

ADVANCED DEVELOPMENT - FUELST

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ABSTRACT

This paper describes the solar thermal fuels and chemicals program at JPL. The primary objective is to develop and apply high technology to displace fossil fuel (oil) use in the production/processing of valuable fuels and chemicals: it is the aim to demonstrate the technical and economic feasibility to an extent that enables the industry to participate and commercialize the product. A representative process, namely Furfural production with a bottoming of acetone, butanol and ethanol (ABE), is described. Experimental data from all solar production of furfural is discussed. Estimates are given to show the attractiveness of this process especially considering its flexibility to be adaptable to dishes, troughs or central receivers. Peat, lignite and low rank coal processing, heavy oil stripping and innovative technologies for process diagnostics and control are mentioned as examples of current projects under intensive development.

FURFURAL AND ABE BOTTOMING

As part of the SUNFUELS program sponsored by the U.S. Department of Energy, JPL has demonstrated the technical feasibility of producing liquid fuels. The general philosophy has been one of maximizing the utility of the solar application; instead of producing one fuel or one chemical in the process, several fuels and chemicals are produced in the overall process. A brief description of the background, proven test results and the future plan is outlined here.

BACKGROUND

Solar energy processed fuels and chemicals are expected to gain prominence in the mid (1985-1990) and the long (2000) range future of the United States if not the world. Solar energy processed fuels and chemicals are of course available in nature as plants and derivatives. In an attempt to identify transportable and storable liquid fuels and to displace fossil fuels (Example: imported oil) in their processing, FURFURAL is identified as an important candidate: conventional furfural production from biomass is seen to offer possibilities of simultaneously producing valuable alcohols and acetone at little extra energy cost.

At the present time 10^8 kilograms ($\approx 2 \times 10^8$ lb.) of furfural are produced in the U.S.A. annually. Practically all of this is produced by Quaker Oats. The feedstock is biomass that have hemicelluloses in them (corncobs, peanut shells, soft woods...). The theoretical maximum yield is in the range of 10% - 20% by weight of the feedstock. Furfural can be used as a liquid fuel (≈ 5550 kcal/kg or 10,000 Btu/lb. of energy release upon complete combustion in air), although there exist more valuable uses such as feedstock for furan resins. (The Germans used furfural as a Diesel fuel

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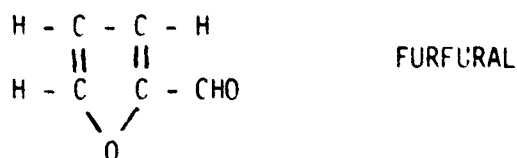
during the second World War.) The 1980 price is nearly 1\$/kg or (\$0.45 per pound). It takes nearly 9992 kcal/lit (150,000 Btu per gallon) of furfural produced. The feedstock is acid hydrolyzed and steam "cooked" to release the furfural which is subsequently extracted from the water by dichloromethane. Hence, the use of solar produced steam in the process would displace at least 0.75×10^{12} kcal/yr (3×10^{12} Btu/yr) worth of fossil fuels (mostly oil and natural gas in the U.S.A.). This number of 0.003 Quad*/yr is just the proverbial tip of the iceberg.

The acid hydrolysis process (with typically 5% dilute H_2SO_4) prepares the cellulosic portion of the biofeedstock also ideal for fermentation to acetone, butanol and ethanol (called ABE, for short). Since the cellulosic portion consists of at least 50% of the typical feedstock, while the hemicellulose is typically 15%, the product breakdown may be expected to be:

0.15 kg Furfural
 0.45 kg of alcohols
 0.2 kg of solid spent mass

per kilogram of feedstock. Even if the difference (0.2 kg) is not recovered, 0.45 kg. of alcohols yield an equivalent of $(\frac{0.45}{0.75}) \times 2 \times 10^8 \times 10^4 = 0.006$ Quad/yr in energy. The solid spent mass can be used as cattlefeed after deacidification, or just burned to augment the steam production. This ABE "bottomer" also enables the production of furfural on a continuous basis (as opposed to solar dependence always). Thus 0.009, or nearly 0.01 Quad/yr. is the maximum fossil energy displacement to be expected.

With the dwindling petroleum supplies the furfural derived chemicals can possibly provide the plastics feedstock and pseudo aromatics.



The chemical structure of furfural suggests that furfural could be a potential additive to engine fuels for knock suppression. After the elimination of tetraethyllead from the fuels, aromatics are being used to raise the octane numbers to acceptable values. With the natural petroleum derived aromatics becoming increasingly expensive, furfural could rise to meet the demands. Even at a conservative rate of 1% addition to gasoline (synthetic or natural) the demand for furfural (in furfural derived pseudo aromatics) potentially is seen to be $10^9 - 10^{10}$ kg/yr.

* 1 Quad = 0.25×10^{15} kcal.

THE PROCESS REQUIREMENTS

Furfural production requires steam in the pressure range of 3.4-6.8 atm (50-100 psi) and temperature range of 422-533°K (300°-500°F). Typically 30 kg of steam are used per kg of furfural produced or 30 kg for nearly 7 kg of feedstock. These rather mild conditions show that the process steam can be obtained by troughs, dishes, or central receivers. This flexibility is particularly valuable considering that the solar collector technology (viz, troughs vs CR's vs. dishes) has not been finalized yet.

THE RUNS AT JPL

Four successful runs were conducted at JPL (Pasadena) with 9.08 kg (20 lb) feedstock of coracobs each and electrically produced steam. The pressure and temperatures used were 3.4 atm (50 psig) and 422°K (300°F). The runs lasted 1-1 1/2 hrs. Electrical preheat was used to raise the temperature before the steam cooking.

After these initial tests the reactor was tied to the steam generator at the Test Bed Concentrator - 1 at the Edwards Test Station at JPL. This *all solar* production of furfural was highly successful even at the very first attempt. It should be mentioned that the design capacity of 80 kw (thermal) of TBC-1 was far in excess of the small reactor requirements. One half of the reflector area was blocked off during this run.

FUTURE PLANS

The reactor exists to handle nearly 10 kg feedstock per batch. The runs last typically 1-2 hrs. A reactor properly matched to the TBC is in design and will be matched with the TBC-1 later in FY81. Runs will be conducted at the trough facility of Albuquerque, New Mexico. Process optimizations will be performed. The furfural will be tried as a fuel in the diesel engine and as a fuel additive in a gasoline engine. Fermentation of the spent mass is in progress to prove the ABE process.

TRANSITORY SUMMARY ON THE FURFURAL PROCESSES

It is interesting to note that after the JPL effort got underway three important developments have taken place with regard to furfural in the world.

1. Cetus Corporation and Standard Oil of California have entered an agreement to produce large quantities of furfural. The production is expected to start in the next three years (ref. Chem. Eng. 28 July 1980).
2. Mitsubishi Company in Japan is setting up a huge plant in Japan for making a derivative of furfural (tetrahydrofuran).

3. Quaker Oaks and IITRI have jointly submitted to JPL a proposal for a feasibility demonstration of solarization of furfural production on a commercial basis.

The future looks bright for furfural.

LOW RANK COAL, PEAT AND LIGNITE PROCESSING

It is estimated that the deposits in the USA correspond to 1443 quads of peat, 3082 quads of lignite and 3534 quads of subbituminous (low rank) coals (Ref. 1). The high moisture content (frequently in excess of 50% by weight) of these fuels poses special problems. Transportation in wet form is not economical and drying them invariably introduces severe problems of spontaneous reactivity. Utilizing the energy content of the peat/lignite/low rank coal to process them would diminish their heating value. A process is sought to obviate all of these problems simultaneously.

An innovative process developed at JPL is shown in Fig. 1 here. The as-mined material is mixed with a heat transfer fluid in which it is wet ground. The heat is supplied in a heat exchanger that circulates solar steam. A flash separator gets out the high BTU vapors which can be directly fed into a gas pipeline or used as a feedstock for making liquid fuels. Preliminary economics calculations show that 3.25×10^2 Kcal/1000 kg can be recovered in transportable, storable high BTU fuel with this solar assist process. Laboratory experiments are underway to prove the process.

HEAVY OIL STRIPPING

The solar derived steam is ideally suited for the stripping of heavy oil that occurs in a distributed manner in many parts of the U.S.A. (example: California). A reactor is being built to utilize the TBC-1 steam at 811°K (1000°F) for this purpose. It is expected that the same reactor can be used for processing synthetic crudes also.

INNOVATIVE PROCESS DIAGNOSTIC TOOLS

Acoustic imaging is being developed to diagnose in real-time local details in processes. The acoustic field can be mapped locally with non-interfering Ellipsoidal Acoustic Mirror Microphones (EAMM). Details of spatial and temporal resolutions are being worked out.

REFERENCE

1. Skrotzky and Vopat, Power Station Engineering and Economy, McGraw Hill, pp. 16-17 (1960).

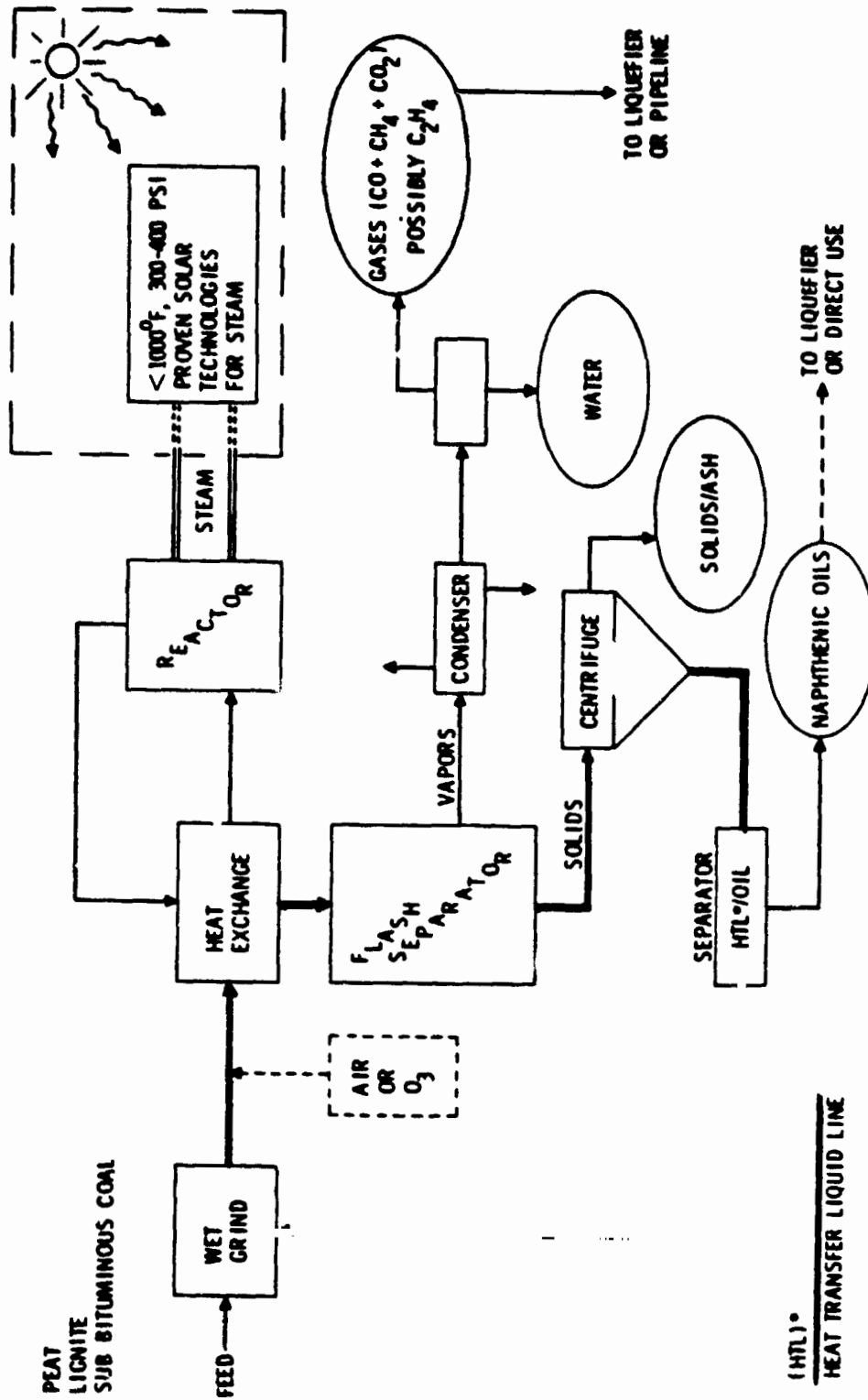


Fig.1 The proposed modified wet oxidation process to convert peat/lignite and low rank coals to high BTU fuels.