University of Alabama in Huntsville

LOUIS

Honors Capstone Projects and Theses

Honors College

4-13-1995

Reduced Small Engine Emissions with Perforated Plates

Derek S. Lindsay

Follow this and additional works at: https://louis.uah.edu/honors-capstones

Part of the Energy Systems Commons, and the Transportation Engineering Commons

Recommended Citation

Lindsay, Derek S., "Reduced Small Engine Emissions with Perforated Plates" (1995). *Honors Capstone Projects and Theses*. 466.
https://louis.uah.edu/honors-capstones/466

This Thesis is brought to you for free and open access by the Honors College at LOUIS. It has been accepted for inclusion in Honors Capstone Projects and Theses by an authorized administrator of LOUIS.

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Honors Program

HONORS SENIOR PROJECT APPROVAL FORM

(To be submitted by the student to the Honors Program with a copy of the Honors Project suitable for binding. All signatures must be obtained.)

Name of Candidate: Derek S. Lindsay

Department: Mechanical Engineering

Degree: BSEME

Full Title of Project: Reduced Small Engine Emissions with Perforated Plates

Approved by:

[signature] 4/18/95
Project Advisor Date

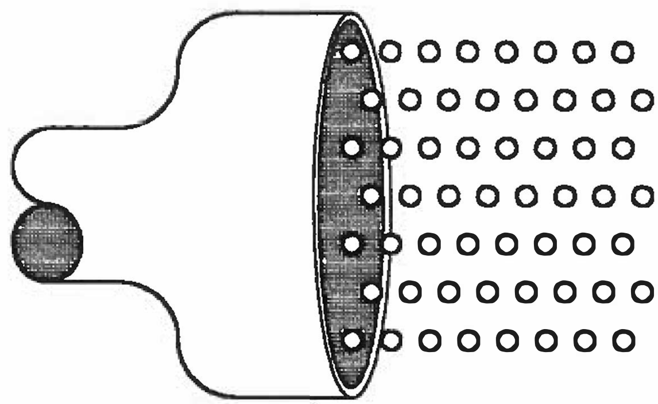
[signature] 4/18/95
Department Chair Date

Honors Program Director for Honors Council Date

SPForm.doc 05/07/93

REDUCED SMALL ENGINE

EMISSIONS WITH PERFORATED PLATES



HONORS SENIOR PROJECT, SPRING 1995

Author: Derek S. Lindsay

Faculty Advisor: Dr. Gerald Karr

April 13, 1995

ABSTRACT

The purpose of this research project is to reduce small engine emissions by improving the fuel-air mixture with a perforated plate injector. Performance and emissions were monitored for both the stock and modified cases. A fair reduction in emissions was achieved as well as a reduction in fuel consumption directly related to the improved emissions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.00 INTRODUCTION:

The purpose of this research project has been to attempt a low cost method of reducing harmful emissions from small utility engines. The stimulus for this research was a report originally aired on Paul Harvey's News and Comment (date unknown) and later found in a USA Today article that stated non-road engines including lawnmowers have come under fire from the EPA for being heavy polluters (CBS; "Off-Road"). The USA Today gave the following examples:

- ◆In a year, 40 outboard motors or 1000 chain saws emit the same amount of smog-producing chemicals as 620 cars.
- ◆Non-road engines produce 12% of carbon monoxide pollutants; cars, nearly 61% ("Off-Road").

As of January 1, 1995, California placed the following restrictions on hydrocarbon (HC) and carbon monoxide (CO) emissions from small engines:

Hydrocarbons	12 g/Hp-hr
Carbon Monoxide	300 g/Hp-hr

Table 1. Emissions Restrictions in California (Gault, Letter).

The EPA is expected to implement these restrictions nationwide in April 1996 (Gault, Letter). Both the EPA and California are already planning further restriction in the near future (Gault, Letter).

HC and CO are the undesired byproducts of incomplete combustion. Frequent causes for this in internal combustion engines are poor fuel air mixing and a mixture that is too rich (more

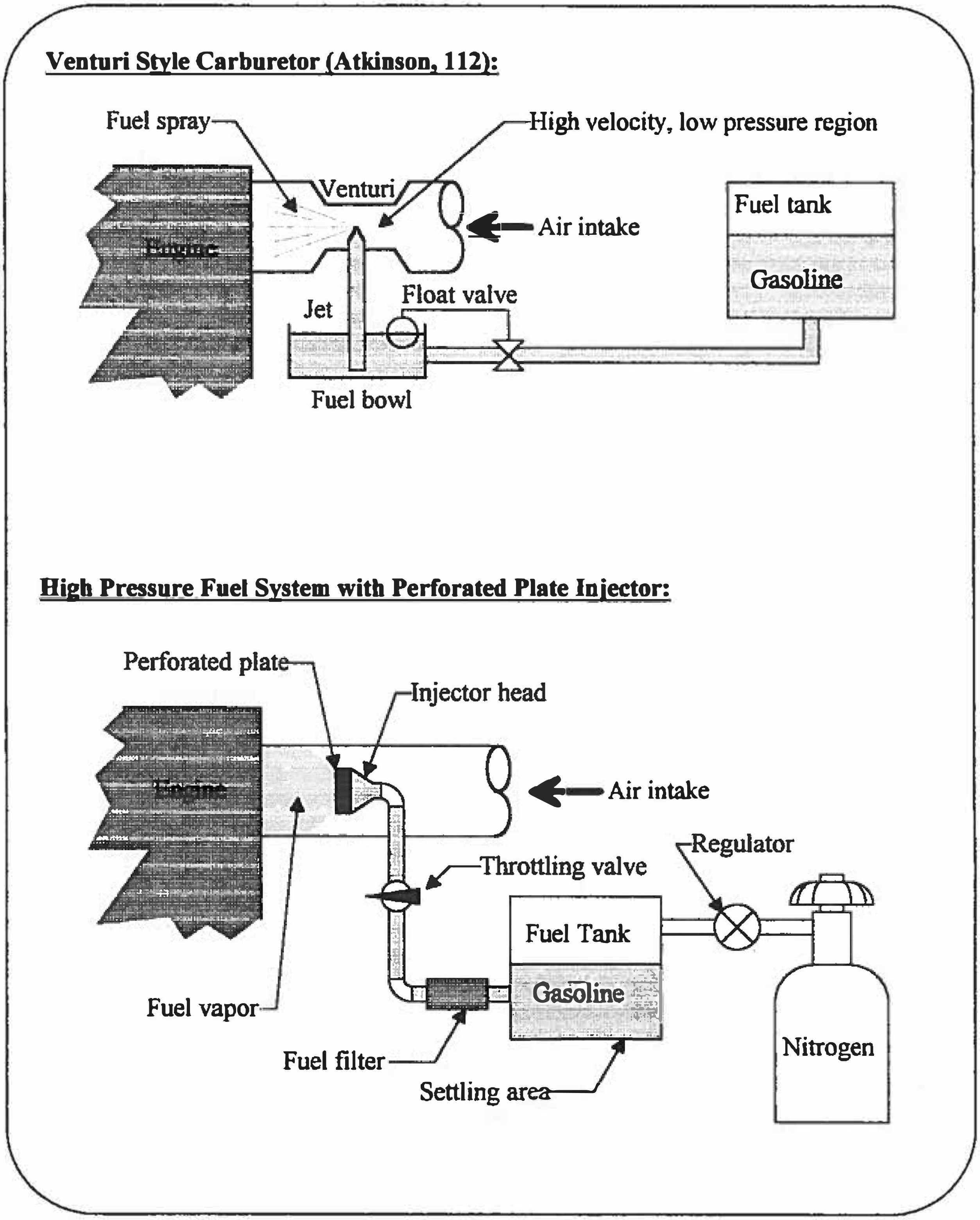


Figure 1. Fuel Delivery Systems.

fuel than the available oxygen can react with). Both of these are key causes to the polluting nature of small engines since small engines are built as simply as possible to reduce costs and difficulty of repair. The poor fuel mixing is the result of the simple, inexpensive venturi carburetor. The rich fuel/air mix is desirable to keep engine temperatures low; excess liquid fuel evaporates at the high engine temperatures removing heat in the process.

This projects proposed method for reducing emissions is to replace the venturi carburetor of a small engine with a pressurized fuel system using a perforated plate injector. A venturi style carburetor uses an accelerated air flow to generate a low pressure region to suck fuel through an orifice thus mixing air with fuel (See Figure 1.). A pressurized fuel system would use a pump (or in this case a pressurized fuel tank) to achieve a high pressure to force the fuel through a restrictive orifice in order to atomize the fuel more completely (See Figure 1.). A perforated plate, developed by Dr. John Hendricks of Alabama Cryogenic Engineering in Huntsville, would provide low cost, highly restrictive orifices.

2.00 EQUIPMENT:

2.10 The Perforated Plate: A perforated plate is a composite metal material formed by extruding dissimilar metals together, one or more acting as the matrix and one or more as filaments, and etching out the filament metal(s) (See Figure 2.). The perforated plate used in this project was an oxygen free copper matrix with niobium-titanium filaments. The plate was cut from extruded stock and mirror-polished to 1 mm thickness. The niobium-titanium was etched out with hydrofluoric acid leaving holes through the plate. The holes numbered 17, with diameters of 75 microns spaced 0.1 mm center-to-center. This plate was originally extruded

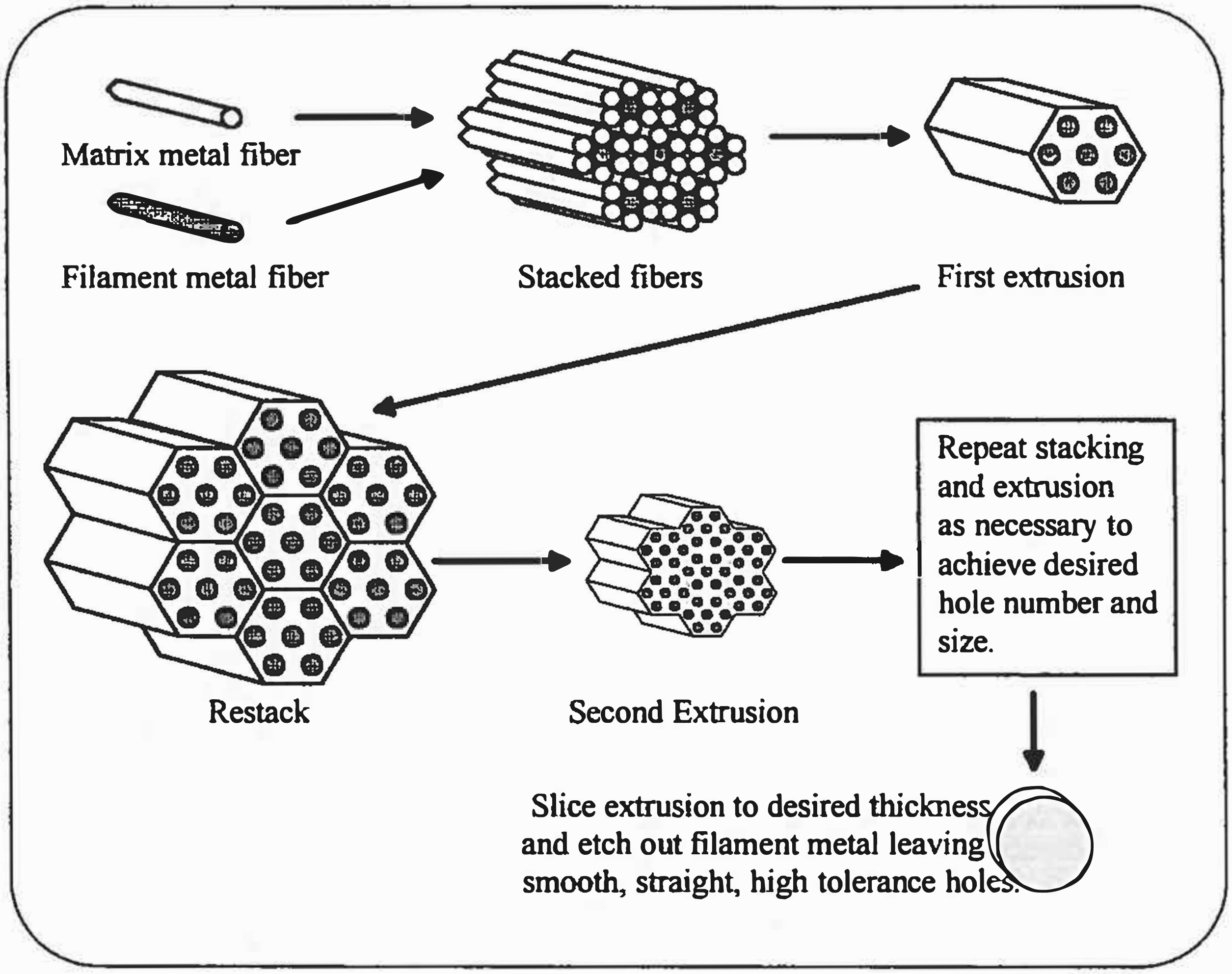


Figure 2. Perforated Plate Technology (Dingus).

with 31 holes, but it was too porous for a fluid as nearly inviscid as gasoline so all but 17 were blocked with an epoxy resin. The reasons for selecting this plate were that it was readily available from stock, easily and quickly etched, and previous experiments have shown that this hole pattern could easily produce fuel flow rates in the 5 to 100 mL/min regime with relatively low pressures (Landrum, p. 13). Also, experience has shown that this plate is prone to clogging if a filter is not used and care is not taken to keep contaminants from the system, so anything smaller would be harder if not impossible to keep flowing.

What makes these plates affordable materials for injectors and other applications is the fact that such extremely small holes (down to 5 microns diameter) with incredible length to diameter ratios (near 1000) can be produced much cheaper than machining. Many of the hole diameters achievable with perforated plates are impossible to machine. The regularity and smoothness of the holes are very competitive with machining also. Porosities of up to 70% are attainable with these plates. The plate used in this experiment could be produced for less than $25. It would be much more expensive to have machined if possible.

2.20 The Engine: The small utility engine used in this project was a Tecumseh 3.5 horsepower horizontal shaft engine, model H35. The horizontal shaft was necessary for connection to the dynamometer. A centrifugal chain clutch was purchased also for the purpose of dynamometer connection. The engine's specifics are as follows:

Bore	2.5"
Stroke	1.938"
Speed Range	2100 rpm to 4000 rpm (3600 optimum rpm)
Compression Ratio	7.5
Carburetor Jet Diameter	0.079"
Carburetor Venturi Diameter	0.500"

Table 2. Engine Specs (Gault, Letter).

2.30 The Dynamometer: The dynamometer service was supplied by Bama Johnson's Welding in Hartselle, Alabama. The dyno provided a performance reading in the form of pressure generated by a hydraulic pump powered by the engine. RPM and head temperature measurements were simultaneously provided by a digital readout connected through a metal ring placed between the spark plug and head. The dynamometer provided room for measuring exhaust emissions while dyno testing was being performed.

2.40 The Emissions Tester: Emissions testing was performed with a Chrysler Model III C exhaust emission analyzer provided by the University of Alabama in Huntsville's (UAH) Johnson Research Center. It has readouts for both HC's measured in parts-per- million as n-Heptane and CO read in percentage. Both readings are molar (or volumetric) rather than mass concentrations. This unit has a self calibration procedure that ensured accurate and repeatable readings. During the course of several tests of the engine and various automobiles it never lost initial calibration. As a demonstration of how an emissions tester can be used, a 1993 Honda Civic Si with 29,000 miles on the odometer was tested at idle before and after warm-up. This was to demonstrate the effect of the catalytic converter which only operates when hot. The converter causes the HC and CO pollutants to react to form water (H_2O) and carbon dioxide (CO_2), the ideal products of complete combustion. EPA BAR-90 standards in Alabama call for 1981 and newer models to have no more than 220 ppm HC and 1.2% CO (Compton). The Civic met these standards when warmed: HC 220 ppm, CO 0.39%. When cold, the readings were: HC 300 ppm, CO 2%. The HC's barely met the requirements when warm, but idle is the worst operating point typically for pollution. As the speed was increased, the engine got into its power band (efficient operating range), and a trend of lower readings was noted. As expected, the car's emissions were worst when the catalytic converter was not operational.

2.50 Miscellaneous Jigs: On several occasions while carrying out this research, it was necessary to construct adapters. Most were simple brazed steel or copper adapters for flow meters to mount to the engine intake or exhaust. One was required to mount the injector to the engine; this also doubled as the intake manifold.

An exhaust canister had to be built to replace the stock exhaust. This dead volume allowed thorough mixing of the exhaust gases and prevented mixing with outside air so an accurate emissions reading could be sampled in accordance with Society of Automotive Engineers J1088 recommended practice for small engine emission testing (*1990 SAE*, p. 25.131)

3.00 EXPERIMENTAL PROCEDURE:

The experimental procedure can be separated into three phases: stock engine measurements, qualitative analysis of the fuel spray patterns, and modified engine measurements. Key observations for comparison are emissions levels, fuel consumption, engine temperature, engine power, and fuel/air mixture quality.

3.10 The Stock Engine: Fuel consumption at idle for the stock engine was measured by filling the tank with a pre-measured amount of fuel and timing the engine for how long it could operate before running out of gas. The most accurate reading was taken when 200 mL of fuel allowed 31.25 minutes of operation resulting in a fuel flow rate of 6.4 mL/min or 0.073 g/sec.

Many attempts were made to measure the air flow rate at idle and full throttle (where the governor cuts in, approximately 4000 rpm). An electronic mass flow meter was attached to the intake but was too restrictive for the engine to run. It was then moved to the exhaust where the higher pressures easily passed through it allowing the engine to run, but the flow rate was greater than the 30 standard-liters-per-second maximum of the gage. The best readings were obtained from a sliding bearing mechanical gage attached to the exhaust. At full throttle, it read 600 standard-cubic-feet-per-hour (SCFH). A simple calculation for what the ideal air flow rate should be is to multiply the speed (4000 rpm) by 1/2 (since air is taken in only every other rotation in a 4-stroke engine) and by the displacement (9.52 in^3 or 5.5E-3 ft^3). This produces an ideal air flow rate at full throttle of 661 SCFH. This means the engines volumetric efficiency -- volumetric flow rate divided by ideal volumetric flow rate -- is about 91%. This is a reasonable efficiency for an engine with a side valve configuration and low compression ratio such as the Tecumseh. This means that at idle (2100 rpm) the flow rate should be 350 SCFH ideally and 315 SCFH in actuality assuming the volumetric efficiency is constant. So when the fuel flow rate is 6.4 mL/min at idle, the air speed in the venturi is the volumetric flow rate divided by the venturi cross-sectional area of 0.196 in^2, 64.3 ft/sec. It is important to note that this is an average air velocity for the entire two cycles of the 4-stroke; the intake velocity is roughly 4 times this (257.2 ft/sec or 78.4 m/sec) since air is only taken in during 1 of the four strokes and during the other three strokes it is essentially zero. These are all important numbers to know when calculating the theoretical spray diameter in the next section.

Dyno testing was done from idle, 2100 rpm, to just beyond the recommended limit of 3600 rpm. The following temperature, emissions, and performance data were obtained at this time and are provided in Table 3. Two readings were taken at each speed to ensure the dynamometer and thermometer were repeatable. Emissions were measured at idle since this is the worst case; higher speeds drastically reduce the emissions.

Speed (rpm)	Pressure (psi)	Temperature (°F)	Emissions
2,100	150, 150	289, 290	HC 1400 ppm, CO 4.8%
3,500	1080, 1080	303, 300	—
4,000	940, 920	326, 321	—

Table 3. Stock Engine Dyno and Emissions Test Results.

One immediate observation made by the dynamometer technician was that this engine ran hotter than the Briggs and Stratton engines that he works with. This doesn't necessarily mean the Tecumseh engine was faulty or badly adjusted; it is very likely that the engine has hot spots in different areas that the Briggs engines and that one is just beneath the spark plug. Cylinder temperatures might still be very similar.

Another observation was that the power peaked at about 3500 rpm. The Grainger catalog recommends a continuous operating speed for this engine of 3600 rpm (*Grainger*, p. 1550). This is where the engine is supposed to produce its claimed 3.5 Hp. As expected, a sharp decline in power was experienced after the peak.

To check and see if the engine met California's standards, one needs to convert the readings for HC and CO into grams-per-hour. The mass flow rate of air to gasoline in a stoichiometric (ideal) reaction is 14.91 (Sorensen, p. 35). With 4.35 g/min fuel flow rate, 64.9 g/min air is required for a total intake mass flow rate into the engine of 69.2 g/min which is equal to the exhaust mass flow rate. The average molecular weight (grams per mole) for the exhaust from the stoichiometric combustion of gasoline is 30.63. This molecular weight is a weighted sum of the ideal components of emissions: CO_2, H_2O, and N_2. This is still a good approximation since CO and HC in particular represent a very small percentage of the exhaust gases, and CO has a molecular weight of 28.01 which wouldn't sway the average much anyway. The HC reading of 1400 ppm (parts n-Heptane per 10^6 parts exhaust) can be multiplied by the molar conversions 100.21 gram n-Heptane per mole and one mole exhaust per 30.63 grams and the exhaust mass flow rate, 69.2 gram exhaust per minute, to produce an HC reading of 0.32 g/min or 19 g/hr. The new California standards call for a less than 12 g/hr-Hp which for the 3.5 Hp Tecumseh engine the upper limit at 42 g/hr which this engine clearly met. The CO reading of 4.8% (parts CO per 100 parts exhaust) can be multiplied by the molar conversion 28.01 grams CO per mole, the exhaust molar conversion, and the exhaust mass flow rate to produce a CO measurement of 3.03 g/min or 182 g/hr. The California standard for a 3.5 Hp engine is less than 1050 g/hr. Obviously, the stock engine was well within the standards to begin with by a factor of about 2 on HC and almost 6 on CO.

One could calculate the density of the exhaust gas as a check of the experimental data by dividing the mass flow rate by the volumetric flow rate, however, the flow meter reads in standard cubic feet per hour which is referenced to one atmosphere and 25° C. This is ideal for measuring the intake air, but must be calculated for the exhaust using its pressure and temperature using tables or a relationship such as the ideal gas law if one could consider exhaust an ideal gas. If one calculated the density of the exhaust using the air flow rate as read of the flow meter the density would be $(69.2 \text{ g/min})/(315 \text{ ft}^3/\text{hr}) = 0.5 \text{ kg/m}^3$. This is about half the density of air, and too low since the exhaust gas is pressurized. One would expect the exhaust to be more dense than the intake air. Since Alabama Cryogenic Engineering lacked the equipment to measure temperatures this high and the pressure of a free gas stream, the density of the exhaust could not be calculated. This is no setback as the exhaust density is never needed for the experimental analysis.

3.20 Qualitative Analysis of Sprays: Whether the experiment is a failure or a success, it is important to know if the spray quality was related. Reduced emissions and a finer spray would support one another as would increased emissions and a coarser spray. The spray of the carburetor and injector were analyzed both visually and mathematically.

3.21 The Carburetor: After the stock engine has been analyzed, the carburetor could be removed for observation of the spray pattern. Being a venturi, all one had to do to get the carburetor to spray fuel/air mixture was to force air through the throat and ensure the float bowl was at the same pressure as the incoming air. Compressed air was forced through at a low pressure (free jet) at approximately 80 m/s in order to simulate idle conditions and the maximum air velocities. With a diffuse dark background and a scale in the vicinity of the spray, a photo was taken (See Appendix A.). The globules of gasoline varied wildly in size from fog like to large enough to see clearly with the naked eye (the largest being approximately 0.050 in). The action was very random and may be best described as a rapid "spitting." Also, a sheet of gasoline poured along the walls of the throat and spattered droplets as is was agitated by the air flow. The fuel/air mixture had a wide range of conditions and could be described as sloppy.

An empirical formula for estimating the mean diameter (Sauter mean diameter, SMD) of the droplets formed by this type of cross-flow spray--where the air flow impinges upon the fuel flow perpendicularly--is as follows:

$$SMD = 37\left(\frac{\sigma_L \mu_L d_o^{0.5}}{\rho_A U_R^3 \rho_L}\right)^{0.4}$$

d_o is the orifice diameter (0.002 m jet diameter).
U_R is the relative velocity of the air (78.4 m/s during intake).
μ_L is the liquid viscosity (2.92E-4 Ns/m^2 for gasoline).
ρ_A is the air density (1.18 kg/m^3 at atmospheric conditions).
ρ_L is the liquid density (680 kg/m^3 for gasoline).
σ_L is the liquid surface tension (2.16E-2 N/m for gasoline).

(Lefebvre, p. 253)

This applies so long as the product of the Weber and Reynolds Number, We-Re, is greater than 10^6 which is given by:

$$\frac{d_o^2 \rho_A U_R^3 \rho_L}{\sigma_L \mu_L} > 10^6$$

(Lefebvre, p. 253)

The values given meet this constraint (We-Re = 2.5E8) and the SMD turns out to be 33 microns. This is a very small diameter but only an estimated average droplet diameter, and although some of the discharge was fog like, several globs were given off that were clearly visible.

3.22 The Injector: With the fuel flow rate know to be approximately 6.4 mL/min for the carbureted engine, the injector spray was analyzed at this flow rate since the modified engine will require a similar amount of fuel (perhaps a little more or a little less). By varying the pressure in the fuel tank, the fuel flow rate was altered until 6.4 mL of gasoline was collected in one minute; this occurred at a tank pressure of approximately 4 psi. The plate was obviously very porous to gasoline for so low a pressure to create a discernible flow rate. This pressure will be important when dyno testing the modified engine as it will be where testing will begin and the pressure varied at the regulator or the throttling valve to control engine speed.

Against the same backdrop as the carburetor, the injector was set up for photographing. A linear scale was provided in the picture. As the photo in Appendix A shows, the spray was very uniform, straight and coherent, breaking into distinct droplets at less than 2 inches break-up length (measured from injector plate). The diameter of the droplets was about three times the diameter of the initial stream which is the same as the hole diameter of 75 microns for an approximated mean droplet diameter of 225 microns or 0.0085 in.

An empirical relationship to calculate the Sauter mean diameter was developed by Dr. Brian Landrum, Dr. Clark Hawk, and Robert Beard of UAH's Propulsion Research Center. This equation was derived from data collected from perforated plate flow tests performed at Alabama Cryogenic Engineering. The equation is as follows:

$$SMD = 1.1(D_h)(\#holes)^{0.1}(L/D)^{-0.15}(Ca)^{0.1}(Re/We)^{0.3}$$

D_h is the hole diameter (75 microns or 75E-6 m).
#holes is the number of holes in the perforated plate (17).
L/D is the hole length to diameter ratio (13.3).
Ca is the cavitation number, (ambient pressure-vapor pressure)/(pressure drop).
Re is the Reynolds number, (density)(velocity)(hole diameter)/(viscosity).
We is the Weber number, (density)$(\text{velocity})^2$ (hole diameter)/(surface tension).
Ambient pressure is 101,300 N/m^2.
Vapor pressure of gasoline is 55,100 N/m^2.
Pressure drop is the gage pressure of the fuel tank, 4 psi or 27,579 N/m^2.
Density of gasoline is 680 kg/m^3.
Fluid velocity is flow rate, 6.4 mL/min, divided by the number of holes, 17,
divided by the hole area, 4.42E-9 m^2: 85.2 m/min or 1.42 m/sec.
Viscosity of gasoline is 2.92E-4 Ns/m^2.
Surface tension of gasoline is 2.16E-2 N/m.

(Landrum, p. 46)

These parameters reveal that the Reynolds number is 250, the Weber number is 4.8, and the cavitation number is 1.7. The limits of experimentation have till this point been for Reynolds numbers between 250 and 3800, Weber numbers of 10 to 2200, and cavitation numbers of 0.1 to 0.3. Although the Weber number and Cavitation number do not fall into these ranges, they are within an order of magnitude of these ranges, and since so little work has been done at this time with these plates, this is the best approximation to date one can go by. This relationship produces an SMD of 256 microns, not an altogether bad approximation considering the limited experimentation this relationship represents.

One thing to consider with this equation and the original photograph of the injector spray is that the effects of an air blast are neglected. With a blower behind the injector simulating the air rushing into the cylinder, the spray ceased to be straight and coherent, rather, it immediately disintegrated and spread wildly becoming even more fog-like.

So the carburetor produced a wide range of drop sizes, some smaller than that of the injector, some larger. The injector, in contrast, produced very uniform drops. If, as the empirical equations would indicate, the carburetor produces smaller droplets on average and the injector improves emissions, one logical conclusion would be that the large fuel globs from the carburetor are the key polluters.

3.30 The Modified Engine: Connecting a straight tube intake tract to the engine at the point the carburetor was mounted and inserting the injector plate into the throttle completed the assembly of the modified engine. With the pressurized nitrogen tank and the fuel tank assembled with the engine as shown in Figure 1. and the tank pressure set at 4 psi, the engine was started on the second pull of the cord. On the first assembly and fueling of the engine, this major hurdle had been crossed; an operational engine with a perforated plate injector had been constructed. Caution had to be taken not to over-rev the engine since the speed governor was removed with the carburetor. A slight surge was noted, and is most likely related to the constant streaming nature of the fuel spray; the carburetor only sprayed fuel while the engine was taking in air. The constant spray would cause a fuel buildup in the engine while it was not taking in air and go lean toward the end of the intake. It is possible that the resulting eccentric fuel/air mix could force an undulating engine response. However, it was a small undulation, just noticeable to the ear. The only inconveniences encountered were that the engine required two people to start it – one to turn on the fuel and one to pull the cord to start it – and it ran rough for a minute till it warmed up.

On the dyno, the first order of business was to trim or increase the fuel flow rate from 6.4 mL/min with the throttling valve, or the pressure regulator if needed, till the idle speed, 2100 rpm, was attained. A small reduction in fuel flow was required as the engine originally turned 2800 rpm. The undulation previously noted turned out to be about ±50 rpm at idle, and was immeasurable at high speeds, perhaps because the fuel had less time to stagnate in the intake tract. Closing the throttling valve a small amount was all that was required to achieve idle. With the injector pressure set, 200 mL of fuel was poured into the tank and resulted in an engine operation time of 33 minutes and 18 seconds, for a fuel consumption rate of 6.0 mL/min or 4.08 g/min. This represents a 6.25% reduction in fuel consumption.

Speed (rpm)	Pressure (psi)	Temperature (°F)	Emissions
2,100	160, 160	295, 298	HC 1100 ppm, CO 3.8%
3,500	1100, 1120	311, 315	—
4,000	950, 940	328, 327	—

Table 4. Modified Engine Dyno and Emissions Test Results.

Air flow rate is the same for both the stock and modified engine since air flow is only a function of displacement (constant), volumetric efficiency (assumed constant since it is primarily a function of displacement and clearance volume), and engine speed. Volumetric efficiency is also a function of flow losses (Sorensen, p. 65), but both the stock and modified engines had short, free-flowing intake tracks.

Engine temperatures were notably higher, perhaps too high for the engine's welfare. Also, the emissions were lower. The reasons and ramifications of these occurrences will be discussed in more detail in the conclusion.

Obviously this engine met standards if the stock engine did, but it would be good to have the emissions in a g/hr form for comparison to the car and the other engine. The exhaust mass flow rate is the fuel flow rate, 4.08 g/min, plus the air flow rate which should be the same as last time, 64.9 g/min. The exhaust flows at approximately 69.0 g/min. Again multiplying the HC emissions by the exhaust flow rate, the molar conversion for n-Heptane, and the inverse of the exhaust molar conversion, a mass flow rate of HC of 14.9 g/hr was produced. Similarly, the CO reading becomes 144 g/hr.

4.00 COMPARISON OF CAR TO SMALL ENGINES:

To calculate the g/hr pollution rates for the Civic Si, the exhaust flow rate must be known or at least estimated. The car idles at 1100 rpm and has a displacement of 1.6 liters. A volumetric efficiency of 90% is used only because the real one is not known and this in the range of efficiencies Harry Sorensen states as common for spark-ignition, four-stroke engines (Sorensen, pp. 100,101). The product of the speed, displacement, and efficiency gives an air flow rate of 0.792 m^3/min or 935 kg/min if the density of air is figured in. The fuel flow rate is approximately the air flow rate divided by the stoichiometric air-to-fuel ratio (14.91); the fuel flow rate is thus 62.7 g/min. The exhaust flow rate is the sum of the air and fuel flow rate, 997 g/min. So the HC production rate is (220 parts HC/10^6 parts exhaust)(100.21 g HC/mole HC)(mole exhaust/30.63 g)(997 g exhaust/min)(60 min/hr) = 43.1 g/hr. The production of CO is (0.39 parts CO/100 parts exhaust) (28.01 g CO/mole)(mole exhaust/30.63 g)(997 g exhaust/min)(60 min/hr) = 213 g/hr. The following table summarizes the emissions data for the Civic and the stock and modified Tecumseh engines.

Pollutant	'93 Honda Civic Si	Stock Small Engine	Modified Small Engine
HC	43.1 g/hr	19 g/hr	14.9 g/hr
CO	213 g/hr	182 g/hr	144 g/hr

Table 5. Summary of Emissions Testing Information.

As the table shows, two of the stock engines would produce almost as much HC pollution as the car in the same amount of time and almost twice the CO pollution of the car. It would take three modified engines to produce the HC pollution of the car in the same time, but one would still produce about 70% the CO as the car.

It is notable that the California emissions proposed for January 1999 are 11.2 g/hr and 350 g/hr for HC and CO emissions respectively for a 3.5 Hp engine (Gault, Letter). Both the stock and modified engine met this CO requirement but neither met the HC standard.

5.00 CONCLUSIONS:

The perforated plate injected engine represents a 22% reduction in HC and a 21% reduction in CO emissions compared to the stock engine. Fuel consumption was reduced 6% and the engine temperature increased from one to two percent. What is the causal relationship? It is a reasonable conclusion that the reduced emissions are the result of lower fuel consumption; the engine is burning leaner so less fuel is being left unburned. This loss of unburned fuel is very likely the cause of the higher temperatures, less evaporating fuel to remove excess heat. This higher heat means higher pressure combustion gases, thus the higher power readings in comparison to the stock engine (See Figure 3.). There is good evidence that the improved fuel/air mixture of the injector allowed the engine to make more efficient use of the fuel it received and thus burn leaner. The majority of the fuel from the carburetor was carried in the large blobs of fuel. The injector drops were more than 5 times smaller in diameter and thus more than 125 times less fuel was carried per drop. Smaller drops burn quicker, thus the higher efficiency.

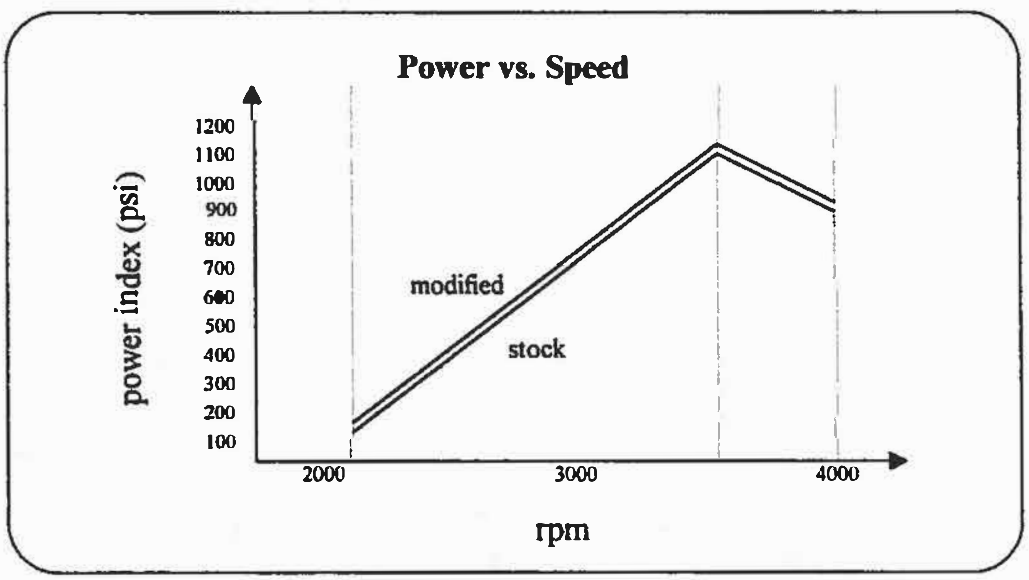


Figure 3. Comparison of Small Engine Power.

Greater efficiency is the key to low emissions. The overall efficiency -- the power out divided by the power equivalent of the fuel provided -- of the two engines could easily be compared. At idle, the stock engine consumed 0.0725 g/sec of gasoline which has a heating value of 44,315 kJ/kg (Sorensen, p. 35). The product of these numbers means the engine consumes 3.2 kW. This engine produces a claimed 5.2 ft-lb of torque at 2600 rpm; the torque is relatively constant and can be assumed to be 5.2 ft-lb at 2100 rpm (Gault, Letter). The power output of the engine is the torque multiplied by the shaft speed: (5.2 ft-lb)(2100 rpm) = (5.2 ft-lb)(220 radians/sec) = 1144 ft-lb/sec = 1.55 kW. Thus, the stock engines overall efficiency is (1.55 kW)/(3.2 kW) = 48%, not a bad efficiency for a simple internal combustion engine. The modified engine consumed 3.0 kW of power while producing 1.65 kW (the ratio of modified engine pressure on the dyno versus the stock engine, 160 psi/150 psi, multiplied by the power of the stock engine). The modified engine's efficiency is 55%, for an increase in overall efficiency of 15%.

Error in this experiment was considerable. Much can be attributed to bias and random error in such instruments as the mass flow meters and the emissions analyzer. Unfortunately, the statistics on the error expected from these instruments is unknown due to their age. Average values for such variables as ambient pressure and material properties contribute some unknown error. Round-off of calculations also plays a role in the error in this research. Another error is introduced in the estimation of droplet size from the photographs and the empirical equations which at best provide an answer which can be considered to have ±20% error. At any rate, error was of little consequence since only one engine was run and no statistical data can be produced; at least three engines would be required to make a statistical statement about the variations from engine to engine. Only one dynamometer test could be afforded for the stock and modified engine. Also, error was not a major concern so long as care was taken to produce the best data available resources allowed since this is truly a preliminary experiment which may lead to more in-depth graduate research or further, more scientific research by Alabama Cryogenic Engineering.

What are possible future routes of research in this area? A similar experiment could be run with multiple engines, a variety of perforated plate geometries (thickness, diameter, number of holes, etc.), and more sophisticated equipment. Alabama Cryogenic Engineering has considered doing similar work with an automotive engine. Direct fuel injection into the cylinder, such as in diesel engines, could be an area for perforated plate experiments. A domed plate can be made so as to produce a conical spray pattern. Instead of a continuous stream, a pump could be devised to pulse fuel at 1/4 the engine speed so fuel only flowed during intake. This has been done in the past by simply hydrostaticly deforming a plate in a rubber block with a ball bearing pressed into it with a hand press. Nitrous oxide (NO_x) emissions could also be monitored, since NO_x production is a function of engine temperature; the higher the temperature, the more NO_x is produced from atmospheric oxygen and nitrogen. This NO_x production is important since the engine temperature in this experiment increased and NO_x is a smog gas monitored in some states.

As the USA Today article indicated, small engines are major culprits in air pollution, but there is room for improvement. Manufacturers must be prepared to design engines for higher efficiencies due to future regulations. This means designing for such obstacles as higher temperatures. If manufacturers go to injectors, they are probably going to face higher production costs. An injector has fewer parts than a carburetor and simpler geometry, but they involve the addition of a fuel pump. Fuel injection may be a better, cheaper solution than adding a catalytic converter to a lawnmower, and a perforated plate is an affordable alternative to existing injectors.

WORKS CITED

1990 SAE Handbook, Vol. 3: Engines, Fuels, Lubricants, Emissions and Noise. Society of Automotive Engineers, Inc.: Warrendale, 1990.

Atkinson, Henry F. *Mechanics of Small Engines.* McGraw Hill Publishing Company: New York, 1990.

CBS, date unknown, "Paul Harvey's News and Comment," Paul Harvey, commentator.

Compton, Scott. Environmental Protection Agency, Columbus, Ohio. Interview, 30 March 1995.

Dingus, Michael. "Perforated Plate Technology for Propulsion Applications." Alabama Cryogenic Engineering, Inc.: Huntsville, 1994.

Gault, Roger T. Letter summarizing engine specifics and emissions requirements, 19 December 1994.

Grainger General Catalog, No. 385. Grainger: USA., 1994.

Landrum, D.B., Beard, R.M., and Hawk, C.W. *A Novel Approach to Oxidizer Injection in Hybrid Propulsion, Final Report, Task I: Injector Performance Modeling.* Propulsion Research Center: Huntsville, 1994.

Lefebvre, Arthur H. *Atomization and Sprays.* Hemisphere Publishing Corporation: New York, 1989.

"Off-Road Engines Are Polluters, Say EPA," *USA Today*, 30 October 1991, p. 1A.

Sorensen, Harry A. *Energy Conversion Systems.* John Wiley & Sons: New York, 1983.

WORKS CONSULTED

Atomization and Sprays 2000. National Science Foundation: Pittsburgh, 1991.

Gault, Roger T. Emissions Control Manager, Tecumseh Products Company, Engine and Transmission Group, New Holstein, Wisconsin. Interview, 17 December 1994.

Instruction Manual for Model III C Exhaust Emission Analyzer. Chrysler Corporation, Huntsville Electronics Division: Huntsville, 1974.

Obert, Edward F. *Internal Combustion Engines and Air Pollution*. Harper & Row, Publishers, Inc.: New York, 1973.

Owner's Manual and Operating Instructions for Tecumseh Models: H30, H35, HS40, HS50. Tecumseh Products Company: USA., 1992.

Razin, Andrew. Chairperson, Automotive Technology, Columbus State Community College, Columbus, Ohio. Interview, 29 March 1995.

Sims, J.D., Greiner, B.E., and Frederick, R.A., Jr. *A Novel Approach to Oxidizer Injection in Hybrid Propulsion, Final Report, Task II: Develop Hardware Designs*. Propulsion Research Center: Huntsville, 1994.

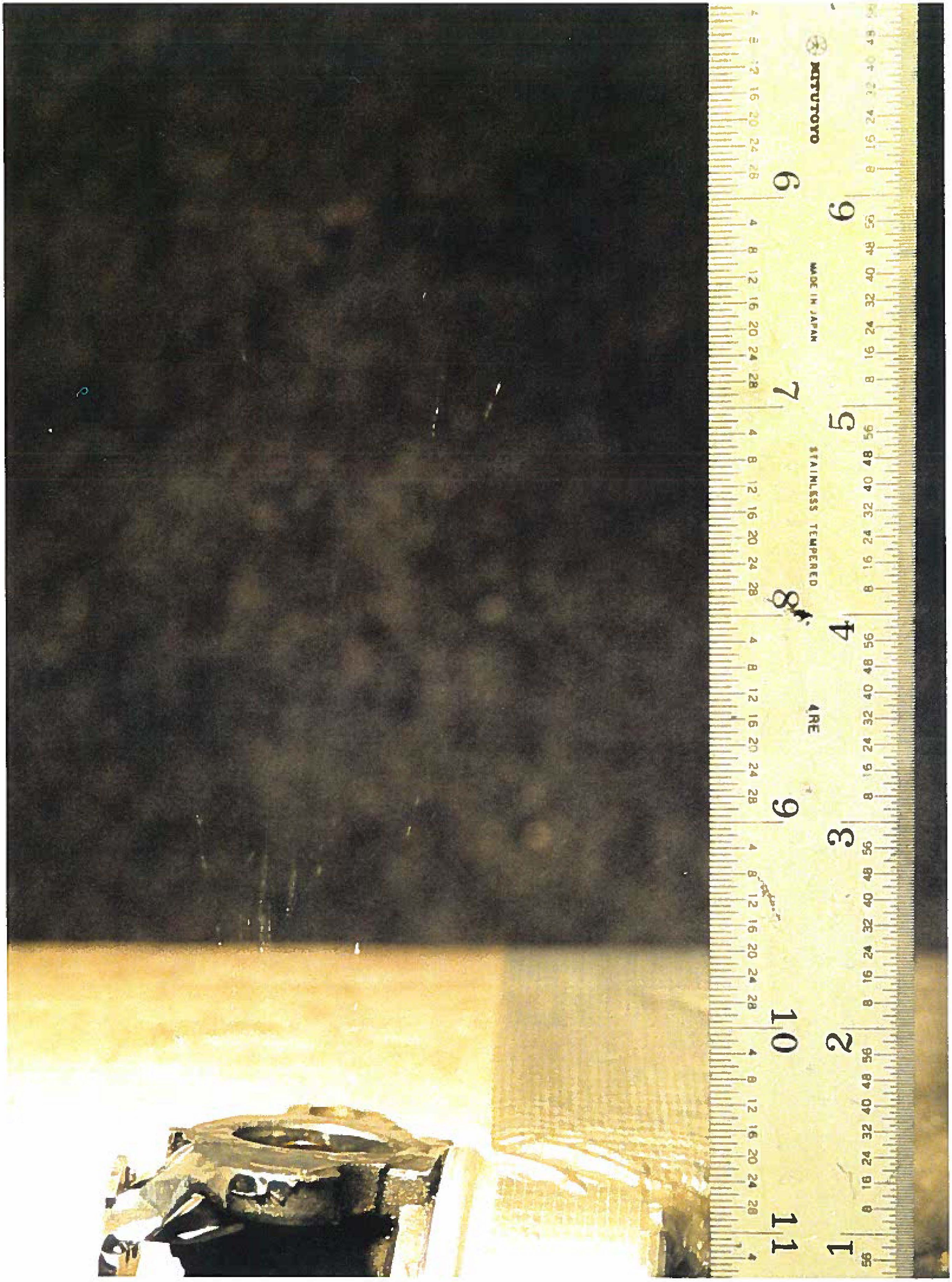
White, Frank M. *Fluid Mechanics*. McGraw Hill, Inc.: New York, 1986.

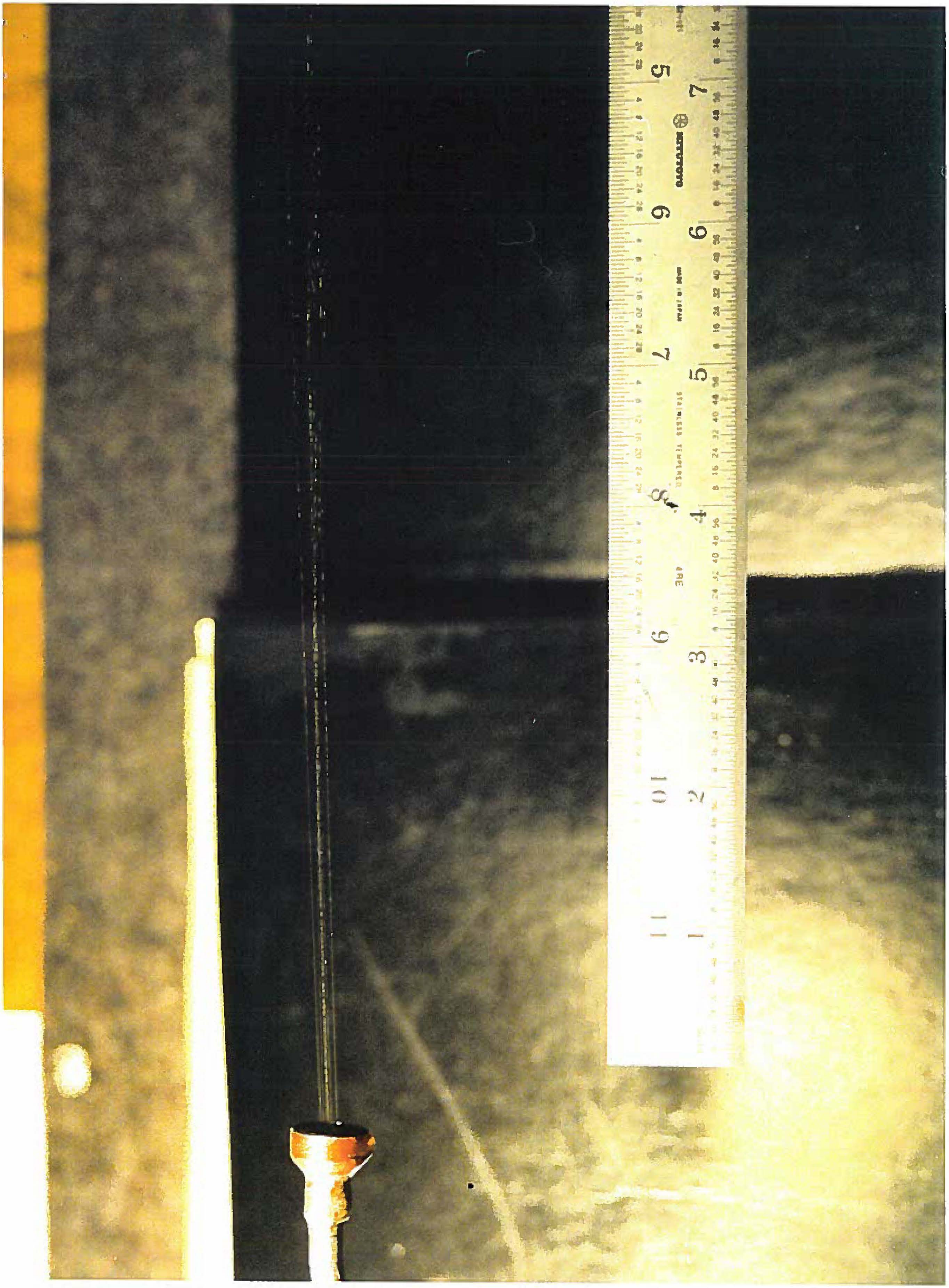
APPENDIX

A. Fuel Spray Photographs.

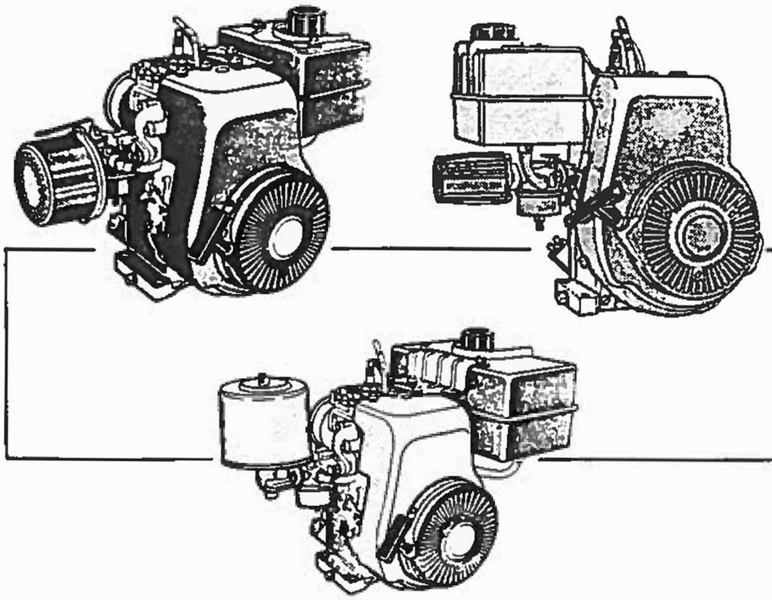
B. Tecumseh Owners Manual.

A. Fuel Spray Photographs.


MITUTOYO
MADE IN JAPAN
STAINLESS TEMPERED
4RE



B. Tecumseh Owner's Manual.



OWNER'S MANUAL

and OPERATING INSTRUCTIONS for

TECUMSEH

MODELS H30 H35 HS40 HS50

HORIZONTAL CRANKSHAFT
AIR COOLED
FOUR-CYCLE ENGINE

THIS SYMBOL POINTS OUT IMPORTANT SAFETY INSTRUCTIONS WHICH IF NOT FOLLOWED COULD ENDANGER THE PERSONAL SAFETY AND/OR PROPERTY OF YOURSELF AND OTHERS. READ AND FOLLOW ALL INSTRUCTIONS IN THIS MANUAL AND ANY PROVIDED WITH THE EQUIPMENT ON WHICH THIS ENGINE IS USED BEFORE ATTEMPTING TO OPERATE YOUR TECUMSEH ENGINE.

THESE SYMBOLS MAY APPEAR ON THE ENGINE:

FAST — SLOW — STOP — OFF / FULL CHOKE

Rev. 3-1-92 **181-659-1**

OIL & FUEL RECOMMENDATIONS

TO OPERATE ENGINE, YOU WILL NEED THE FOLLOWING:

① **A CLEAN, HIGH QUALITY DETERGENT OIL.**
Be sure original container is marked:
A.P.I. service "SF" or "SG".

FOR SUMMER (ABOVE 32°F) USE SAE 30 OIL.
Tecumseh specially formulated oil is available at any Authorized Tecumseh Service Outlet. Order as part number 730225.
Using multigrade oil will increase oil consumption.

FOR WINTER (BELOW 32°F) USE SAE 5W30 OIL.
Tecumseh specially formulated oil is available at any Authorized Tecumseh Service Outlet. Order as part number 730226.
(SAE 10W is an acceptable substitute.)
(BELOW 0°F ONLY): SAE 0W30 OIL is an acceptable substitute.

DO NOT USE SAE 10W40 OIL.

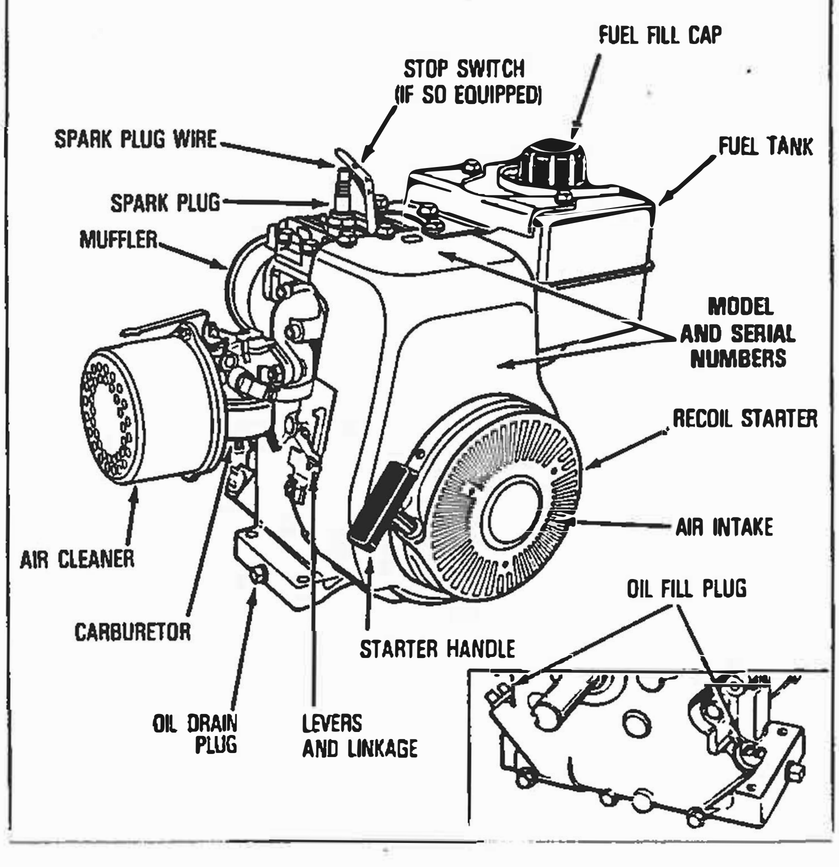
OIL SUMP CAPACITY: 21 ounces (1-1/4 U.S. pints) .62 liter.

② **A FRESH, CLEAN, UNLEADED REGULAR AUTOMOTIVE GASOLINE.** (Leaded Regular and unleaded or leaded premium grades of gasoline are acceptable substitutes.)

NOTE: DO NOT USE GASOLINE CONTAINING METHANOL (WOOD ALCOHOL). Gasoline containing up to 10% ethanol or grain alcohol ("Gasohol") may be used but requires special care when engine is unused for extended periods.
See "STORAGE" instructions on Page 5.

NOTE: Use clean oil and fuel and store in approved, clean, covered containers. Use clean fill funnels.

Never use "stale" gasoline left over from last season or stored for



BEFORE STARTING

① READ ALL INSTRUCTIONS PROVIDED WITH THE EQUIPMENT ON WHICH THIS ENGINE IS USED.

② FILL OIL SUMP OR CHECK OIL LEVEL:

IMPORTANT: To avoid engine damage never run engine unless:

- Oil level is between "FULL" and "ADD" marks on dipstick (if so equipped).
- Oil level is to overflow point in oil fill hole on engine without a dipstick.
- Oil fill plug is tightened securely into oil fill tube or hole.

CHECK OIL LEVEL OFTEN DURING ENGINE BREAK-IN.

A. ENGINE WITHOUT DIPSTICK:

1. POSITION EQUIPMENT SO ENGINE IS LEVEL.
2. Clean area around oil fill plug (see Figure 1).
3. Remove oil fill plug.
4. If oil level is not up to overflow point in oil fill hole, add recommended oil. POUR SLOWLY.
5. Install oil fill plug, tighten securely.

B. ENGINE WITH DIPSTICK:

1. POSITION EQUIPMENT SO ENGINE IS LEVEL.
2. Clean area around oil fill plug (see Figure 1).
3. Remove oil fill plug and dipstick.
4. Wipe dipstick clean, insert it into oil fill hole and tighten securely, remove dipstick. If oil is not up to "FULL" mark on dipstick, add recommended oil. POUR SLOWLY. Wipe dipstick clean each time oil level is checked.
   IMPORTANT: DO NOT FILL ABOVE "FULL" MARK ON DIPSTICK.
5. Install oil fill plug and dipstick, tighten securely.

See "MAINTENANCE" section for further oil instructions.

③ FILL FUEL TANK:

A. Clean area around fuel fill cap, remove cap.

B. Add "UNLEADED" regular gasoline, slowly, to fuel tank. Use a funnel to help avoid spillage.

IMPORTANT: NEVER MIX OIL WITH GASOLINE

C. Install fuel fill cap and wipe up any spilled gasoline.

⚠ **NEVER FILL FUEL TANK INDOORS. NEVER FILL FUEL TANK WHEN ENGINE IS RUNNING OR HOT. DO NOT SMOKE WHEN FILLING FUEL TANK.**

⚠ **NEVER FILL FUEL TANK COMPLETELY. FILL TANK TO 1/2" BELOW BOTTOM OF FILLER NECK TO PROVIDE SPACE FOR FUEL EXPANSION. WIPE ANY FUEL SPILLAGE FROM ENGINE AND EQUIPMENT BEFORE STARTING ENGINE.**

⚠ **ANY LIQUIFIED PETROLEUM (LPG) OR NATURAL GAS FUEL SYSTEM MUST BE LEAKPROOF AND MEET ALL APPLICABLE CODES AND REGULATIONS.**

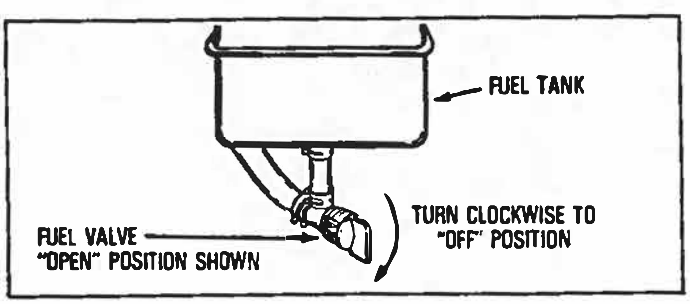


Figure 2

BEFORE STARTING (Continued)

④ CHECK THE FOLLOWING:

A. ⚠ **BE SURE EQUIPMENT IS IN NEUTRAL GEAR WITH CLUTCHES, BELTS, CHAINS AND SAFETY SWITCHES DISENGAGED. (FOLLOW EQUIPMENT MANUFACTURER'S INSTRUCTIONS.) THIS SHOULD PLACE ANY SAFETY SWITCHES IN SAFE STARTING POSITION.**

B. Be sure spark plug wire is attached to spark plug (see Figure 1).

C. Be sure stop switch (if so equipped - see Figure 1) is not contacting spark plug.

D. Be sure any ignition switch and/or control lever on engine or equipment is in "ON", "RUN" or "START" position.

E. Be sure fuel valve (if so equipped - see Figure 2) is open.

STARTING

⚠ **NEVER RUN ENGINE INDOORS OR IN ENCLOSEI POORLY VENTILATED AREAS. ENGINE EXHAUST COI TAINS CARBON MONOXIDE, AN ODORLESS AN DEADLY GAS.**

⚠ **KEEP HANDS, FEET, HAIR AND LOOSE CLOTHIN AWAY FROM ANY MOVING PARTS ON ENGINE AN EQUIPMENT.**

⚠ **WARNING — TEMPERATURE OF MUFFLER AND NEA BY AREAS MAY EXCEED 150°F (65°C). AVOID THE: AREAS.**

① RECOIL STARTER:

A. Move choke lever (see Figure 3) to "FULL CHOKE POS TION."

NOTE: IF RESTARTING A WARM ENGINE AFTER SHORT SHUTDOWN, MOVE CHOKE LEVE TO "NO CHOKE POSITION."

B. Move equipment control (see manufacturer's instructions) engine control to "START".

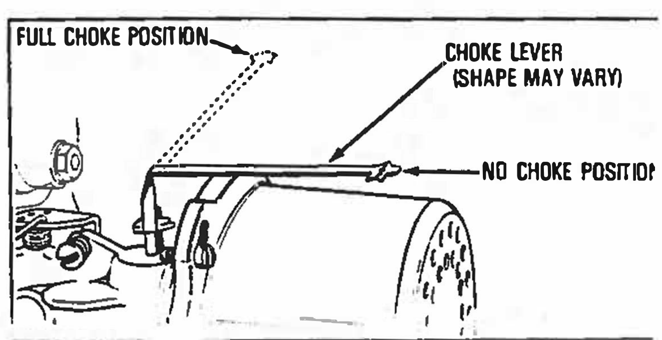
C. Grasp starter handle (see Figure 1) and pull rope out, slow until it pulls harder. Let rope rewind slowly. Then pull ro with a rapid full arm stroke. Let rope return to starter slow

D. When engine starts, move choke lever to "1/2 CHOKE" u engine runs smoothly and then to "NO CHOKE POSITIO

If engine falters, move choke lever to "1/2 CHOKE" u engine runs smoothly and then to "NO CHOKE POSITIO

NOTE: If engine fails to start after three (3) pulls, m choke lever to "NO CHOKE POSITION" and starter rope again.

NOTE: If engine fires, but does not continue to run, m choke lever to "FULL CHOKE" and repeat instr tions B, C and D until engine starts.



STARTING (Continued)

② ELECTRIC STARTER:

A. Move choke lever (see Figure 3) to "FULL CHOKE POSITION."

NOTE: IF RESTARTING A WARM ENGINE AFTER A SHORT SHUTDOWN, MOVE CHOKE LEVER TO "NO CHOKE POSITION."

B. Move equipment control (see manufacturer's instructions) or engine control to "START".

C. Push starter button or turn ignition switch key (see equipment manufacturer's instructions) to crank engine.

D. Crank engine until it fires. When it starts, release starter button or ignition switch key and move choke lever to "1/2 CHOKE" until engine runs smoothly and then to "NO CHOKE POSITION."

If engine falters, move choke lever to "1/2 CHOKE" until engine runs smoothly and then to "NO CHOKE POSITION."

NOTE: If engine fires, but does not continue to run, move choke lever to "NO CHOKE POSITION" and crank engine until it starts.

NOTE: If engine again fires, but does not continue to run, move choke lever to "FULL CHOKE" and repeat instructions B, C and D until engine starts.

STOPPING

① Move equipment control or any ignition stop switch on engine to "STOP" or "OFF" (see equipment manufacturer's instructions).

② Push stop switch (if so equipped - see Figure 1) located next to spark plug on engine against spark plug and hold it in this position until engine is completely stopped.

OR

Move rotary on/off switch (if so equipped - see Figure 1) to "OFF" position.

③ AFTER ENGINE IS STOPPED:

A. Close fuel valve (if so equipped).

⚠ **B. DISCONNECT SPARK PLUG WIRE FROM SPARK PLUG AND KEEP IT AWAY FROM SPARK PLUG.**

⚠ **C. TURN IGNITION SWITCH KEY (IF SO EQUIPPED) TO "OFF" POSITION AND REMOVE KEY FROM SWITCH. THIS WILL REDUCE THE POSSIBILITY OF UNAUTHORIZED STARTING OF ENGINE WHILE EQUIPMENT IS NOT IN USE.**

⚠ **NEVER STORE ENGINE WITH FUEL IN TANK INDOORS OR IN ENCLOSED, POORLY VENTILATED AREAS, WHERE FUEL FUMES MAY REACH AN OPEN FLAME, SPARK OR PILOT LIGHT AS ON A FURNACE, WATER HEATER, CLOTHES DRYER OR OTHER GAS APPLIANCE.**

MAINTENANCE

⚠ **WARNING — TEMPERATURE OF MUFFLER AND NEARBY AREAS MAY EXCEED 150°F (65°C). AVOID THESE AREAS.**

① OIL LEVEL:

Check oil level every five (5) operating hours and before each use. See "FILL OIL SUMP OR CHECK OIL LEVEL" on Page 2.

MAINTENANCE (Continued)

② CHANGE OIL:

Change oil after first two (2) operating hours and every 25 operating hours thereafter, more often if operated in extremely dusty or dirty conditions. Change oil while engine is still warm from recent running.

⚠ **A. DISCONNECT SPARK PLUG WIRE FROM SPARK PLUG AND KEEP IT AWAY FROM SPARK PLUG.**

B. Clean area around oil drain plug (see Figure 1).

C. Position equipment so engine oil drain plug is lowest point on engine.

D. Remove oil drain plug and oil fill plug to drain oil.

E. Install oil drain plug and tighten securely.

F. Fill oil sump with recommended oil. See "OIL & FUEL RECOMMENDATIONS" on Page 1 and "FILL OIL SUMP OR CHECK OIL LEVEL" on Page 2.

G. Install oil fill plug and tighten securely.

H. Wipe up any spilled oil.

③ COOLING SYSTEM (see Figure 1 and 4):

IMPORTANT: Frequently remove grass clippings, dirt anc debris from cooling fins, air intake screen and levers anc linkage. This will help ensure adequate cooling and correc engine speed.

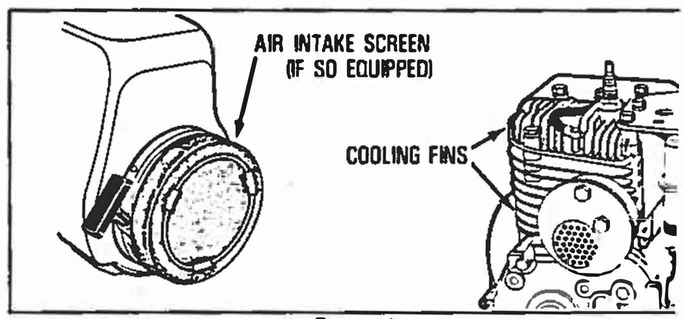


Figure 4

④ SPARK PLUG (see Figure 5):

Check spark plug yearly or every 100 operating hours.

A. Clean area around spark plug.

B. Remove and inspect spark plug.

C. Replace spark plug if electrodes are pitted, burned or porcelain is cracked. For replacement use Champion J-8I Autolite 356 or equivalent.

NOTE: In Canada, replace spark plug with a resistor plu

D. Check electrode gap with wire feeler gauge and set gap .030 if necessary.

E. Install spark plug, tighten securely.

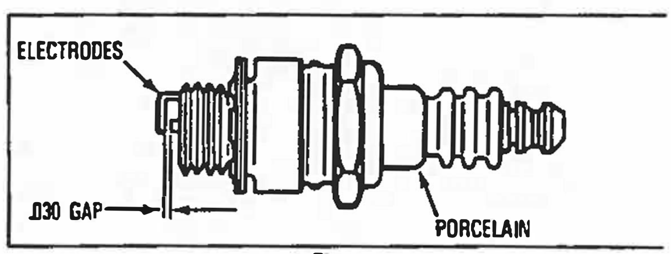


Figure 5

⑤ AIR CLEANER:

IMPORTANT: NEVER RUN ENGINE WITHOUT COMPLETE AIR CLEANER INSTALLED ON ENGINE.

A. TO SERVICE FILTER(S) (see Figure 6):

1. **FOAM FILTER:**

   NOTE: DO NOT OIL FOAM FILTER ON AIR CLEANER B.
   Clean and re-oil every three (3) months or every 25 operating hours. Clean and re-oil daily if used in extremely dusty conditions.

   a. Wash in water and detergent solution and squeeze (don't twist) until all dirt is removed.
   b. Rinse thoroughly in clear water.
   c. Wrap in a clean cloth and squeeze (don't twist) until completely dry.
   d. Saturate with engine oil and squeeze (don't twist) to distribute oil and remove excess oil.

2. **PAPER FILTER:**

   DO NOT ATTEMPT TO CLEAN OR OIL FILTER.

   Replace once a year or every 100 operating hours, more often if used in extremely dusty conditions.

   Replacement filters are available at any Authorized Tecumseh Service Outlet.

B. TO REMOVE AND INSTALL FILTER(S):

AIR CLEANER A (see Figure 6):

1. Loosen two (2) cover screws (these need not be removed completely).
2. Turn cover counterclockwise and remove it from base.
3. Inspect foam filter for discoloration or dirt accumulation. If either is present, service per preceding "TO SERVICE FILTER(S)" instructions.
4. Clean inside of base and cover thoroughly.
5. Replace foam filter and cover making sure the foam filter is seated correctly between base and cover. Tighten cover screws securely.

AIR CLEANER B (see Figure 6):

1. Loosen two (2) cover screws (these need not be removed completely).
2. Turn cover counterclockwise and remove it and paper filter from base. Discard paper filter.
3. Clean inside of base and cover thoroughly.
4. Insert new paper filter into cover and reassemble cover to base as it was before removal. Tighten cover screws securely.

AIR CLEANER C (see Figure 6):

1. Remove wing nut and cover.
2. Slide foam filter off paper filter.
3. Inspect filters for discoloration or dirt accumulation. If either is present, service per preceding "TO SERVICE FILTER(S)" instructions.
4. Remove nut and paper filter (if service is necessary).
5. Clean topside of base and inside of cover thoroughly.
6. Install paper filter and nut. Tighten nut finger tight and then turn it one more complete turn.
7. Slide foam filter over paper filter.
8. Install cover and wing nut. Tighten wing nut.

MAINTENANCE (Continued)

AIR CLEANER D (see Figure 6):

1. Turn cover to the left (counterclockwise) and remove it and filter from flange. Discard filter.
2. Clean cover and flange thoroughly.
3. Insert new filter into cover.
4. Position cover and filter against flange with tab on cover inserted into lower left corner of slot in flange.
5. Push cover firmly against flange and turn it to the right (clockwise) as far as it will go. Be sure retainers are locked around flange.

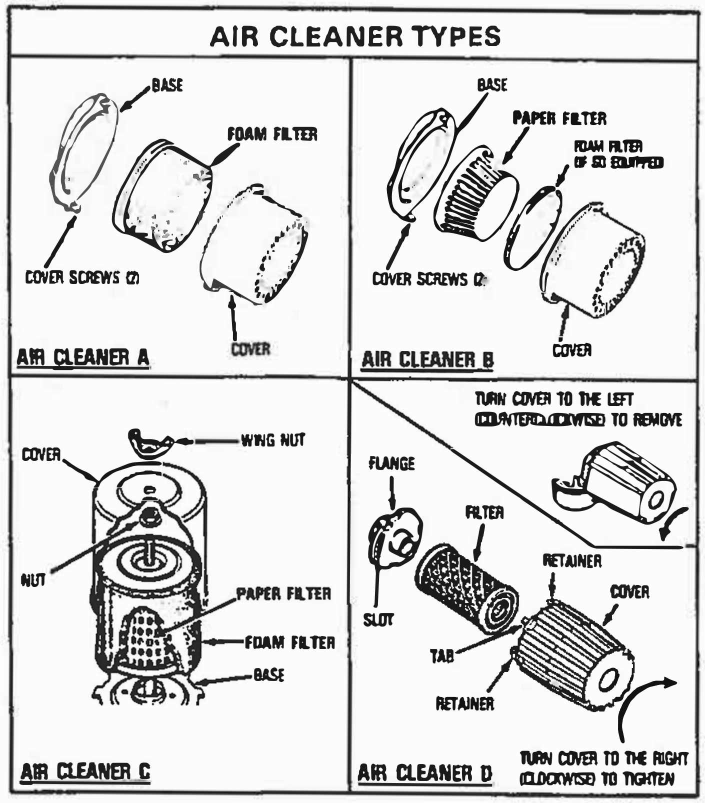


Figure 6

⑥ ALTERNATOR AND BATTERY (if so equipped):

A. ALTERNATOR:

For electrical problems such as inoperative starter or discharged battery see equipment manufacturer's instructions for fuse replacement, maintenance and repairs.

B. BATTERY:

1. When servicing battery, always connect cables to battery exactly as they were before removal (ground cable to battery negative [– or neg.] post). If incorrectly connected, fuse (if so equipped), will blow and alternator won't charge battery. If this happens, connect cables correctly and replace fuse.
2. Never expose engine ignition system to battery power. If battery cable or any live wire contacts ignition system ground wire, engine ignition system may be damaged.
3. If external battery charger is used, disconnect positive (+ or pos.) cable from battery to prevent possible damage.
4. See battery manufacturer's instructions for service and storage.

⑦ ⚠ CHECK ENGINE AND EQUIPMENT OFTEN FOR LOOSE NUTS, BOLTS AND ATTACHMENTS AND KEEP THESE ITEMS TIGHTENED.

ADJUSTMENTS

DO NOT MAKE UNNECESSARY ADJUSTMENTS. FACTORY SETTINGS ARE SATISFACTORY FOR MOST CONDITIONS. IF ADJUSTMENTS ARE NEEDED, PROCEED AS FOLLOWS:

① REMOTE CONTROL (see Figure 7):

For satisfactory engine performance, engine and equipment control must be adjusted properly. To check engine control adjustments, proceed as follows:

A. Set equipment control at "FAST" or "HIGH SPEED" and keep it in this position.

The engine control lever should touch "HIGH SPEED STOP". If it does, the controls are adjusted correctly and no adjustment is necessary.

NOTE: If engine control lever does not touch "HIGH SPEED STOP", proceed to instruction "B".

B. Loosen clamp screw so remote control cable can be moved in cable clamp.

C. Move engine control lever so it is touching "HIGH SPEED STOP" and hold in this position.

D. Tighten clamp screw securely so cable clamp will hold remote control cable in place when equipment control is used.

The engine controls should now be adjusted correctly.

If additional adjustments are needed, make them at the equipment control (see equipment manufacturer's instructions).

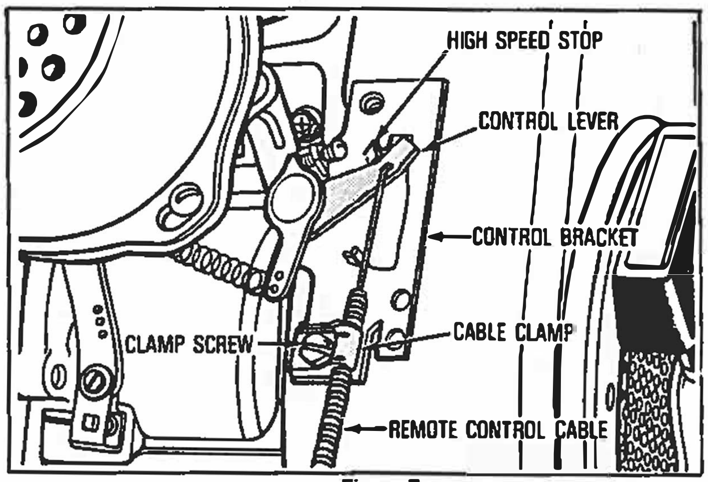


Figure 7

② CARBURETOR:

If you think your carburetor needs adjusting, see your nearest AUTHORIZED TECUMSEH SERVICE OUTLET.

Engine performance may be affected in altitudes above 4,000 feet. To improve engine performance, install a High Altitude Adjustment Kit. To obtain a kit, see your nearest AUTHORIZED TECUMSEH SERVICE OUTLET.

③ ENGINE SPEED:

NEVER TAMPER WITH ENGINE GOVERNOR WHICH IS FACTORY SET FOR PROPER ENGINE SPEED. OVERSPEEDING ENGINE ABOVE FACTORY HIGH SPEED SETTING CAN BE DANGEROUS.

CHANGING OF ENGINE GOVERNED SPEED WILL VOID ENGINE WARRANTY.

For engine adjustments and/or repairs not covered in this "OWNER'S MANUAL" see "WARRANTY & REPAIR" on Page 6.

STORAGE

NEVER STORE ENGINE WITH FUEL IN TANK INDOORS OR IN ENCLOSED, POORLY VENTILATED AREAS, WHERE FUEL FUMES MAY REACH AN OPEN FLAME, SPARK OR PILOT LIGHT AS ON A FURNACE, WATER HEATER, CLOTHES DRYER OR OTHER GAS APPLIANCE.

IF ENGINE IS TO BE UNUSED FOR 30 DAYS OR MORE, PREPARE AS FOLLOWS:

① FUEL SYSTEM:

A. Remove all gasoline from carburetor and fuel tank to preven[t] gum deposits from forming on these parts and causin[g] possible malfunction of engine.

DRAIN FUEL INTO APPROVED CONTAINE[R] OUTDOORS, AWAY FROM OPEN FLAME. BE SUR[E] ENGINE IS COOL. DO NOT SMOKE.

B. Run engine until fuel tank is empty and engine stops due t[o] lack of fuel.

NOTE: If "Gasohol" has been used, complete above Instruc[-]tions and then put 1/2 pint of gasoline into fuel tan[k] and repeat above instructions.

NOTE: Fuel stabilizer (such as STA-BIL) is an acceptabl[e] alternative in minimizing the formation of fuel gu[m] deposits during storage. Add stabilizer to gasoline i[n] fuel tank or storage container. Always follow mix rati[o] found on stabilizer container. Run engine at least 1[0] minutes after adding stabilizer to allow it to reach carburetor.

② DRAIN CARBURETOR (if so equipped):

Drain carburetor by pressing upward on bowl drain (see Figu[re] 8), which is located below carburetor (see Figure 1).

DRAIN FUEL INTO APPROVED CONTAINE[R] OUTDOORS, AWAY FROM OPEN FLAME. BE SUR[E] ENGINE IS COOL. DO NOT SMOKE.

NOTE: Do not drain carburetor if using fuel stabilizer.

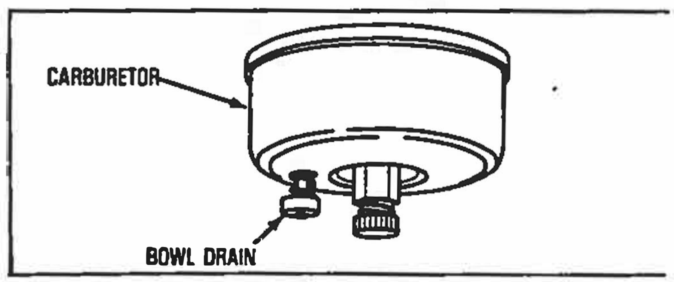


Figure 8

③ CHANGE OIL:

Change oil if it has not been changed in the last three months. See "CHANGE OIL" instructions "MAINTENANCE" section.

④ OIL CYLINDER BORE:

A. Remove spark plug. Squirt one (1) oz. (30 ml) of cl[ean] engine oil into spark plug hole.

B. Cover spark plug hole with a rag.

C. Crank engine over, slowly, several times.

AVOID SPRAY FROM SPARK PLUG HOLE WH[EN] CRANKING ENGINE OVER SLOWLY.

D. Install spark plug. Do not connect spark plug wire.

⑤ CLEAN ENGINE:

Remove any clippings, dirt, or chaff from exterior of engin[e]

⑥ BATTERY (if so equipped):

See equipment manufacturer's instructions for prope[r] sto[rage] of batter[y].

WARRANTY AND REPAIR

For engine adjustments, repairs, or warranty service not covered in this manual, contact your nearest AUTHORIZED TECUMSEH SERVICE OUTLET. It is listed in your telephone book yellow pages under "Engines, Gasoline."

If you have a general understanding of internal combustion engines and wish to repair and service your engine yourself, a "MECHANICS HANDBOOK" which covers repairs and adjustments not covered in this OWNER'S MANUAL is available from your AUTHORIZED TECUMSEH SERVICE OUTLET. Order as Part No. 692509.

Tecumseh manufactures and is responsible only for the engine used on this power equipment. If repair or service is needed for unit, other than engine, contact service source as recommended by equipment manufacturer.

LIMITED WARRANTY FOR NEW TECUMSEH ENGINES AND ELECTRONIC IGNITION MODULES

For the time period shown below from the date of purchase, Tecumseh Products Company will, at its option as the exclusive remedy, either repair or replace for the original purchaser, free of charge, any part of any new Tecumseh engine which is found, upon examination by any Tecumseh Authorized Service Outlet or by Tecumseh's factory in Grafton, Wisconsin, to be DEFECTIVE IN MATERIAL AND/OR WORKMANSHIP, except as provided below. This Limited Warranty does not cover (i) any Tecumseh engine or part(s) thereof used to power any vehicle in competitive racing and/or used on any commercial or rental track, or (ii) defects or damage caused by alterations or modifications of new Tecumseh engines or parts or by normal wear, accidents, improper maintenance, improper use or abuse of the product, or failure to follow the instructions contained in an Instruction Manual for the operation of the new Tecumseh engine or part. The cost of normal maintenance or replacement of service items which are not defective shall be paid for by the original purchaser. At the time warranty service is requested evidence must be presented of the date of purchase by the original purchaser. Any charge for making service calls and/or for transporting any engine or part(s) thereof to and from the place where the inspection and/or warranty work is performed is payable solely by the purchaser. The purchaser is responsible for any damage or loss incurred in connection with the transportation of any engine or part(s) thereof submitted for inspection and/or warranty work. Warranty service can only be performed by a Tecumseh Authorized Service Outlet or by Tecumseh at its factory in Grafton, Wisconsin. Warranty service can be arranged by contacting either a Tecumseh Authorized Service Outlet (any Tecumseh Registered Service Dealer, Tecumseh Master Service Dealer, Tecumseh Authorized Service Distributor, or Tecumseh Central Warehouse Distributor) or by contacting Tecumseh c/o Service Manager, Engine and Transmission Group Service Division, 900 North Street, Grafton, Wisconsin 53024.

Engine Warranty Category*	United States and Canadian Warranty Period (from date of sale)	Warranty Period on engines sold at retail outside the United States or Canada (from date of sale)
(A)	90 days	1 year
(B)	1 year	1 year
(C)	2 years	1 year
(D)	2 years - engine; 10 years - electronic ignition module	2 years - engine; 10 years - electronic ignition module

*The engine warranty category of your engine can be determined by review of the engine serial number on the engine. One letter in the serial number will be surrounded by parens - (A), (B), (C) or (D) - and that letter is your engine warranty category designation.

THIS EXPRESS WARRANTY IS IN LIEU OF ALL OTHER EXPRESS WARRANTIES. Neither Tecumseh nor any of its affiliates makes any warranties, representations, or promises, written or oral, as to the quality of the engine or any of its parts, other than as set forth herein. ANY IMPLIED WARRANTY OF MARKETABILITY OR FITNESS FOR A PARTICULAR PURPOSE, TO THE EXTENT THAT EITHER MAY APPLY TO ANY TECUMSEH ENGINE OR PART(S) THEREOF, SHALL BE LIMITED IN DURATION TO THE PERIODS OF THE EXPRESS WARRANTIES SHOWN IN THE WARRANTY PERIOD CHART ABOVE AND TO THE EXTENT PERMITTED BY LAW ANY AND ALL IMPLIED WARRANTIES ARE EXCLUDED. IN NO EVENT WILL TECUMSEH BE LIABLE FOR ANY INCIDENTAL, CONSEQUENTIAL OR SPECIAL DAMAGES AND/OR EXPENSES. Some states do not allow limitations on how long an implied warranty lasts or the exclusion or limitation of incidental or consequential damages, so the above limitation(s) or exclusion(s) may not apply to you. This Limited Warranty gives you specific legal rights and you may also have other legal rights which vary from state-to-state.

7-1-93