Caltex offers the benefits from the power, resources and technology of three of the world's leading oil companies. In the oldest and most successful joint venture in the oil industry, Caltex was founded by Chevron and Texaco in 1936, and today this powerful team represents over $65 billion (US) in assets and an investment of over $396 million (US) each year in research and development. This competitive advantage means that customers receive the world's most technologically advanced products designed with a single objective in mind - success and profitability.

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In order to reuse polymeric materials, polymer identification and analysis of additives are required. Economic aspects demand fast response times, easy handling and integration in automated or at least semi-automated systems. As macroscopic physical methods, for example, those based on density measurements, are not sufficient to separate polymers, identification has to use methods monitoring structural or molecular properties of the polymer under investigation. A number of techniques have been developed to assist in identification of polymers. They are: Near Infrared Spectroscopy; Direct Pyrolysis Mass-Spectrometry; Electrostatic method; Triboelectric X-ray Spectroscopy; and Chemical Recycling. However, none of these methods has proved to be either completely satisfactory or acceptable in dealing with a wide proportion of the polymer waste. The most recently developed technique, Broadband Ultrasound Attenuation analysis, is a versatile technique that can be applied to a wide variety of material analysis applications.

For recycling purposes, it is necessary to identify which particular polymeric material has been used for a given product. Most consumers recognize the types of polymers by the numerical coding system which was introduced by the Society of the Plastics Industry in the late 1980s. There are six different types of polyolefin resins that are commonly used to package household products. They are:

- Polyethylene Terephthalate (PET)
- High-Density Polyethylene (HDPE)
- Polyvinylchloride (PVC)
- Low-Density Polyethylene (LDPE)
- Polypropylene (PP)
- Polystyrene (PS)

Polymer consumer goods not identified by code numbers are not usually recycled. There are thousands of different varieties of polymer resins or mixtures of resins. For example, PVC bottles are hard to tell apart from PET bottles, but one stray PVC bottle in a melt of 10,000 PET bottles can ruin the entire batch. Therefore, identifying the type of recycled polymers is very important. Equipment to sort polymers is being developed, but currently most recyclers are still sorting polymers manually.

The most recently developed technique, Broadband Ultrasound Attenuation (BUA) analysis, is a versatile technique that can be applied to a wide variety of material analysis applications. It is based on a simple principle of physics. The motion of any wave will be affected by the medium through which it travels. Thus, changes in one or more of any measurable parameters associated with the passage of a high frequency sound wave through a material, such as transit time and attenuation, can be correlated with the physical properties of polymers.

Ultrasonic technique

Ultrasound waves are mechanical vibration, involving movement within the medium in which they are travelling. The particles in the medium vibrate, thus transferring energy from particle to particle, along the wave path. Ultrasound pulses are normally generated and received by piezoelectric transducers that have been acoustically coupled to the test material. An ultrasound wave is launched by exciting the transducer using an electric signal. The sound wave travels through the test material, being received by another transducer at the far side. The received signal is then amplified and analysed.

The relevant measurement parameters will typically be sound velocity, attenuation and spectrum content in the received signal. The speed of sound is directly related to both elastic modules and density. Sound energy is absorbed or attenuated at different rates in different kinds of polymers, governed in a complex fashion by interactive effects of density, hardness, viscosity, and molecular structure. Attenuation normally increases with frequency in a given polymer. All kinds of polymeric materials tend to act in to some degree as a low pass filter, attenuating the higher frequency components of a broadband sound wave more than the lower frequency components. Thus, analysis of changes in the remaining frequency content of a selected broadband pulse that has passed through the test material can track the effect of attenuation.

The time-domain representation of the signal in an ultrasonic spectroscopy}
model is shown in Figure 1. The analysis of subsystems provides the transformation to the frequency domain. In research work the analysis was performed assuming that all subsystems are Linear Time-Invariant (LTI). To identify the impulse response of the unknown polymer \( H(t) \) from input and output signals \( v_1(t) \) and \( v_2(t) \), the impulse response of other subsystems must be known.

The pulser generates a series of sharp spike pulses \( v_1(t) \), which is applied to the first transducer. The piezoelectric crystal is therefore suddenly strained and deformed and then released. However, the displacement of the crystal does not exactly follow the applied pulse. This is due to the mechanical resonance of the crystal. The vibration from the transducer is coupled into the polymer test piece by the liquid couplant. The sound travels through the test piece and the second transducer in the opposite side vibrates, which in turn produces an electrical signal \( v_2(t) \). Figure 2 illustrates the waveforms in different stages of the process.

**Equipment**

A schematic of the hardware setup for the developed system is shown in Figure 3.
The IPR-100 pulser/receiver unit from Physical Acoustics Corporation is a PC based expansion card with a high energy spike pulser, and a wideband (100MHz) amplifier receiver. The pulser produces an impulse (spike) electrical signal. It is a negative pulse programmable from 50V to 400V. The rise time is less than 5 nanoseconds with a repetition rate from 0.5Hz to 10 000Hz. There are four programmable energy levels, and variable damping control from 340ohms to 2 000 ohms.

The ADC-200 data acquisition unit from Pico Technology Limited is a single channel analog to digital converter. The minimum sampling time is 10 nanoseconds (100MHz). This card features a signal generator from 2Hz to 25kHz, which is used as an external trigger for the pulser/receiver unit. The transducers are piezoelectric, having resonant frequencies of 5MHz from Panametrics.

Identification technique
The Fast Fourier Transform (FFT) algorithm calculates the amplitude spectrum, $v_2(t)$, of the received signal $v_1(t)$. The resulting amplitude spectrum for unknown polymers is subtracted from the amplitude spectrum for a reference material, $w(f)$, chosen to be degassed water. Water is used due to its minimal attenuation properties. A typical attenuation trace for polymers is shown in Figure 4.

Attenuation of a certain type of polymer is a function of thickness. To eliminate the effect of thickness, researchers presented a technique to use the velocity of sound to get a signature, independent of the thickness of test materials.

To identify a certain type of polymer, it is necessary to create a set of rules for attenuation information for different kinds of materials. Therefore, a knowledge-based containing the attenuation and velocity information for different polymer types must be established.

When an unknown polymer is presented, the attenuation and velocity information is compared with the information in the knowledge-base. A new technique has been developed using a fuzzy rule-based system to retrieve the right kind of polymer. A new rule is generated when a certain kind of polymer is presented. When there is an unknown polymer, the closest rule from the rule-base is returned indicating the kind of polymer presented.

Conclusions
An intelligent technique, using a fuzzy rule-based system and ultrasound attenuation analysis has been introduced to produce a signature, independent of component dimensions for a range of different polymers such as PET, PE, PS, etc. Early studies indicate that the method is a powerful tool for the identification of components of complex shape.

In this investigation separate transmitting and receiving transducers on opposite sides of the test component are used (through transmission mode). It is more practical for industry to use a single transducer coupled to one side of the test piece serving both as transmitter and receiver (pulse/echo mode).

References
There are 13 references to this article. Please contact Karen Smith on (011) 622-4770 for the full list.

POLYURETHANE ROTORS AND STATORS
Previously imported polyurethane rotors and stators are now available to the minerals processing and mining industries. These are part of a local manufacturing programme embarked on by Propro on behalf of Finnish mining company, Outokumpu.

The moulds have been designed to Outokumpu's stringent specifications. The stators and rotors are used in flotation processes to beneficiate the valuable ores. The rotors are turned from the surface, and the stator runners are machined by Amico Heavy Engineering, one of the few machine shops with the capability of machining components of this size to the extremely tight tolerances necessary for this operation.

The first size produced at the end of last year was a 750mm rotor/stator combination. There are five sizes available which are the 500mm, 650mm, 750mm, 825mm and 1050mm sizes, and within the next quarter, Propro will be able to produce all of these sizes into production. According to Alan Tuck of Allthane Technologies, the company has, under instruction from Outokumpu, investigated the abrasion properties of numerous types of polyurethane, some well known and some specialised systems. These findings showed that one of the new systems, with minor modifications to the formulations, gave the outstanding results required for these arduous and abrasive applications.

Tests under the auspices of Outokumpu are ongoing and when these new generation formulae are developed to offer improved results for other applications, they will become available.

Alan Tuck maintains that the spin-off from the research and development is that Outokumpu will remain in a position to offer leading technology in this field, including the development of other products. Future plans for the company are new product lines.

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