

OST TECHNICAL PROGRESS REPORT TEAM WORK PLAN--FY 1998 RESULTS

TITLE: INDIRECT CONVERSION TEAM

TEAM MEMBERS: MICHAEL F. ZAROCHAK, (Team Leader), ROBERT J. GORMLEY, RICHARD F. HICKEY, FRED W. HARKE, ARTHUR G. BLACKWELL, and EDWARD P. LADNER

DESCRIPTION:

The important factors in the operation of a Fischer-Tropsch (F-T) Slurry Bubble Column Reactor (SBCR) are hydrodynamic parameters and chemistry of the F-T reaction. The hydrodynamics include the rate of mass transfer between the gas and the liquid, gas bubble size, gas holdup, catalyst distribution and flow regimes. The chemistry of the F-T consists of the kinetics, catalyst performance, activation process and selectivities.

Investigations with hydrodynamic measurements on molten wax (a typical F-T slurry medium) as the liquid are limited. Significantly different hydrodynamic behaviors were reported under similar conditions using slurry waxes with like physical properties for these studies. It has become clear that additional experimental data is required on the hydrodynamic behaviors of SBCR systems that employ operating conditions and liquid phase media like those in F-T slurry reactors. This information is necessary for reliable design/scale up of F-T slurry reactors. The distribution of catalyst concentration down the column greatly affects the operation of the SBCR. Recently, an ultrasonic method has been demonstrated at FETC to be a potential non-intrusive technique for the measurement of the catalyst concentration profile in an operational SBCR.

It has been difficult to develop a slurry catalyst, mainly because of the extreme demands of working in the SBCR environment and at low H_2/CO ratios. As the H_2/CO ratio decreases, F-T activity decreases, catalyst deactivation and loss of selectivity worsen, and various physical problems such as catalyst particle disintegration intensify. Many of these crucial problems remain unsolved or only partially solved.

The activities investigated by the Team are centered on hydrodynamic studies, refinement of the ultrasonic diagnostic technique, and slurry catalyst development and evaluation.

RESEARCH OBJECTIVES:

Hydrodynamic Study: Hydrodynamic studies of the liquid medium, catalyst/solids, and nitrogen bubble flow will be conducted to establish flow characteristics in the newly constructed high-temperature, high-pressure 4-in. bubble column using a dual hot-wire anemometer probe and the ultrasonic technique. An attempt will be made to map the three main flow regimes (homogeneous, churn turbulent, and slug) by varying both the superficial gas velocity and solids loading. Parametric testing will be performed to evaluate the effect of various operating condition variables such as: type of liquid medium, gas distributor designs, pressure, temperature, gas velocity, solids loading and type of solid on the gas, liquid and solid behavior.

Development of Ultrasonic Technique: Plans are to apply this technique in the acrylic

(ambient) and hot-pressurized columns at ambient and industrially relevant conditions. Parametric evaluation will be conducted of various media, solids, temperatures, gas flow rate and solids concentrations.

Slurry Catalyst Development and Evaluation: The goal of this year's work will be to prepare and test precipitated iron catalysts, with a high loading of alumina binder, which will be spray dried into their final form of 30 to 100 micrometer spheres. Many conditions can be varied during spray drying and it is these catalysts, which differ in size, shape, and surface area, that will be compared during CSTR testing. Early during the course of the year, the direction of this activity was re-focused to address the catalyst/wax separation issue. The primary evaluation was centered on using powdered sintered stainless steel filters as the separation media.

LONG TERM GOALS/RELATIONSHIP TO FETC'S PRODUCT LINE:

A. MISSION/GOAL

The mission of the Coal Liquefaction Product Team is to help ensure the United States a secure energy supply at an affordable price by fostering the development and deployment of technologies to produce low-emission, coal-derived fuels and chemicals that can compete with those produced from oil.

The goal of the Team is to provide environmentally superior coal-based transportation fuels and chemical feedstocks that can compete with petroleum crude oil by the year 2015. The Team has defined the critical elements necessary for commercialization of the indirect liquefaction technology to be the development of highly active, stable catalysts, and the engineering of effective and economical slurry reactor systems.

B. DRIVING FORCE

Three major driving forces are motivating the United States Department of Energy Coal Fuels Program. These are national energy security, environmental issues and the potential for global warming, and economic and societal considerations.

C. NATIONAL ENERGY SECURITY

The U.S. currently uses 18 million barrels per day of crude oil with over 50 percent imported. The transportation sectors consumes 12 million barrels of that total. EIA projects that by 2015, oil consumption will increase to 22 MMBPD; domestic crude production is forecast to fall from the current 6.6 MMBPD to 5.2 MMBPD and over 60 percent will have to be imported. In addition, rapidly developing countries will also be significantly increasing their demand for oil. Using the United States Geological Survey estimate of conventional oil resource, world oil production potential will peak around the year 2015 and then irreversibly decline because of resource limitations. As the divergence between demand and supply continues to increase after the year 2015, it is essential to pursue a number of options to ensure that the U.S. will continue to have the necessary liquid fuels to be able to sustain economic growth in the 21st century. Since coal represents over 80% of the U.S. fossil fuel resources, coal-derived fuels can contribute significantly to meeting our future fuels requirements with the benefit of having minimal impact on the existing liquid hydrocarbon infrastructure.

D. ENVIRONMENTAL ISSUES

The two major environmental concerns are global climate change and regional air pollution related to the use of transportation fuels.

1. GLOBAL CLIMATE CHANGE:

In the U.S., carbon emissions from transportation account for 32 percent of the 1.6 billion tons per year of carbon released due to human activities. Higher efficiency transportation systems (including new generation diesel engines) and alternative fuels produced from natural gas and renewables can reduce this percentage. The common thinking is that coal-derived fuels will increase carbon dioxide due to the higher carbon content and lower Btu content per pound of coal relative to petroleum. However, strategies to both produce and deploy coal-derived fuels are addressing this issue:

Continued R&D is being performed to increase conversion efficiency and thus lower CO₂ production.

Coproduction of both power and fuels from coal has inherent efficiency advantages that result in significantly lower CO₂ than produced from stand-alone coal-fired power plants and petroleum refineries.

Coal liquefaction produces a concentrated stream of CO₂ that can be readily captured for either utilization or sequestration, the latter being an emerging R&D focus within the Department.

Coal-derived diesel fuel would have an exceptionally high cetane number, produce very low emissions and less CO₂ per mile driven than conventional gasoline-fueled vehicles.

2. REGIONAL POLLUTION:

Highway vehicles produce over 300,000 tons per annum of sulfur dioxide, 300,000 tons of particulate matter, 7.6 million tons of nitrogen oxides, 6.1 million tons of volatile organics, and 58.6 million tons of carbon monoxide. More stringent specifications on transportation fuels have resulted in the introduction of reformulated gasolines that have reduced air pollution, and this trend toward cleaner fuels is likely to continue. At the same time, deteriorating crude oil quality makes production of these ultra clean refined fuels more complex and costly. Deployment of clean transportation fuels from coal can significantly reduce these regional pollutants.

E. ECONOMIC AND SOCIETAL CONSIDERATIONS:

Rising oil imports are worsening the balance of trade. Last year, the U.S. paid over \$60 billion for imported oil and this amount will double in 1996 dollars by the year 2015. If the availability of a potentially large-scale, alternative supply of coal-derived liquid fuels were able to depress oil prices by even \$0.50 per barrel, the yearly cost savings would be over \$3.5 billion. If by the year 2015, we were producing 500,000 barrel per day of coal transportation fuels, this would result in the creation of 135,000 jobs per year for the period of 2015 to 2020.

SUMMARY ACCOMPLISHMENTS:

Hydrodynamics and Ultrasonics:

- **Completed ultrasonic measurement testing of solid/liquid slurry system for a customer**

FETC has completed an initial study to measure solid concentrations in a liquid hydrocarbon. The ability to measure the suspension of catalysts in a liquid hydrocarbon is required to adequately develop the design parameters for the design of slurry phase bubble column reactors for the F-T Process. The measurements at reaction temperatures and pressures are necessary to properly design the reactor. The slurry bubble column reactor is the most efficient reactor system for the F-T Process. Current development of the F-T Process using the slurry bubble column reactor is being done by Shell, Rentech, Energy International, and Air Products. A CRADA is also in place to do work on the development of the hydrodynamic reactor model using data collected at FETC. Measurement techniques and hydrodynamic reactor modeling is being done at Sandia National Laboratory, Washington University of St. Louis, Ohio State University, and Air Products to develop the best measurement techniques and hydrodynamic model for future reactor scale up design.

- **Completed verification testing of ultrasonic testing with hot wire anemometer.**

FETC has completed verification of ultrasonic testing with hot wire anemometer testing. The hot wire anemometer measurement has been determined to be valid for gas/liquid reactor systems using comparisons with physical measurements. This technique has been compared to the ultrasonic tests to determine if the ultrasonic tests were valid. The advantage of the ultrasonic measurement system is the determination of the solids concentration in the reactor over the length of the reactor which is not possible with the hot wire anemometer. This hot wire anemometer measurement technique has been used for many years and considerable data is available for comparison. This work has led to the ultrasonic technique which allows testing without invasive procedures to modify the flow characteristics and under more severe conditions that would be possible with just the hot wire anemometer.

- **Installed new data acquisition system to improve data collection and began testing of new system.**

A new data acquisition system has been installed for the hydrodynamic modeling project bubble columns. The new system allows much more data to be collected on a real time basis in an efficient manner. The data from the new data acquisition system is compatible with the existing data base.

Slurry-Phase Fischer-Tropsch Catalysis:

Four catalyst formulations were tested during the year to improve filtering rate. Two formulations of iron catalyst that were produced at FETC, filtered more easily than other preparations from the F-T product wax. All the tests conducted in FY-98 were with a "powdered sintered stainless" filter of 0.5 micron nominal pore size. The filtering rate of 20 to 25 g wax/hr per 20 cm² filter surface area, still falls short of the estimated 100 to 110 g wax/hr needed in a

high wax producing slurry reactor. The results in filtering rate by altering catalyst formulation are expected to lead to improvements that can be used by DOE and other F-T researchers in producing more robust catalysts.

A simpler test was developed to determine the filtering rate of un-activated catalyst from previously produced F-T wax in an inert gas flow. From these tests it was learned that the alumina powder, which is used as a starting support for iron catalysts is not as robust in the stirred reactor as the new formulations of iron catalyst mentioned above. The wax filtered at 50 g wax/hr per 20 cm² filter surface area, by the end of 10 days, from a 10 weight percent mixture of one of the improved iron catalysts with previously made product wax. This information is valuable for catalyst researchers in determining which directions to explore in catalyst formulation. This is also valuable for FETC and other F-T researchers to decide if the 1000 rpm used in a stirred reactor is too harsh in comparison with the conditions experienced in an unstirred slurry bubble column.

RESULTS:

Hydrodynamics and Ultrasonics:

- **Completed ultrasonic measurement testing of solid/liquid slurry system for a customer**

An ultrasonic study was conducted to measure slurry concentrations in an autoclave reactor. Preliminary measurements were conducted on slurries consisting of a liquid hydrocarbon, solid particles (up to 50 wt.%), and nitrogen bubbles (up to 4 liter/min) at temperatures up to 260°C, and at stirring speeds up to 900 rpm. The transit time and amplitude ratio of the sound wave shows a maximum (transit time) and a minimum (amplitude ratio) relationship with the concentration of the solid under the experimental conditions studied. The effects of particle size on the ultrasonic spectrum are significant and may be used to correlate the sizes of solid particles at a given solid concentrations. The results suggests possibilities for measuring the concentration of solids and particle size distribution during operation of a three-phase slurry reactor under reaction temperature.

Figure 1 illustrates an ideal ultrasonic wave propagating in liquid in the setup described in this study. Since the received signal is undistorted, the distinct zero crossing time is chosen as the transit time. Here, t_0 is the arbitrary first distinct zero crossing time in liquid. The travel time between the transmitter and receiver in the liquid is defined as t_0 . t_1 is the arbitrary second distinct zero crossing time. t_2 , t_3 , t_4 , and t_5 are also defined as the distinct zero crossing times. The speed of sound in the liquid can be determined by utilizing the following equation and the transit time.

$$t_0 = 2 L_1 / V_1 + L_2 / V_2 \quad (1)$$

Here, t_0 is the transit time defined as the first distinct zero crossing time, L_1 is the distance of the adapter, V_1 is the speed of sound travel in stainless steel at 20°C of 5660 m/sec, L_2 is the distance between two adapters, and V_2 is the speed of sound travel in the liquid at 20°C or conditions of interest.

The transit time was unaffected by the stirring speeds under the selected experimental conditions as shown in Figure 2. Figure 3 illustrates the effect of the stirring speed on the amplitude of the transmitted ultrasonic signal in a hydrocarbon liquid at 21 °C. Figure 3 also suggests that the amplitude is independent of the stirring speeds if the stirring speed is 600 rpm or less. However, the amplitude decreases when the stirring speed is above 600 rpm. The amplitude of the signal obtained under 900 rpm is approximately 30 to 40 % of that obtained under 600 rpm. The decrease in amplitude with increasing stirring speed is probably due to the presence of vortexes under higher stirring speed. The creating of vortexes will introduce gas bubbles in the ultrasonic path that will reduce the amplitude of the transmitted ultrasonic signal. To overcome this complication, the initial liquid level should be sufficiently higher than the stirrer. Most of the data collected in this study was collected at both 600 and 800/900 rpm.

Figure 4 shows the effect of the nitrogen flow on the transit time, t_0 . It was approximately 88.76 μ s at all nitrogen flows in the liquid hydrocarbon at 600 rpm and 20 °C. Apparently the transit time was unaffected by the nitrogen flow under the current experimental conditions, because what was measured was the signal not transmitted through the nitrogen. Thus, the measured transit time should not be affected by the nitrogen flow.

Figure 5 illustrates the change in the amplitude of the transmitted ultrasonic signal in the reactor as a function of nitrogen flow in a hydrocarbon liquid at 20 °C and 600 rpm. Figure 5 suggests that the amplitude is approximately an inverse exponential function of the nitrogen flow. The impedances of the two media will determine the transmission of the wave from one medium to another and the amount of reflection of sound at the boundary between the two media. Equation (2) can be used to express transmission in terms of the acoustic impedance Z for media 1 and 2 respectively:

$$\alpha_t = (4 Z_2 Z_1) / (Z_1 + Z_2) \quad (2)$$

where α_t is the sound power transmission coefficient. If the impedances of two media are widely separated, e.g., nitrogen and liquid hydrocarbon, then most of the energy is reflected back in the first medium with some transmission into the second medium (nitrogen). It can be assumed that the ultrasonic pulse cannot penetrate through much of the nitrogen/liquid interface at the current experimental frequency due to the acoustic impedance mismatch of this combination. Therefore, the amount of attenuation of the ultrasound beam by nitrogen bubbles is proportional to the gas volume fraction but also can be dependent on bubble size presents in the path of the ultrasound, especially when the ultrasound wave is near the resonance frequency. The attenuation is greatest at frequencies near resonant [2]. The frequency (ω_r) at which resonance occurs depends on the physical properties of the component phases and the bubble size.

$$\omega_r^2 = 3 \rho_b c_b^2 / (\rho r^2) \quad (3)$$

where ρ is the density of the liquid, ρ_b and c_b are the density and ultrasonic velocity of the nitrogen bubble, respectively, and r is the radius of the nitrogen bubble. For the case of this

study, the frequency utilized is not near the bubble resonance frequency; therefore, the data collected in this study is not affected by the resonance effect. The results showed that the transmitted ultrasonic signal could be approximated by the exponential relationship:

$$A/A_0 = \exp [-f(d_b) \epsilon] \quad (4)$$

where ϵ is the void fraction and $f(d_b)$ is a function dependent on the Sauter mean diameter. This correlation shows that the A/A_0 ratio has an exponential relationship with both the void fraction and with a function dependent on the bubble diameter. The effect of air bubble diameter on A/A_0 ratio was found to be significant, with A/A_0 decreasing with increasing bubble size. The transmitted ultrasonic signal can also be expressed by an exponential relationship:

$$A/A_0 = \exp [\Gamma x/8 S(kd_b/2)] = \exp [\Gamma x/8 S(k3\epsilon/\Gamma)] \quad (5)$$

where Γ is the volumetric interfacial area, x is the travel distance in the path, S is the scattering coefficient, k is the wave number of the ultrasonic waves which surrounds the bubble, ϵ is the gas holdup and d_b is the Sauter mean bubble diameter. Eq. (5) shows that the A/A_0 ratio has an exponential relationship with the interfacial area and the scattering cross section, which is a function of the bubble radius, gas holdup and the wave number of the ultrasonic wave surrounding the bubble. Our observations of A in the nitrogen/liquid system are in qualitative agreement. The decreasing A/A_0 as the nitrogen flow increased in Figure 5 may be attributed to a combination of the void fraction, bubble size, the number of bubbles, and the scattering cross section. The results indicate that only the amplitude and not the transit time of the ultrasonic signal are affected by the nitrogen flow rate in the reactor under the current experimental conditions. The testing work was done in the Slurry-Bubble Column Facility.

- **Completed verification testing of ultrasonic testing with hot wire anemometer.**

The comparison of gas holdup using ultrasonic testing compared to the hot wire anemometer has shown that the gas changes the amplitude of the ultrasonic pulse when it intradicts gas in the liquid system. The change in amplitude can be correlated to the gas in the liquid in the same manner for ultrasonic pulses as for a hot wire anemometer.

- **Installed new data acquisition system to improve data collection and began testing of new system.**

A new Gould data acquisition system was installed to improve data collection. The new data collection system will handle 16 isolated analog inputs, mix or match channel to channel, RTD, thermocouple, strain gage, frequency converter, current, and millivolt/volt signal conditioning. The system will capture multiple data sets or a single data set, continuously acquire data to a disk at 50,000 samples per sec, trigger on any input channel or digital input, and external sample rate.

Slurry-Phase Fischer-Tropsch Catalysis:

Reactive and non-reactive tests were performed in the OST 1-Liter Continuous Stir Test Reactor

System Facility. The details of the one liter stirred tank reactor are presented in Ref (1). In the F-T reaction, hydrogen and carbon monoxide gases come into the reactor. Exiting the reactor are: unreacted gases, carbon dioxide, hydrocarbon vapors, liquids (gasoline and diesel oil) and molten waxes. In the 4 reactive synthesis tests conducted this fiscal year, with 4 different catalyst formulations, typically 40% to 60% by weight of the product was liquid (gasoline and diesel) along with molten wax. At a typical reaction temperature, 265°C, most of the products vaporize out of the reactor except the heavier (in molecular weight) portions of the molten wax. These heavy waxes must be removed from the reactor at least every 24 hours, otherwise, the height of the molten liquid level of wax with catalyst would rise to the top of the reactor. When removing the waxes to keep the liquid height down, it is important to keep the catalyst within the reactor. The catalyst powder, of submicron to 100 micron size, is kept in the reactor by steel filters on the ends of each wax withdrawal line. As long as catalyst is not removed, the reaction is sustained. In these tests, the conversion was maintained, with no more than 1 % loss in conversion per day, for at least two weeks. The sintered filters are cylinders of porous steel, lying horizontally inside the reactor, approximately two-thirds of the way up the height. Molten wax passes through the 0.5 micron pores of the filters and flows to a collection trap. Catalyst gradually plugs some of the pores of the filters and the filtering rate slows down over several days. Dr. Burt Davis at Kentucky CAER has conducted experiments which indicate that the wax is also contributing to the plugging of the filter [2]. Carbon particles and iron carbide particles are also forming, then breaking off of the catalyst surface. These particles can be seen using TEM as shown by Professor Abhaya Datye et al at the University of New Mexico [3]. These carbon and carbides may also contribute to the plugging of the filter.

For the present, the assumption has been made that the catalyst plays the major role in plugging the filters. The heavy wax products and the carbon are assumed to play a minor role.

Several new formulations of catalyst were prepared and tested in reactive, syngas conversion tests to improve the filtering rate of product wax from catalyst powder. Previous preparations had exhibited decreasing filtering rates after several days of synthesis. By co-precipitating aluminum nitrate, along with iron nitrate and copper nitrate, using ammonium hydroxide, it was hoped to increase the strength of the iron oxide particles. These “co-precipitated” catalysts were oven dried, then air-calcined. Results from the “co-precipitated” catalysts indicate that catalyst break-through had not occurred; however, the filtering rate was slowing down with time.

The filtering rate could be improved by altering the particle size distribution and method of manufacture of the catalyst. In figure 6 are plotted the filtering rates of wax from several catalyst/wax slurries near the end of 11 day tests, versus the total grams of reactor wax filtered. The two formulations of catalyst which filtered fastest, at 20 and 24 g wax/hr per 20 cm² filter surface area, were the “co-precipitated with 9% alumina” and the “co-precipitated with 19% alumina”. The “co-precipitated 9% alumina” did not have its particles less than 40 microns sieved out, while the “co-precipitated 19% alumina” catalyst did. This removal of some of the smaller particles may have helped the “co-precipitated 19% alumina” filter better than the other catalysts. Some uncertainty arises from the results because the cumulative grams of reactor wax filtered was

not the same for each of the catalyst tested. The two co-precipitated catalysts as well as several others had only had a total of 200 grams of wax filtered by 11 days. The spray dried catalyst which filtered the slowest, had 1,400 grams of wax filtered by 11 days. The spray dried catalyst was prepared with 11% silica as the strengthening agent. To compare filtering rates accurately, one would prefer to hold constant the cumulative grams of wax filtered.

The difficulty in holding constant the cumulative grams of wax filtered lies in controlling the selectivity of each of these catalysts towards wax production. This was adjusted to some extent, by changing the amounts of potassium in each catalyst. Potassium is reported to promote hydrocarbon chain growth [4]. However, the amount of alumina present also affects the effectiveness of the potassium in promoting chain growth [5]. Therefore, many variations of the catalyst, with different alumina and potassium contents, should be prepared and evaluated.

To decrease the testing time needed to compare catalysts with equal wax production, a new type of test procedure was devised. In this method, fresh catalyst was used with inert gas so that no conversion of the iron oxide to iron carbides and magnetite occurred. Previously produced F-T wax was used initially in the reactor. The wax was filtered, then replenished by addition through a heated loading vessel. Wax was filtered frequently (approximately every two hours) from the catalyst/wax slurry instead of once every 24 hours, as was the case for the reactive tests. Within 5 to 11 days, the total grams of wax filtered during these non-reactive tests was close to 800 grams. Preliminary results are promising, with the “co-precipitated 19% alumina” catalyst (fresh) showing a filtering rate of approximately 50 g wax/hr per 20 cm² of filter area. The filtering rate test of the spray dried catalyst (fresh) is currently in progress. The melt impregnated catalyst (fresh) has not yet been tested. The pure alumina, from which the melt impregnated catalyst (60% alumina) was made, filtered at about 13 g wax/hr per 20 cm² of filter area. The pure alumina was sieved to remove the particles less than 40 microns. It was thought that alumina was, in general, more robust than iron oxide, Fe₂O₃, and that the alumina would filter faster than any of the iron oxide catalysts. This proved not to be the case. Using this information, the search for a more robust catalyst can be directed toward the co-precipitated type of preparation rather than the melt impregnated type.

References:

1. R.J. Gormley, M.F. Zarochak, P.W. Deffenbaugh and K.R.P.M. Rao, “Effect of Initial Wax Medium on the Fischer-Tropsch Slurry Reactor”, *Applied Catalysis A: General*, 161 (1997) 263.
2. R.J. O’Brien, A. Raje, R.L. Spicer, L.Xu, S.Bao, R.A. Keogh, S.H. Lambert, S-J. Liaw, S. Chokkaram, D.J. Houpt and B.H. Davis, “Technology Development for Iron Fischer-Tropsch Catalysts”, *Proceedings of the First Joint Power & Fuel Systems Contractors Conference*, Pittsburgh, PA, July 9-11, 1996,
3. D.S. Kalakkad, M.D. Shroff, S. Köhler, N. Jackson and A.K. Datye, “Attrition of precipitated iron Fischer-Tropsch Catalysts”, *Applied Catalysis A: General*, 133 (1995) 335.
4. H. Pichler, “Twenty-five Years of Synthesis of Gasoline by Catalytic Conversion of Carbon Monoxide and Hydrogen”, *Advances in Catalysis*, 4 (1952) 271.
5. B.H. Davis, “Technology Development for Iron Fischer-Tropsch Catalysts”, *Quarterly*

Technical Progress Report No. 8, Nov. 1996, DOE Contract No. DE-AC2291PC94055.

ACKNOWLEDGMENTS:

Technical contributors to the Hydrodynamics and Ultrasonics projects include Yee Soong, Richard Anderson, Isaac Gamwo, Richard Tischer, and Richard Schehl. Additional input has been received from Sandia National Laboratory, Washington University of St. Louis, Ohio State University and Air Products and Chemical Corp.

Contributing to the success of the Slurry-Phase Fischer-Tropsch Catalysis project were many individuals and organizations. Reactor system operations and chemical analysis were provided by Parsons Infrastructure and Technology. Technical contributors include Terri Newby, Joseph Tamilya, Donald Martello, Paul Rohar, Joseph Hackett and Mark McDonald. Collaborations in support of this activity were held with the University of New Mexico, Texas A&M University, the University of Kentucky's Center for Applied Energy Research and United Catalysts Inc.

Funding for all the activities was provided through the Coal Liquefaction Product Team at FETC, led by John Winslow, as well as by the Office of Science and Technology (OST) group, led by Dr. Larry Headley. Reactor facilities are under the direction of Dr. Richard Lett, director of the OST Fuels and Chemicals Division. For additional information, contact Robert Gormley, chemist; Richard Hickey, chemical engineer; or Michael Zarochak, chemical engineer, all of the Fuels and Chemicals Division.

Ultrasonic Signal in Liquid Hydrocarbon

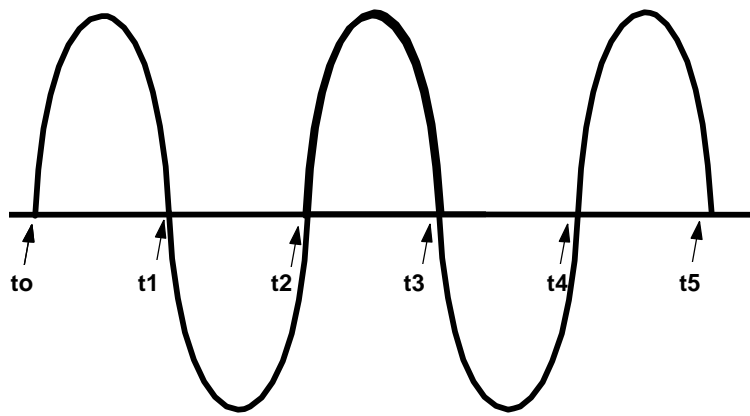


Figure 1

Effects of Stirring Speed on Ultrasonic Signal at 21 °C, 14.7 psig

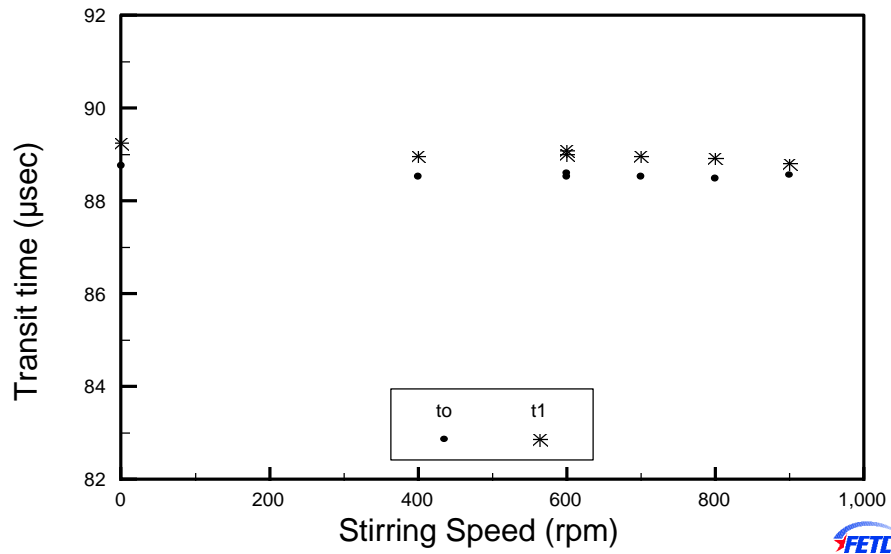


Figure 2

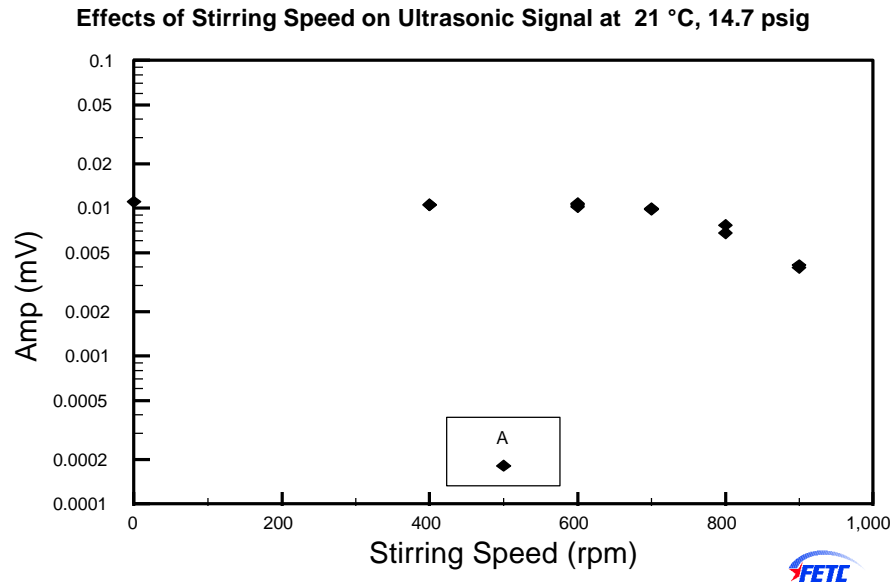


Figure 3

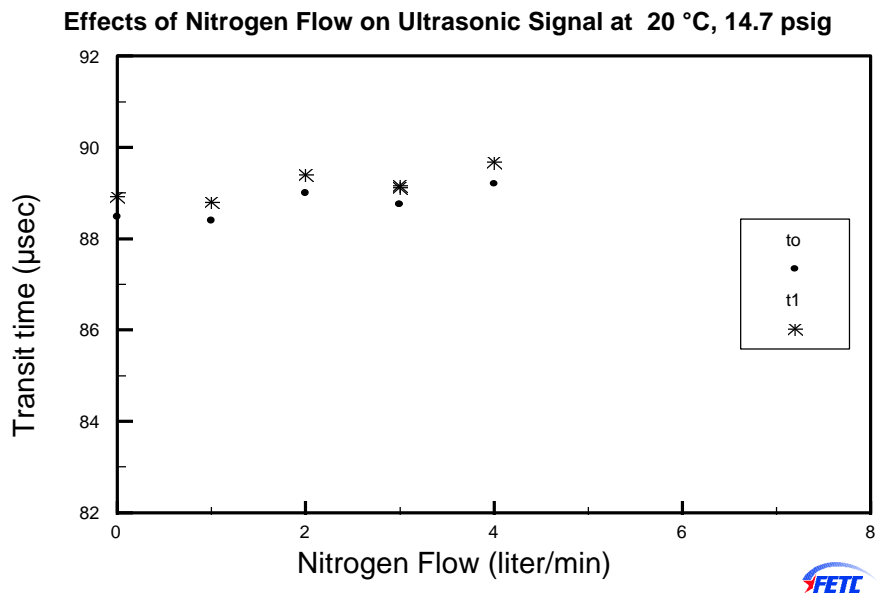


Figure 4

Effects of Nitrogen flow on Ultrasonic Signal at 20 °C, 14.7 psig

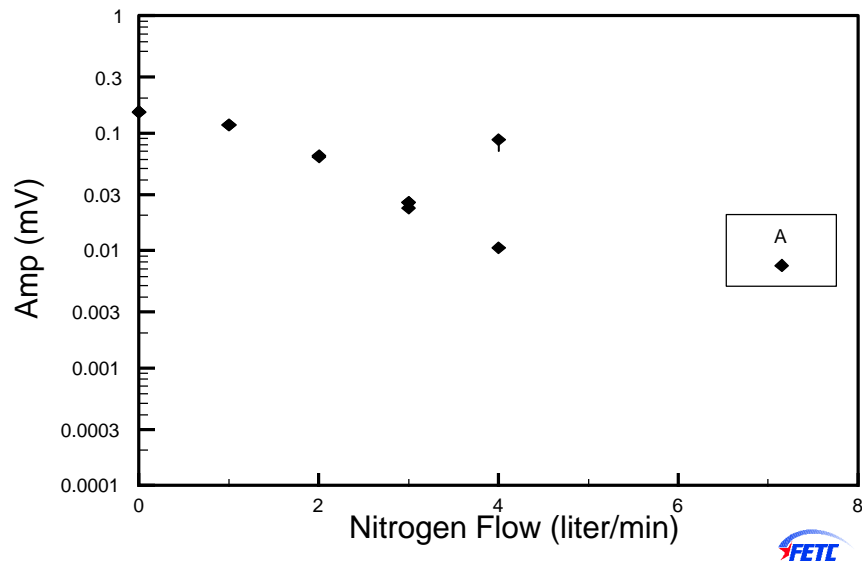


Figure 5

Correlation between cumulative grams of wax filtered @ 11 days vs. speed of filtering wax from used catalyst

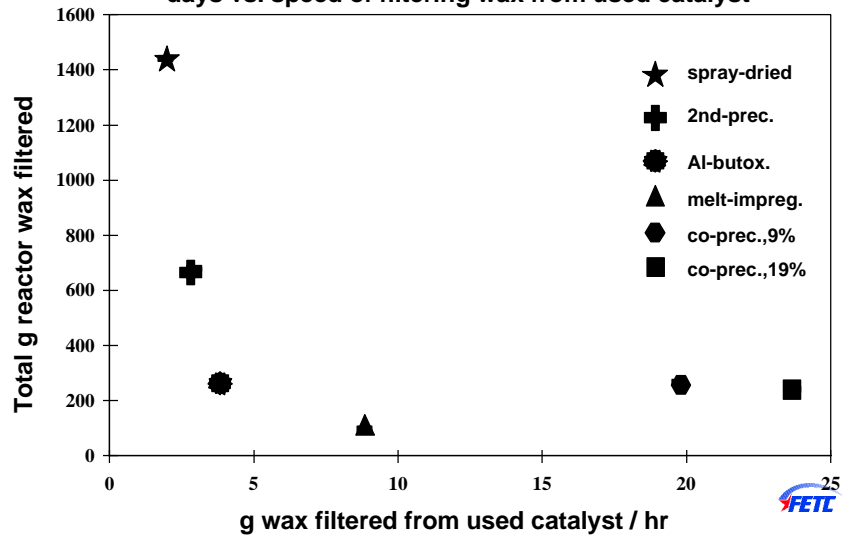


Figure 6