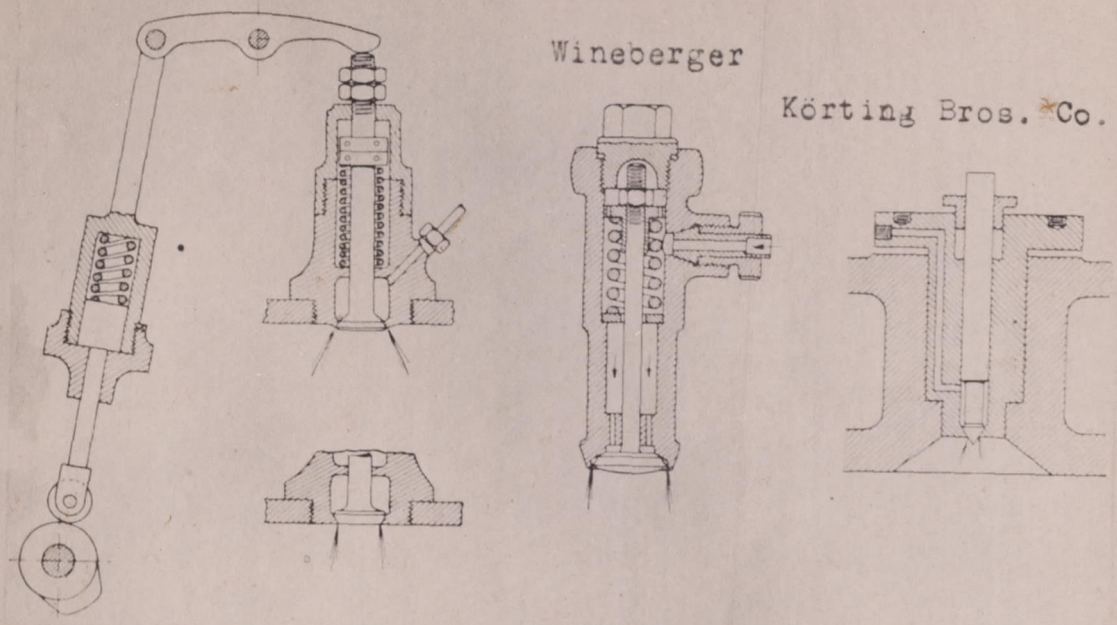


Fig.12

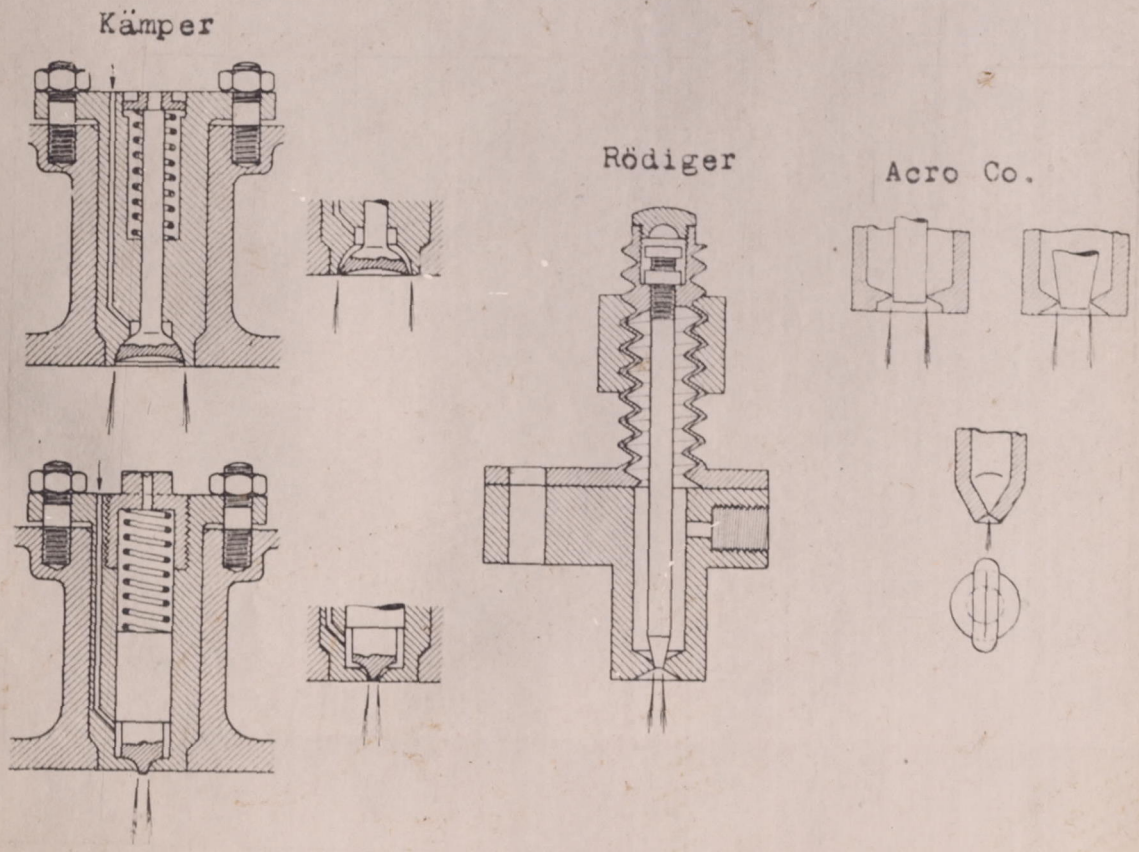


Fig.13

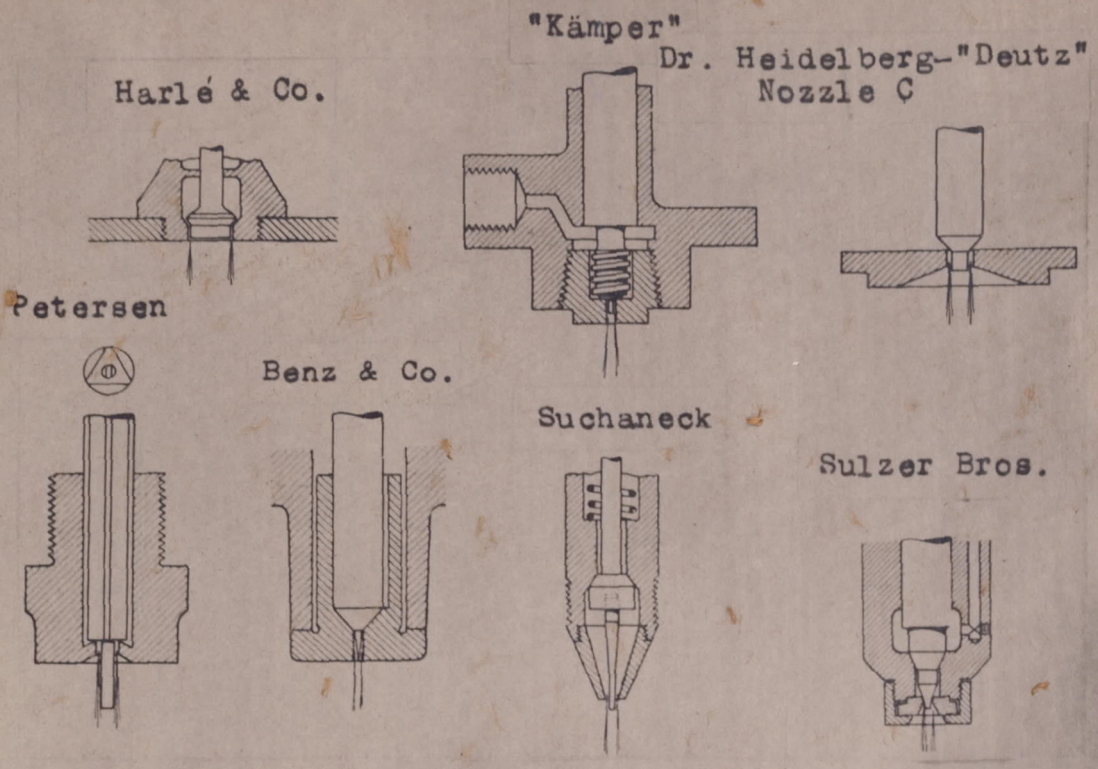

"Kämper"
Dr. Heidelberg-"Deutz"
Nozzle C
Harlé & Co.
Petersen
Benz & Co.
Suchaneck
Sulzer Bros.

Fig.14

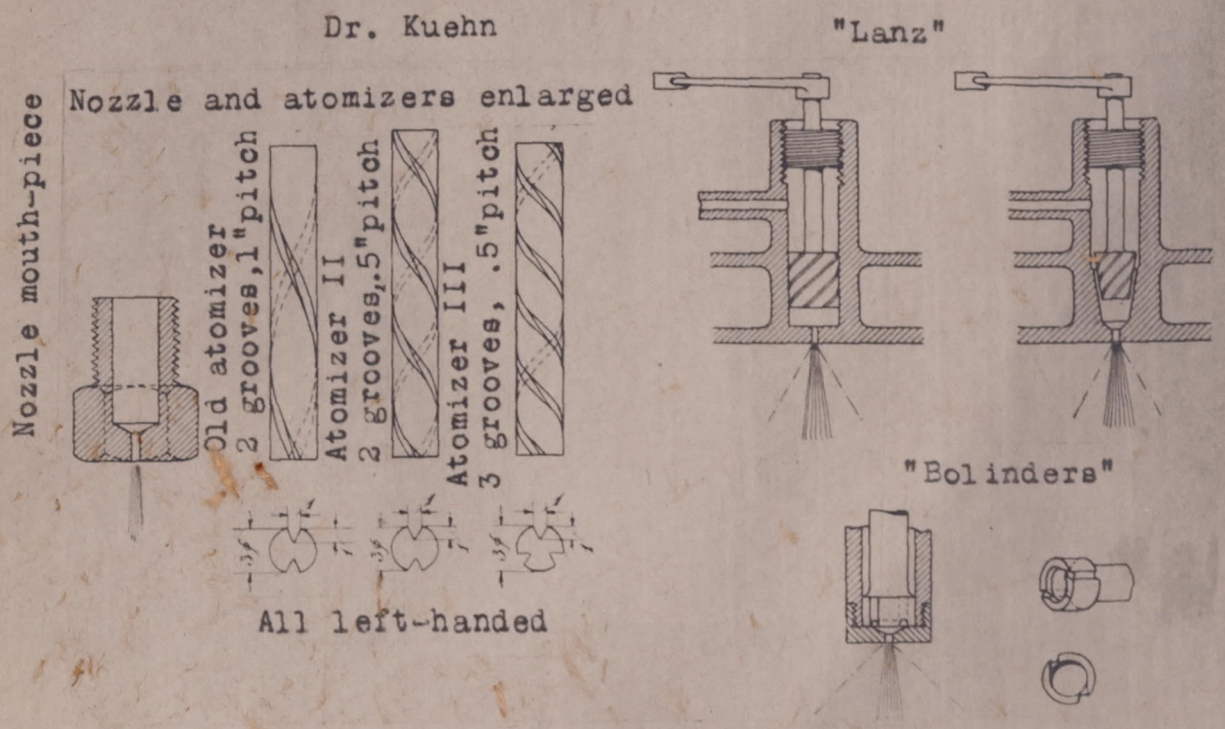

Dr. Kuehn
"Lanz"
Nozzle and atomizers enlarged
Nozzle mouth-piece
Old atomizer
2 grooves, 1" pitch
Atomizer II
2 grooves, .5" pitch
Atomizer III
3 grooves, .5" pitch
All left-handed
"Bolinders"

Fig.15