Mineral Oil Tests for the MiniBooNE Detector

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Abstract— **The MiniBooNE experiment will unambiguously confirm or refute the existence of the neutrino oscillation signal seen by the Liquid Scintillator Neutrino Detector (LSND) Experiment at Los Alamos National Laboratory. MiniBooNE will search for the appearance of electron neutrinos in a beam of muon neutrinos. The MiniBooNE detector is a 12 m diameter sphere filled with mineral oil and instrumented with photomultiplier tubes. The properties of the mineral oil chosen to fill this Čerenkov detector will be important to the experiment. The production of scintillation light in the oil, the attenuation of light across the detector, and the index of refraction of the oil are all important properties that must be known in order to properly model the detector. Fluorescence of the oil, optical dispersion, and oil density are also important quantities. The fluorescence spectra for several pure mineral oils as well as mineral oils doped with a small amount of various fluors were measured to determine the expected scintillation spectra from those oils. Index of refraction measurements were made in order to determine the Čerenkov angle and the dispersion for each oil. Attenuation tests were performed to find an oil with maximal attenuation length and with no abnormal absorption features. This work presents measurements of some of the oil properties which are made at Fermilab using several experimental setups. Based on the results of these tests (and a price within budget constraints), Marcol 7 oil was selected for the MiniBooNE experiment.**

Keywords— **Attenuation, Fluorescence, Index of Refraction, Mineral Oil**

I. Introduction

THE Mini Booster Neutrino Experiment (MiniBooNE) is currently under construction at the Fermi National Accelerator Laboratory (Fermilab). It is motivated by the evidence for neutrino oscillations ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$) seen by the Liquid Scintillator Neutrino Detector (LSND) experiment at Los Alamos National Laboratory [1]. MiniBooNE will be a definitive test of the LSND signal, making use of tried-and-true detector technology [2]. The MiniBooNE detector is a 12 m diameter sphere, filled with mineral oil, and lined with photomultiplier tubes (PMTs) [3]. The light signature of particle interactions seen in the MiniBooNE detector will consist of both scintillation and Čerenkov light. Because event reconstruction and particle identification will depend upon the ability to distinguish scintillation from Čerenkov light, the properties of the chosen mineral oil must be well understood. Oil properties of interest to the MiniBooNE experiment are attenuation length and amount of scintillation light and fluorescence produced, as well as index of refraction, dispersion, and density.

Manuscript received November 13, 2001. E. A. Hawker, R. A. Johnson, and J. L. Raaf are with the University of Cincinnati, Cincinnati, OH 45221. A. O. Bazarko is with Princeton University, Princeton, NJ 08544. G. T. Garvey and G. B. Mills are with Los Alamos National Laboratory, Los Alamos, NM 87545. A. Pla-Dalmau is with the Fermi National Accelerator Laboratory, Batavia, IL 60510. R. Tayloe is with Indiana University, Bloomington, IN 47405. For the full BooNE collaboration list, see http://www-boone.fnal.gov/collaboration.html

II. Technical Specifications of Mineral Oil

The MiniBooNE detector system will hold 950,330 liters of oil. A request for bids [4] was released on July 18, 2001, leading to submission of ten oil samples from six different vendors. The oil was required to be Light Mineral Oil (Industrial NF grade) with the following properties certified by the manufacturer

- Density: Specific gravity between 0.76 and 0.87 as measured via the American Society for Testing and Materials (ASTM) D 4052 or ASTM D 1298
- Viscosity: Less than 34.5 cSt at 40 °C as measured via ASTM D 445
- Color: Greater than or equal to 30 Saybolt Color units as measured via ASTM D 156

A more dense oil will provide more interactions in the detector. The oil must be recirculated, however, which imposes an upper limit on the viscosity of the oil (and an implicit maximum density). In addition, the oil must be clear to the light that will be detected by the PMTs, light in the wavelength range of 320 nm to 600 nm. The oil was required to have an attenuation length of greater than 20 m for 420 nm (blue) light. This will result in loss of less than 25 percent of the light generated in the center of the detector by a neutrino interaction [5].

Additional properties requested were high index of refraction, a small dispersion over the wavelength range 320 to 600 nm, low reactivity with materials in the detector, and a small amount of scintillation light. Index of refraction is usually a function of an oil's density, increasing with increased density.

Reactivity with materials in the detector was tested by soaking samples of the detector materials in the oil at an elevated temperature (66 °C) for a period of one week. Degradation of the soaked sample was checked by comparing transmission of light through an oil path length of 1 cm for both the test sample and a pristine sample. The transmission tests used a spectrophotometer and scanned over the wavelength range 190 to 600 nm. Comparison with previous tests of several oils showed that the top three oil candidates from the bidding process all behaved as expected, reacting minimally with detector materials.

Since scintillation light produced by charged particles travelling in the oil will be used as part of the particle identification scheme, it is important to control the amount of scintillation light these particles produce. The initial mineral oil was required to be as free of scintillating materials, such as alkenes and aromatics, as possible. A known concentration of an organic scintillator may be added to the oil later to aid in event reconstruction.

Each of the ten oils received in the bidding process was subjected to a battery of tests designed to identify which oil would be best for the MiniBooNE detector. The tests included two types of attenuation length measurements, an index of refraction and dispersion measurement, and a density measurement. Based on the results of these tests, a final decision was made to use Marcol 7 mineral oil in the detector. Fluorescence tests of the chosen oil were then performed and compared to earlier tests of similar oils. Two types of scintillation tests are in progress.

III. Attenuation Tests

Two complementary tests of the attenuation length of mineral oil were performed at Fermilab. The first test setup was known as the "Cincinnati tester" because it was designed and built by collaboration members from the University of Cincinnati. The second test setup, borrowed from the Palo Verde neutrino oscillation experiment by a collaboration member from the University of Alabama, was dubbed the "Alabama tester." The Cincinnati tester was able to determine the shape of the light transmission curve for one path length as a function of wavelength, giving relative attenuations between oils. The complementary test by the Alabama tester determined actual attenuation lengths for one wavelength of light as a function of path length in the oil. Both tests were important in choosing an oil.

A. Cincinnati Tester

This test setup consisted of a monochromator with deuterium light source, two EMI 9813 photomultiplier tubes, two lenses, and a light-tight box containing an oil sample tube [6]. A schematic diagram of the setup is shown in Fig. 1. The monochromator selected light of a particular wavelength and directed it to an optics box where the beam was split by a borosilicate glass window placed at a 45 degree angle to the incident light. This effective beam splitter reflected approximately 10 percent of the beam to a reference PMT and transmitted the rest through a sample of oil to the test PMT. The oil sample was contained in a 160 cm long cylindrical lucite tube of 5.4 cm diameter with borosilicate glass ends. The sample container was housed in a light-tight box.

The outputs of the PMTs were fed into a LeCroy Model 612 amplifier, followed by a LeCroy 821 discriminator, and finally to a LeCroy 2551 scaler. The data were read to a PC via CAMAC. Data consist of recorded scaler counts for the test and reference PMTs over wavelengths covering the range from 300 to 500 nm in steps of 1 nm.

Data are plotted as the ratio of light transmitted through the sample tube to light in the reference beam versus the wavelength. Fig. 2 shows the typical amount of variation between consecutive runs. For final selection of oil, the mean of each oil's runs was divided by the mean of all runs taken with no oil sample in the light-tight box.

Each of the ten oils submitted during the bidding process was tested, and results are shown in Fig. 3. Although this experimental setup was not able to determine *actual* attenuation length, it showed relative attenuation between oils. More importantly though, it showed the *shape* of the light transmission curve as a function of wavelength in the range 300 to 500 nm.

B. Alabama Tester

The Alabama attenuation tester made use of a 460 nm PicoQuant LED light source, a pinhole, a 1 mm diameter collimator, a 23 cm focal length lens, a 1 m long stainless steel sample tube with a 3.5 cm inner diameter, and an Amperex XP2264B PMT [7]. All of the above components were placed in a darkroom. A schematic of the setup is shown in Fig. 4. Oil level in the sample tube was changed by discharging oil through a teflon tube which went through the darkroom wall to the testing area. A 1.3 cm outer diameter Lexan sight tube affixed to the wall outside the darkroom was incorporated into the plumbing of the system to indicate the level of fluid in the sample tube. This allowed measurement of the oil path length without opening the darkroom door.

The LED was pulsed with 1 ns long pulses and an 80 MHz repetition rate during normal operation. Spectral output was centered at 460 nm with a width of approximately 30 nm [8]. Light from the LED passed through the oil, and was collected by the PMT. The PMT was run at 1100 V, producing a maximum anode current of 3μA as measured with a Keithley picoammeter. After a 20 minute settling time, the stability of the current measurement was better than one part per thousand (0.1%). The linearity of the system was good to one part per thousand in this operating range, although some non-linearity was observed at higher PMT currents.

The picoammeter was used to record anode current and the Lexan sight tube was used to record oil level for each data point taken; oil level was lowered from 90 to 0 cm in increments of approximately 10 cm. Attenuation length is the coefficient from an exponential fit to the data. At least two datasets were taken for each oil tested. A typical result from this test setup is shown in Fig. 5. Due to circuitry in the high voltage supply, the PMT did not necessarily settle to exactly the same operating voltage each time the power was turned on, leading to relative scaling between runs. Attenuation length results are independent of this scaling. Final results from the ten oils tested are shown in Table I.

IV. Index of Refraction, Dispersion, and Density Measurements

A simple spectrometer was used to measure the index of refraction of each mineral oil as a function of wavelength for six lines of the mercury spectrum [9]. The apparatus consisted of a mercury lamp, a spectrometer table which measured angles to 1 minute of arc, and an approximately equilateral triangular Plexiglas container with 3 mm wall thickness. The triangular container was filled with distilled water and the resulting angle of deflection was measured to obtain the interior angle of the prism. Index of refraction measurements for each oil were then obtained by filling the container with oil and rotating it on the spectrometer table until the minimum deflection was observed. Under these conditions, the incoming angle with respect to the normal to the front face is equal to the outgoing angle with respect to the normal of the back face. The relationship between total angular deflection (α_t), interior angle of the prism (α_i), and index of refraction (n) is given by $\sin[\frac{\alpha_t+\alpha_i}{2}] = n\sin[\frac{\alpha_i}{2}]$. Data collected for each of the ten oils were fit to a single resonance model for dense materials in order to determine their indices of refraction and dispersions. The data are described very well by this model, as shown with Marcol 7 results in Fig. 6.

Density measurements were made by weighing a 250 mL graduated flask both empty and filled. The flask was filled such that the bottom of the oil meniscus was level with the 250 mL line. Table II summarizes the results of the density and index of refraction tests. The range of specific gravities considered acceptable for the MiniBooNE detector was 0.76 to 0.87. Density and index of refraction were acceptable for all ten oils.

V. Fluorescence Tests

Fluorescence tests of various mineral oils were performed to ensure that there was no excessive fluorescence in the range of wavelengths important to the experiment. Oils tested included both pure samples, and samples doped with a small amount of various organic fluors. All measurements were made on a Hitachi F-4500 fluorescence spectrophotometer. The oil samples were tested using quartz cells with a 3 cm^3 volume. Front surface (FS) excitation wavelengths used were 220 nm, 254 nm, and 313 nm. Selection of the excitation wavelength was based on the absorption spectra of the oils and of possible fluorescent contaminants. No unusual features were seen in any of the oils tested. Results from Marcol 7 are shown in Fig. 7.

VI. Conclusions

Understanding and characterizing the properties of the mineral oil chosen to fill the MiniBooNE detector has been an important task. Marcol 7 was chosen on the basis of its long attentuation length for 460 nm light and its light transmission curve for wavelengths in the range 300 to 500 nm. Its density and index of refraction were within specified ranges, and it showed no unusual fluorescent properties. The oil tests presented here have been crucial in choosing the best oil for maximizing event reconstruction and particle identification in the MiniBooNE experiment.

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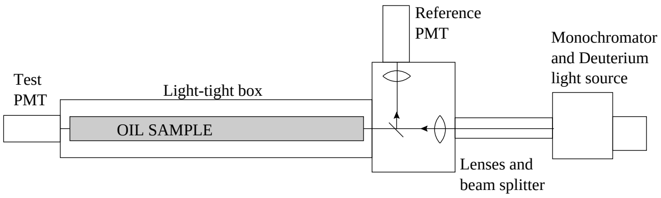

Fig. 1. Schematic diagram of the Cincinnati attenuation test setup

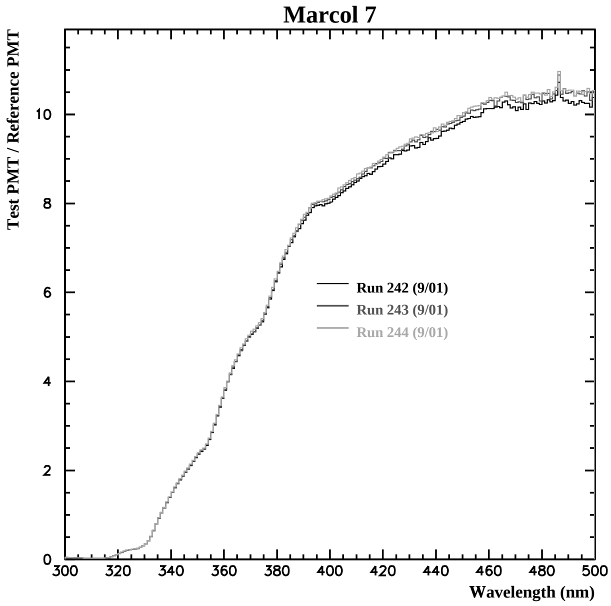

Fig. 2. Typical variation between runs taken with the Cincinnati attenuation tester

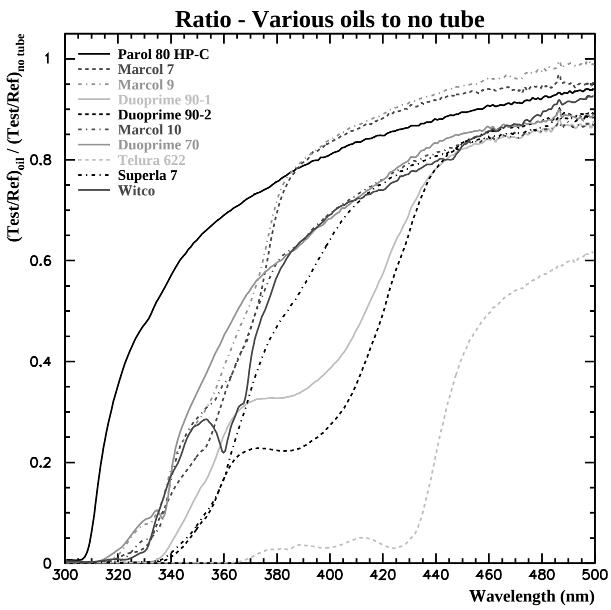

Fig. 3. Relative attenuation of ten oils tested with the Cincinnati attenuation tester

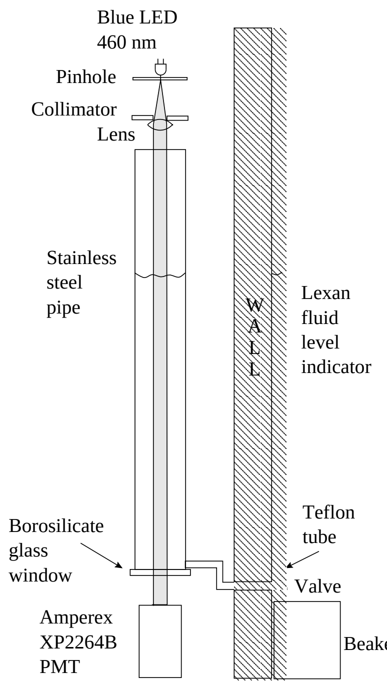

Fig. 4. Schematic diagram of the Alabama attenuation test setup

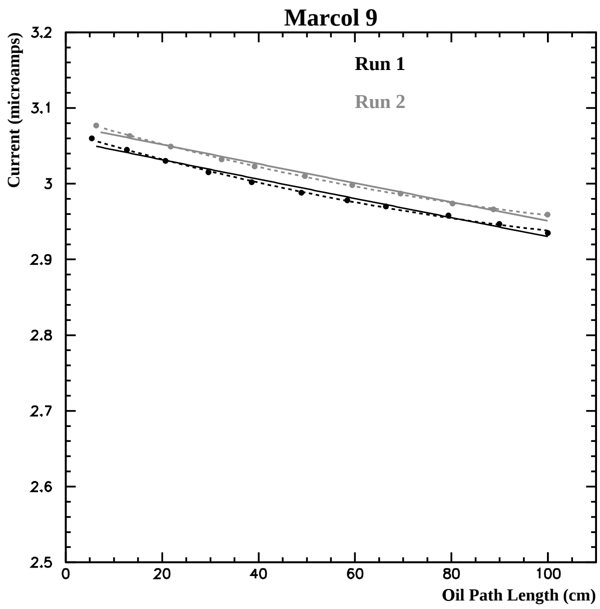

Fig. 5. Typical result from Alabama attenuation tester. Attenuation length is the coefficient determined from an exponential fit to the data.

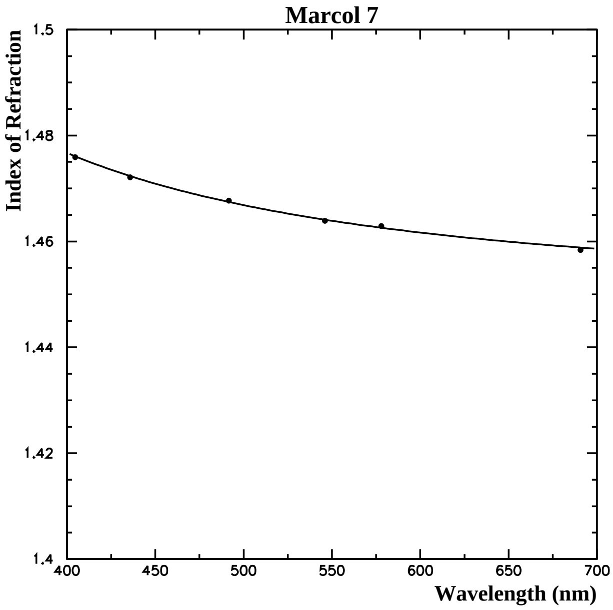

Fig. 6. Single resonance model for dense media fit to Marcol 7 data

TABLE I

Results from ten oils tested with the Alabama attenuation tester. Oils are listed from lowest to highest attenuation length. Duoprime 90-1 and 90-2 are the same oil from two different vendors.

Oil Type	Attenuation Length Fit (m)
Telura 622	2.21±0.01
Superla 7	9.84±0.09
Witco	10.79±0.11
Duoprime 90-2	12.78±0.14
Duoprime 70	13.96±0.16
Duoprime 90-1	14.33±0.19
Marcol 10	14.52±0.18
Parol 80 HP-C	15.41±0.21
Marcol 9	23.65±0.46
Marcol 7	26.45±0.59

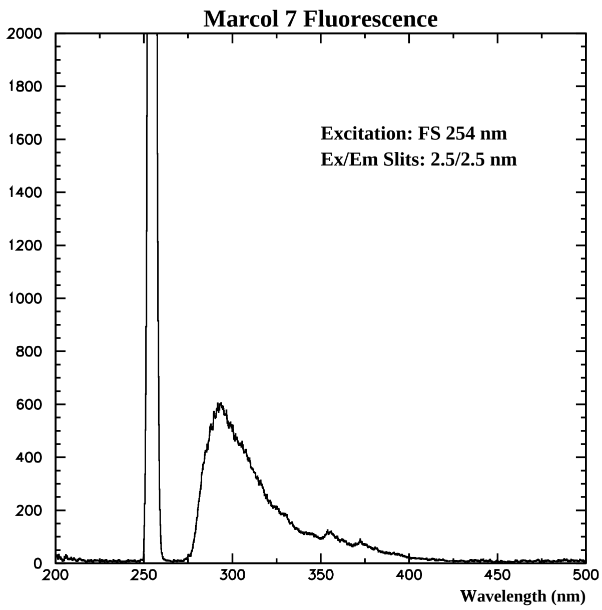

Fig. 7. Results of Marcol 7 fluorescence test. Fluorescence is seen in the wavelength range 275 to 400 nm. The peak at 254 nm is the reflection of incident light.

TABLE II

Results from density and index of refraction tests. Oils are listed from lowest to highest attenuation length according to the Alabama attenuation tester.

Oil Type	Specific Gravity	Index of Refraction	Dispersion ($\frac{n_D-1}{n_F-n_C}$)
Telura 622	0.8380	1.4638	54.8
Superla 7	0.8384	1.4634	56.0
Witco	0.8488	1.4667	55.6
Duoprime 90-2	0.8504	1.4682	55.4
Duoprime 70	0.8532	1.4691	58.1
Duoprime 90-1	0.8496	1.4680	56.4
Marcol 10	0.8540	1.4699	57.1
Parol 80 HP-C	0.8580	1.4716	59.0
Marcol 9	0.8528	1.4689	53.9
Marcol 7	0.8356	1.4620	57.2