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► **To cite this version:**

Nadia Mrad, Fethi Aloui, Mohand Tazerout. Performance and Emissions of Diesel Engine Using Bio-Fuel Derived From Waste Fish Oil. ASME 2012 Fluids Engineering Division Summer Meeting, Jul 2012, Rio Grande, United States. pp.1101-1107, 10.1115/FEDSM2012-72292 . hal-00935917

HAL Id: hal-00935917

<https://hal.science/hal-00935917>

Submitted on 14 Jun 2021

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PERFORMANCE AND EMISSIONS OF DIESEL ENGINE USING BIO-FUEL DERIVED FROM WASTE FISH OIL

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ABSTRACT

In the present work, waste fish fat from fish processing industry is considered as an energy source for diesel engines. In this regard, catalytic cracking process is considered for this present study. The physical and chemical properties of biofuel are very close to diesel fuel. The experiments were conducted in a single cylinder diesel engine to study the performance, emission and combustion characteristics of biofuel. As a result, fuel undergoes good combustion and hence there is significant improvement in performance and reduction in emissions. Experimental results indicate a marginal increase in brake thermal efficiency at all loads compared to diesel fuel. The results show that despite of high NO_x and CO₂, the engine has lesser UHC, CO and PM than standard diesel fuel. The premixed and diffusion combustion duration is decreased with biofuel compared to diesel fuel. The engine was running smooth at all load conditions with biofuel. It is concluded that the biofuel derived from waste fish fat can be consider as a substitute for diesel fuel.

1. INTRODUCTION

The depletion of world petroleum reserves and the increased environmental concerns have stimulated

the search for alternative sources for petroleum-based fuel, including diesel fuels. Biofuel have been used as an alternative fuel for diesel engines [1-2]. It derived from biomass (generally vegetable oil) using various technologies. The methods can be divided into biochemical conversion and thermochemical conversion. The thermochemical conversion is performed using some processes such as: direct combustion, gasification, liquefaction, and pyrolysis (thermal cracking) [3]. Pyrolysis process appears to be a simple method for biomass conversion and it is the subject of many research studies; it is the technique of applying high heat to organic matter under the inert atmosphere [3]. The products of this decomposition are: a mixture of non-condensable gases or bio-gas (CO₂, CO, H₂ and CH₄), liquid (bio-oil or biofuel), and coke (solid carbon). The liquid pyrolysis product is composed generally of a complex mixture of hydrocarbons with different chemical groups and carboxylic acids. The large scale utilization of bio-oil directly as biofuel resources has been quite limited due to its high carboxylic acids content (acidity). The acidity is the main reason that restricts the direct use of bio-oil as a fuel for diesel engine [4]. The upgrading of bio-oil becomes an important issue. The recent upgrading technologies contain molecular distillation [4] catalytic hydrotreatment,

emulsification, and catalytic esterification [5] and catalytic cracking [6 - 7], which is the best way to upgrade the bio-oil to biofuel.

An increase in world population as well as industrialization, massive amounts of waste material is thrown away from the industries. It was suggested that the production of biofuel from this waste are the key areas for developing bioenergy for the future [8].

According to the FAO (Food and Agriculture Organization), the world fish production in 2009 was 144 million tons of fish, and around 50% of the total fish material processed becomes waste material. Most of the known technologies for the use of grease waste from fish industries are not economically attractive, and sanitary landfills and effluent treatment ponds are not recommended due to the unpleasant odour they produce. In this regard, catalytic cracking can be used as an alternative to convert this grease waste to biofuel.

Many studies have been reported that biofuel derived from waste can be used directly in diesel engine without any modification in the engine [9-10]. Most of the researchers quantified the effects of different biofuels with performance and emission characteristics of diesel engines. It has been reported that some of the biofuel have higher and others have slightly lower brake thermal efficiency and gives lesser CO, HC, PM and higher NO_x compared to base diesel fuel [11-12]. This change in performance and emission characteristics of different biofuels is due to the physico-chemical properties of the biofuels.

The aim of the work is to produce biofuel from catalytic cracking of fish waste industries and evaluate the performance, emission and combustion characteristics of this biofuel, in a diesel engine.

2. BIOFUEL PREPARATION

2.1. WASTE FISH OIL

The feedstock used in our work is an industry waste and it is obtained from, SIRH group specialized in vegetable, animal and marine oils located in north of France. To produce an edible omega 3 fish oils, the fish was treated by a series of processes, starting with cooking it thoroughly in boiling water, pressure it and centrifugation of the product to separate the crude oil and the water and impurities. The crude oil undergone a filtration by winterization to make it limpid by removing the waxes or fats

naturally contained. Indeed, the oil is slowly cooled down to obtain a homogeneous crystallization of waxes and fats. It is then filtered through cloths that retain these waxes or fats. The Fat, residue of this treatment, is brown in color and was used in this study without any special purification treatment. The main components of this organic matter are triglycerides. The typical fatty acid composition has been analyzed by gas chromatography analysis (GC/FID). The saturated acids C14:0, C16:0 and C18:0 are identified. The major fatty acids found are the unsaturated acids C18:1 and C18:2 responsible for 45.6 % and 20.6 % respectively of the total composition.

2.2. CATALYTIC CRACKING PROCEDURE

Catalytic cracking experiments were carried out at temperatures ranging from 320 to 480°C with a slow heating rate using a laboratory scale reactor. The schematic diagram of the process is shown in Fig. 1. The fat was introduced in the reactor and then heated by an external electric resistance. The catalyst is placed just above the fat on a bed with small holes. When the temperature inside the reactor achieved 320°C, the wax fish was cracking. The generated vapors were passed directly over the catalyst surface, before leaving through the top of the reactor and they enter in a water-cooled, counter flow, heat ex-change which water was kept at 15°C. As a result, two fractions were collected in the flask, which the first is the pyrolysis water, and the other represents the bio-oil fraction.

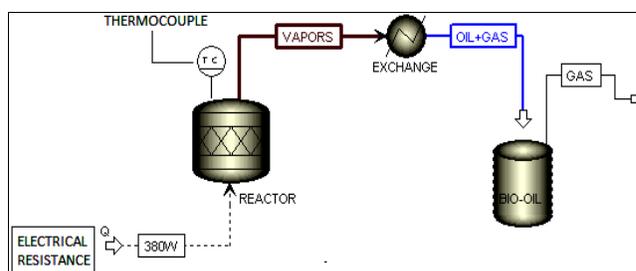


Figure 1. Schematic diagram of catalytic cracking process

The bio-oil fraction was collected in two steps (from 320 to 400°C and from 400 to 480°C). The first fraction with a high acid (28 0.8mg_{KOH}/g_{oil}) value and the second with a low acid fraction (0.8mg_{KOH}/g_{oil}) and this later which consists mainly of hydrocarbons, was analyzed and used as a biofuel for diesel engine. The properties and the major chemical compounds of biofuel and diesel are given

respectively in Table 1 and Table 2. The flash point was measured by NPM 440 model (PENSKY-MARTENS). The acid value was determined by titration with KOH/C₂H₅OH solution using phenolphthalein as an indicator. The density of the bio-oil was estimated with a pycnometer. The gross heating value was measured using an oxygen bomb calorimeter (model 6200, Parr Instruments Company). The dynamic viscosity was measured with a SV 10 Fibro viscometer. The compositions of the main organic elements (C, O, H, S, and N) were determined using an Elemental Analyzer (Flash EA 1112, CE Instruments). The chemical compounds of the biofuel, was identified using a CG/MS (Gas chromatography / mass spectrometry) analysis. For this purpose a Perkin Elmer Turbo Mass Gold Mass Spectrometer coupled with a gas chromatograph CLARUS 500 was used. The column was SBLTM-5ms Capillary type, 30 m in length and 0.25 mm in internal diameter.

Table 1: Properties of biofuel and diesel

Properties	Biofuel	Diesel
Density, at 20°C (Kg/m ³)	825	830
LHV (MJ/kg)	42.74	43.36
Dynamic viscosity (Ns/m ²), at 40°C	2.30	2.52
Acid value (mg KOH/g _{oil})	0.80	-
Flash point (°C)	57	56
Auto ignition temperature	230	220
Cetane Number	57	52
Composition		
H	11.59	13.30
C	72.33	86.00
N	0	0.20
O	5.34	0.20

Table 2: Chemical composition of biofuel and diesel

Biofuel	Diesel
Alkene	Iso-alcane
Alcane	Alcane
Cycloalcane	Aromatic
ketone	Cycloalcane

3. ENGINE TEST

3.1. EXPERIMENTAL SETUP

Fig. 2 shows the schematic diagram of the experimental set-up. The technical specifications of the engine are given in Table 3. The engine was mounted on a fixed table and coupled with an eddy

current dynamometer that converts mechanical energy generated by the engine power directly to the net work.

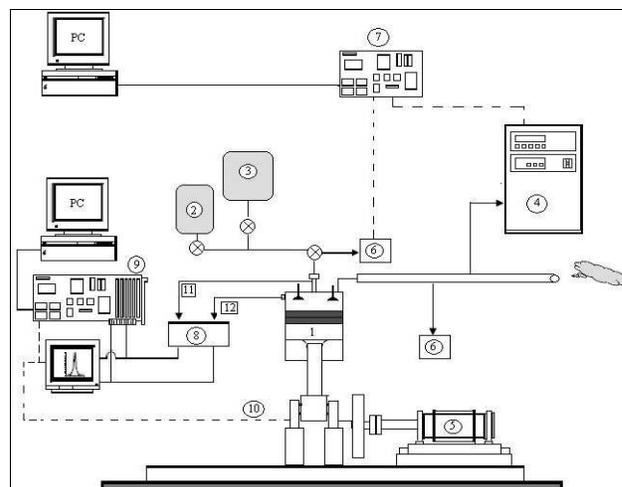


Figure 2. Schematic diagram of the engine setup

(1) Test Engine, (2) Biofuel Tank, (3) Diesel Fuel Tank, (4) Exhaust Gas Analyzer, (5) Eddy Current Dynamometer, (6) Particulate Matter Analyzer, (7) Low Frequency Data Acquisition System, (8) Charge Amplifier, (9) High Frequency Data Acquisition System, (10) Crank Angle Encoder/ Speed Sensor, (11) Injection Pressure Signal, (12) Cylinder Pressure Signal.

Table 3. Specifications of engine

Make	Lister Petter
Number of Cylinders	One
Type	Direct injection, air Cooled
BoreStroke (mm)	95,5 x 88,94 mm
Compression ratio	18:1
Rated power	4.5 kW
Rated speed	1500rpm
Start of injection	20°b TDC

3.2. DATA ACQUISITION SYSTEM

Two systems modes are used to manage the control and acquisition of measured signal:

- Slow acquisition (0.5 Hz): The data concerned by this type of acquisition are the air and fuel flow rates, torque, engine speed, pressure and temperature in the collectors.
- Quick acquisition (90 kHz): this type of acquisition is used for the intake and in-cylinder pressures. It is also used for the crank angle measures. The in-cylinder pressure is measured using a piezoelectric sensor AVL QH32D installed on the cylinder head. The crank angle determination is realized with an angular encoder (AVL 364C), installed on the crankshaft.

A differential pressure transmitter type LPX 5481 measured the flow of intake air. For temperature measurements, the test engine was equipped with a series of thermocouples type K. Ambient temperature was measured by an active transmitter for humidity and temperature, type HD 2012 TC/150. The fuel flow was measured using a Coriolis mass flowmeter. A bay of analysis (Crystal COSMA 500) placed on the line of engine exhaust gas was used to analyze the main pollutant gases. The emissions of hydrocarbons (HC) were measured by FID flame ionization using a heated hydrocarbon analyzer (model GRAPHITE 52M), the emissions of nitric oxide (NO) and nitrogen oxides (NO_x) were measured via a chemiluminescence nitrogen oxide analyzer TOPAZE 32M. Emissions of carbon monoxide (CO), carbon dioxide (CO₂) and oxygen (O₂) were measured by absorption of infrared radiation using a 2M MIR analyzer. Particulate emissions were measured using a dust analyzer in real time (TEOM model 1105), for measurement and continuous weighing of the mass concentration of particulate exhaust.

3.3. RESULTS AND DISCUSSION

The engine performance and emission characteristics of the biofuel, was analyzed and compared using a commercial diesel. The results were as follows.

3.3.1. Brake thermal efficiency

The influence of brake power on brake thermal efficiency for diesel and biofuel is presented in Fig. 3. It can be observed from the figure that as the brake power increases, the brake thermal efficiency increases to the maximum at 80% load and then decreases for the two type of fuel tested. It is observed too that the brake thermal efficiency of biofuel is always higher compared to diesel fuel at various load conditions. This is mainly due to good compound of hydrocarbons are present in the biofuel compared to diesel. The brake thermal efficiency is mainly due on how much amount of energy released during the initial phase of combustion.

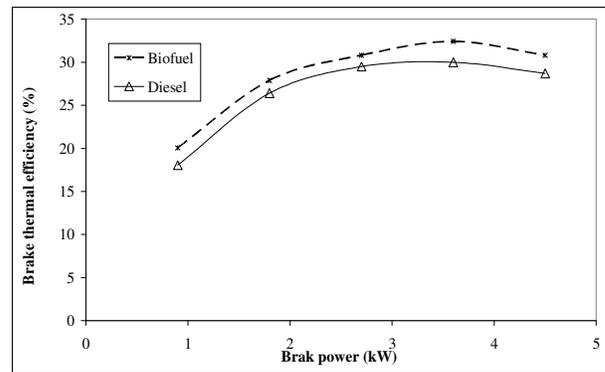


Figure 3. Brake thermal efficiency for different brake power

3.3.2. Emissions

Nitrogen Oxides

The formation of nitrogen oxides (NO_x), is affected by the peak flame temperature, the residence time of the high burning gas temperature, ignition delay, and the content of nitrogen and oxygen available in the reacting mixture [13]. The variation of NO_x emissions with brake power for the diesel and the biofuel is shown in Fig. 4. Oxides of nitrogen (NO_x) in the exhaust emission increase from 20% load to 80%. NO_x emissions for the neat biofuel operation are 857 ppm at full load, which is maximum, compared to the diesel. The increase in NO_x with biofuel is due to the higher intensity of premixed combustion. The higher premixed combustion is due to higher centane number of biofuel, which initiates the combustion early. Also the fuel is burned quickly due to its higher oxygen content which is 5.34 %.

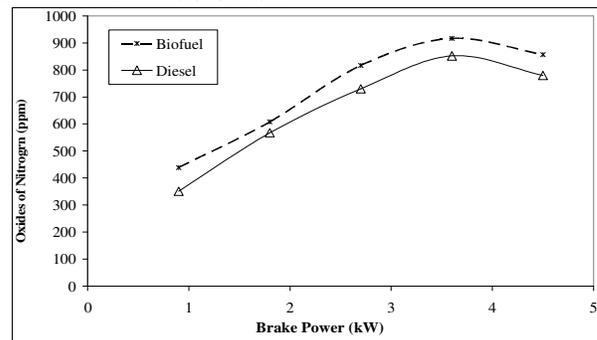


Figure 4. Variation of the NO_x emissions

Unburned Hydrocarbon

Fig. 5 shows the variation of unburned hydrocarbons (UHC) with brake power. The UHC in the exhaust gas is due to the fuel droplets unable to reach the ignition temperature leads to incomplete combustion. It is also due to insufficient

quantity of oxygen to oxidize the fuel present in the combustion chamber. It is seen that neat biofuel operation emits lower UHC compared to diesel. The UHC emission for biofuel and diesel at full load is 502 ppm and 575 ppm respectively. The ignition is started earlier and proceeding good combustion is achieved with biofuel and diesel due to good fuel quality and high cetane number. It is lowest with biofuel, due to sufficient quantity of oxygen present in the fuel itself (5.34 %).

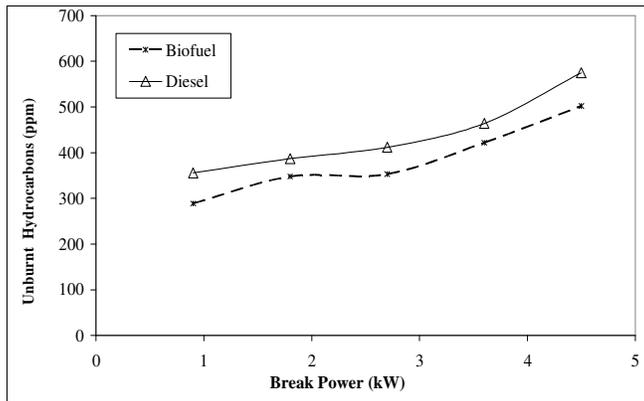


Figure 5. Unburned hydrocarbon variation

Carbon Monoxide Emission (CO)

Lin and Wang [14] indicated that a lower burning gas temperature would inhibit the conversion rate of CO to CO₂. The variation of carbon monoxide for biofuel and diesel fuel with brake power is shown in Fig. 6. The neat biofuel gives slightly lower CO emission compared to diesel. Indeed, at full load, the CO emission with diesel is 0.59 % and it is 0.39 % with biofuel. Due to the good spray characteristics as a result of low viscosity of biofuel, all the fuel droplets are mixed with air in the end part of the compression stroke, oxidation reaction of the fuel occurs which results complete combustion. Also, biofuel itself has higher oxygen content tends to increase the oxidation process.

load and during transient events when boost pressure is limited. High cylinder temperatures and the availability of oxygen increase the oxidization of the solid carbon particles and hydrocarbons to carbon monoxide and carbon dioxide. The PM emission for biofuel is very low compared to diesel fuel, are less than the PM emitted during engine operation with diesel. The PM emission is about 0.028 g/h and 0.03 g/h at full load with biofuel and diesel respectively. The presences of oxygen in the fuel and intake air improve the air fuel mixing rates which help to prepare more quantity of fuel for premixed combustion. The high cetane number of biofuel starts the combustion early. Also, the combustion duration is very less with biofuel. All the above mentioned reasons will lead to reduce the PM in the exhaust.

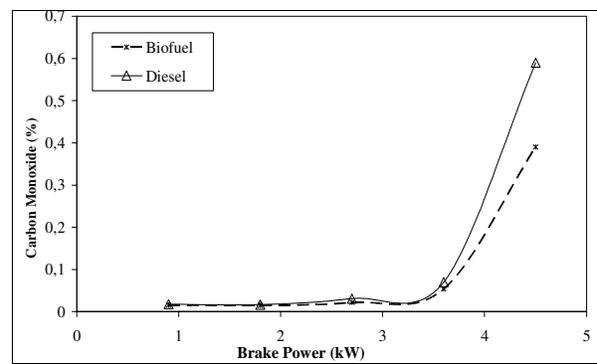


Figure 6. Variation of CO emissions

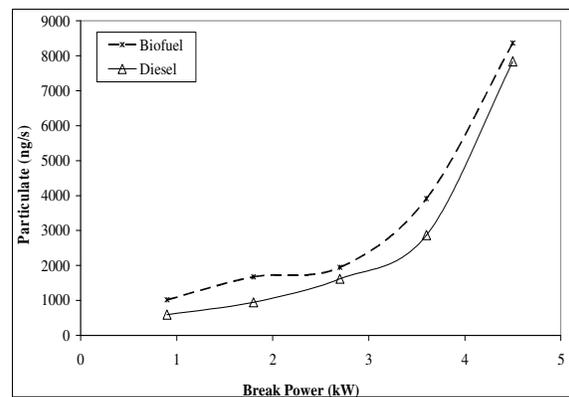


Figure 7. Variation of particulate matter

Particulate Matter

The results of particulate matter (PM) emissions of the biofuel and diesel are presented in Fig. 7. PM consists of a solid portion (carbon and ash), soluble organic fraction and sulfates (mostly heavy hydrocarbons) that have condensed on the carbon particles. The formation of the PM resulted from the incomplete burning of the hydrocarbon fuel and the partially reacted carbon content in the liquid fuel [15]. This occurs at low air-fuel ratios such as high

3.3.2. Combustion parameters

Cylinder Pressure

The variation of cylinder peak pressure with brake power at maximum load is shown in Fig. 8. The cylinder peak pressure with neat biofuel is higher compared to diesel fuel. The chemically bound oxygen in biofuel is the reason for the increased

cylinder pressure. This is mainly due to fast and enhanced combustion of biofuel inside the combustion chamber. The fuel inside the combustion chamber reacts with oxygen and releases energy, which is used to increase the cylinder pressure.

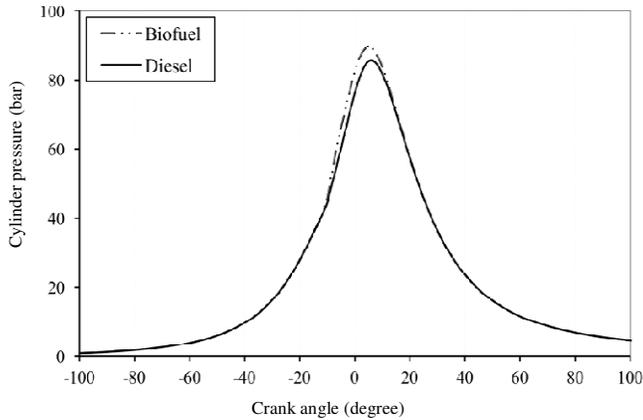


Figure 8. Variation of cylinder pressure crank angle at maximum load

Rate of Heat Release

The rate of heat release with crank angle for biofuel and diesel at maximum efficiency point (80 % load) is shown in Fig. 9. The premixed combustion with biofuel is very sharp and the diffusion combustion is low which reflects on the rate of combustion. This indicates that most of the fuel injected during the delay period is prepared for ignition and it is participated during premixed combustion process, which is reflected on the formation of NO_x. Higher oxygen concentration, high cetane number and more group of hydrocarbons present in the biofuel increase the rate of combustion. The premixed combustion is higher with biofuel followed by diesel, which shows that the combustion with biofuel is very good when compared to diesel.

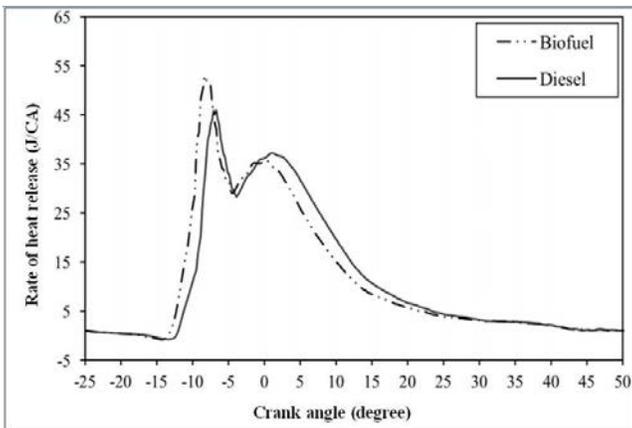


Figure 9. Variation of heat release rate at maximum load

4. ANALYSIS OF UNCERTAINTY

In measuring any quantity, the results will always differ from the true value even with careful experimentation. This error in measurement may be either random or systematic. By adding a correction value, the systematic error can be removed. Random error can only be estimated statistically and cannot be predicted in advance. Its presence can be detected only when the same quantity is measured again and again under the same conditions and with the same care. The uncertainty was estimated based on Gaussian distribution method. From the measured parameters, the uncertainty is computed based on Kline and McClintock method [16].

The estimated uncertainty values at different operating conditions are:

- Brake power: 0.4–1.7%
- Brake thermal efficiency: 0.6–1.9%.

5. CONCLUSION

The engine performance and emission characteristics of biofuel produced from catalytic cracking of waste grease fish were investigated and compared with diesel fuel in the study reported herein. The two fuels (diesel and biofuel) were tested in a single-cylinder direct-injection diesel engine at a constant speed of 1500 rpm. The experimental results of the study can be summarized as follows.

- Compared with the diesel fuel properties, biofuel have a higher kinematic viscosity, oxygen content and cetane number.
- Heat release rate with neat biofuel indicates higher premixed burning and lower diffusion burning rates as compared to diesel. The higher premixed combustion is due to higher oxygen content of biofuel which increase the air fuel mixing rate and high cetane number results the combustion starts early.
- NO_x levels are higher with biofuel compared with neat diesel due to the higher premixed heat release rate.
- Lower CO and UHC emission is observed with biofuel is due to high combustion rate.
- There is a large reduction in PM emission of engine with biofuel operation. The reduction in PM emission is due to the better combustion of

injected fuel in the hotter combustion chamber by the early combustion of biofuel.

ACKNOWLEDGMENTS

This research was supported by the GEPEA Laboratory and the Department of Energetic and Environmental Systems at the École des Mines de Nantes. These supports are gratefully acknowledged.

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