# ULTRAPYROLYSIS OF WOOD BIOMASS FOR PRODUCTION OF ECOLOGICALLY CLEAN BOILER FUELS AND MOTOR FUELS

A. A. SPITSYN, Y. N. PILSHCHIKOV, V. N. PIYALKIN,
H. D. METTEE[*] and V. I. SHIRSHIKOV[**]

*St. Petersburg State Forestry Engineering Academy, Russia*
*[*]Youngstown State University, Ohio, USA*
*[**]Vyborg Coal Company, Russia*

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A formed-layer based pyrolytic reactor, incorporating the counter flow of heated gas and the particles of raw waste wood, has been designed and constructed on a mobile platform. The basis of the design is a computer model (POLY.TERM 2), which calculates the gas and particle temperatures as they proceed from the opposing ends of the reactor, as a function of particle size and flow rates. The time of residence in the reactor, necessary to optimize the yields of biopetroleum (BPT) and fine charcoal (FCC), may be evaluated accordingly. Typical data are presented, based on preliminary results with wood chip fuel, a comparison between the theoretical and the experimental values being performed. The results of some early thermoliquefaction experiments are also included.

***Keywords***: ultrapyrolysis, diesel fuel, biomass, counter flow reactor

## INTRODUCTION

Wood biomass is one of the most promising types of renewable raw materials in Russia, its use increasing annually by about 700 million $m^3$. The processing of biomass as wastes generated during forest harvesting (dead culls, improvement cuttings, sawing and woodworking) yields up to 60% of the raw materials produced. Pyrogenetic methods of wood biomass treatment (charring, resinous wood distillation, tar distillation, pyrolysis, energy-chemical gasification, inverse gasification liquefaction) have gone through ups and downs, as depending on consumer demand on the world market. In view of the trends developing on a world scale, including the replacement of traditional mineral fuels by renewable materials, wood resins and charcoal can and must be used as boiler fuels and motor fuels for local and external consumers, particularly for enterprises of the forest industry. The obvious advantages of such a line of development include the relatively simple implementation, process interdependency without involvement of any external fuel, the "omnivorous" character of the raw materials processed, the high energy density of the commercial product (Table 1), transportability and possibility to accumulate and store the given liquid fuel type for utilization during peak periods.

The main products of pyrogenetic wood biomass processing are biopetroleum (BPT) and fine charcoal (FCC). BPT is a most promising type of fuel obtained from renewable raw materials, due to its ease of transportation, storability and utilization as a boiler fuel.

Its combustion products are actually free of $SO_2$ and the quantity of $NO_2$ generated is a

half lower than that produced by mineral fuels.

A number of new processes for wood biomass processing have been developed in Russia and abroad.

They include retorts of the shaft type, drum type, screw type, vacuum pyrolysis, high-speed pyrolysis, pyrolysis in the entrainment flow, ablation type, fluidized bed type, etc. In our opinion, a promising process for BPT and FCC production is the formed-layer process, based on the principle of counter flow of a dense raw material layer and of a gas heat carrier (Fig. 1). This method gave positive results on thermal and material balances and minimization of apparatus requirements. Russian Federation Patents № 2338770 and 75657, and a favorable decision on awarding RF Patent № 2008119065 provide interesting details.

A computer program POLY.TERM 2, developed to implement this process (Table 2), offers solutions to the following problems: (i) calculation of the temperature field distribution inside the raw material particles at a definite time and in a pre-determined cross-section along the retort length; (ii) determination of the reasonably necessary length and height of the retort for conduction of pyrolysis within a minimum time; (iii) gas heat carrier velocity and temperature, raw material particle size and moisture content, and wood species. The results on the calculation of the raw material particles and heat carrier temperature fields are plotted in Figure 2. A comparison of the calculated and experimental data, in relation to the equivalent diameter of the raw material particles processed, is presented in Figure 3.

Table 1
Comparative densities of different fuel types

| Fuel type | Ordinary density ($kg/m^3$) | Primitive fuel value (MJ/kg) | Energy density ($GJ/m^3$) |
|---|---|---|---|
| Sawdust | 130 | 18.0 | 2.3 |
| Wood chips | 400 | 18.0 | 7.2 |
| Pellets | 660 | 18.0 | 11.7 |
| Wood charcoal | 300 | 30.0 | 9.0 |
| Charcoal briquettes | 660 | 30.0 | 19.6 |
| Pyro fuel | 1200 | 23.0 | 27.6 |
| Methanol | 796 | 22.2 | 17.7 |
| Ethanol | 800 | 28.0 | 22.4 |
| Biobutanol | 803 | 36.5 | 29.2 |
| Diesel fuel | 800 | 46.0 | 36.0 |
| Boiler oil | 960 | 40.0 | 38.4 |
| Ensyn bio-oil (Canada) | 1180 | 23.1 | 27.3 |
| Dynamotive bio-gas (Canada) | 1200 | 23.0 | 27.6 |
| Residual pyrolytic tar | 1086 | 29.5 | 32.0 |
| Soluble pyrolytic tar | 1080 | 28.6 | 33.7 |
| Combined pyrolytic tar | 1160 | 29.0 | 33.3 |

Table 2
Input data for the POLY.TERM 2 program

| Description | Theoretical symbol | Program variable in POLY.TERM 2 | Numerical values Options 1 (2) |
|---|---|---|---|
| Raw material consumption (kg/h) | $G_M$ | $G_m$ | 322 |
| Heat carrier flow rate (kg/h) | $G_r$ | $G_r$ | 346.5 |
| Raw material feed speed (m/h) | u | U | 11.05 (14.7) |
| Heat carrier feed velocity (m/s) | w | W | 40 (10) |
| Heat carrier temperature (inlet) (°C) | T’ | TGA | 900 |
| Heat carrier temperature (outlet) (°C) | T” | TGB | 165 |

| | | | |
|---|---|---|---|
| Raw material temperature (inlet) (°C) | $t'_M$ | TC | 15 |
| Thermal diffusivity of raw material ($m^2/h$) | a | AP | 0.00027 |
| Heat conductivity of raw material (W/m.°C) | λ | RL | 0.269 |
| Layer porosity | f | Z | 0.2 (0.4) |
| Pyrolysis temperature (°C) | $T_{pyr}$ | TK | 550 |
| Equivalent diameter of raw material particles ($10^{-3}$ m) | $d_{eq}$ | D | 5.1/7.4/5.3/1.3 |
| Design pyrolysis time (s) for average/large/medium/small particle sizes | $t_{pyr}$ | - | 226/373/236/45.6 (420/650/445/102.5) |

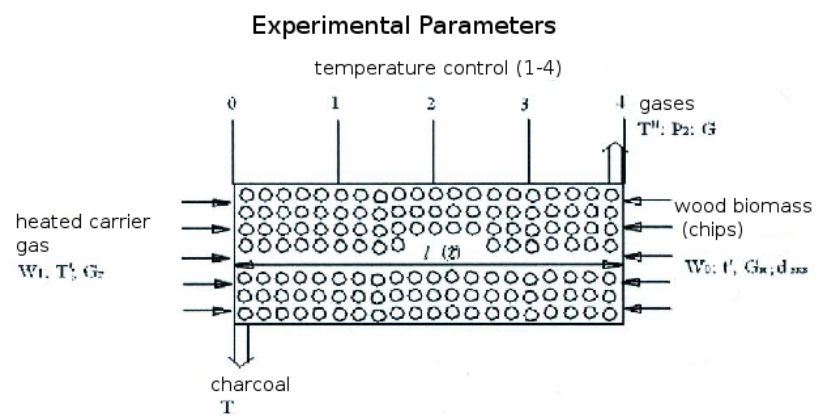


Figure 1: Model of formed-layer computation: hot gas flows in on the left, wood particles – from the right (temperature profiles are given for startup conditions)

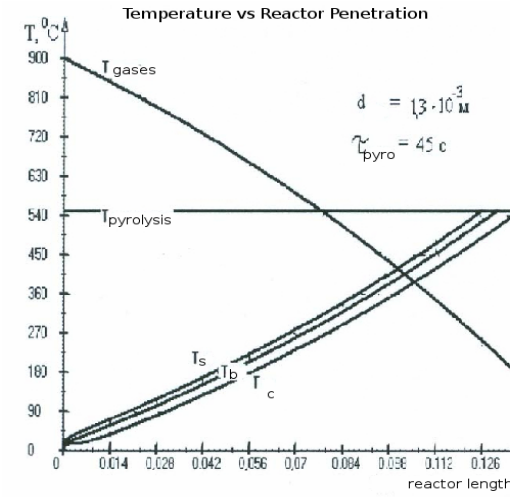


Figure 2: Plots of the temperature distribution in raw materials and heat carrier gas during pyrolysis in the formed layer (particle temperatures refer to surface, center and body)

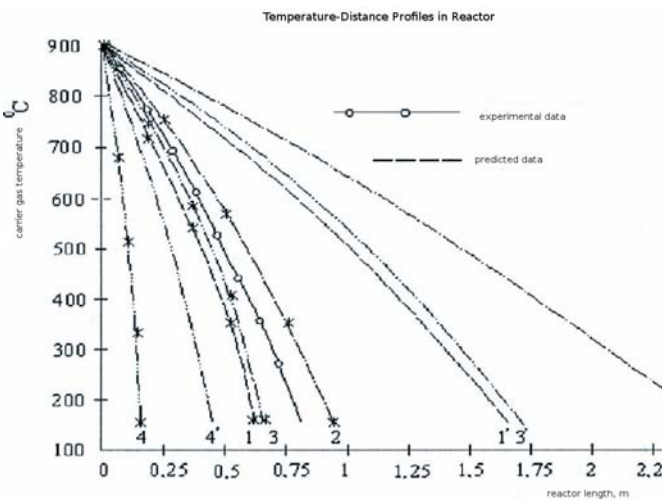


Figure 3: Temperatures of heat carrier gas along the reactor length in relation to $d_{eq}$ (equivalent diameter) of the raw material particles processed (see Table 3, lines 11 and 13 for data sets)

On the basis of the data obtained with this program, a mobile ultra-pyrolysis plant for wood biomass processing has been developed in Russia. The plant has a capacity of 7200 t/year in terms of raw material (chip fuel); the specific capacity of the retort, in

terms of absolutely dry raw material, is of 6 t/h·m$^3$, the output being of 1440 t/year for BPT and of 1080 t/year for FCC.

Considering environmental protection, the production of motor fuel (or of an additive to it) from biopetroleum appears as reasonable. This would allow a dramatic decrease in the emission toxicity of petrol and diesel powered engines, which is of essential importance for megalopolises. The characteristics of such products are given in Table 3. It should be also emphasized that pyrogenic wood resins can be used not only as fuel, but also as a high quality chemical raw feed stock for the production of surfactants, preservatives, flavoring agents and antioxidants, for smoking fluids and in road and building constructions.

It is also suggested that FCC may be used as a feed stock for the production of active carbons for cleaning both water and air, as for example in RF Patent № 2344997 and 2351390.

The fine charcoal may be processed into two products – oxidized activated charcoal (OACC) and wood-charcoal briquettes. The Forest Technical Academy and Youngstown State University have developed a new production method[1] for oxidizing and activating charcoal. A sample of FCC was ground into particles and sorted into groups of the same size. Particles of a particular size range were subsequently reacted with hydrogen peroxide, at elevated temperature and pressure values. The advantages of this method over others include a much lower production temperature and a shorter contact time. OACC has been used for the absorption of lead and benzene from water solutions.[1] The FTA has developed another method for FCC utilization – namely, wood charcoal briquette production. The main advantages of this product include longer burning time and higher mechanical strength than those of conventional briquettes. The wood charcoal briquettes also have the advantage of no sulfur and lower nitrogen oxide emissions.

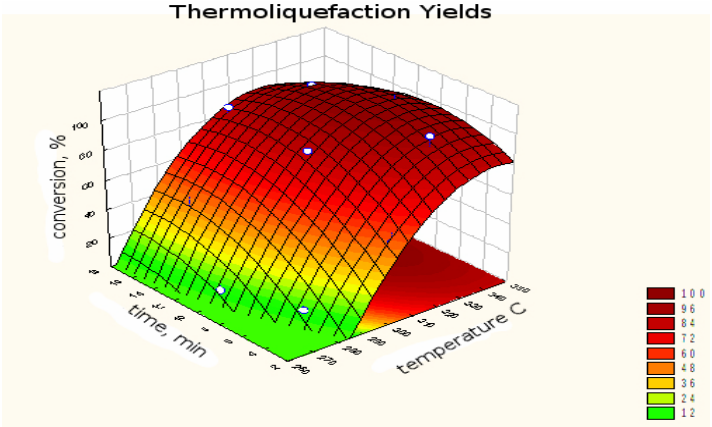


Figure 4: Percent conversion of wood to liquid wood as a function of temperature and pressure

Table 3
Characteristics of ecologically clean motor fuel additives

| Property | Bio-oil, St. Petersburg Forest Technical Academy |
|---|---|
| Kinematic viscosity at 100 °C (mm$^2$/s) | 6.89 (40 °C) |
| Water content (mass %) | 4.4 |
| Mechanical impurities (mass %) | None |
| Ash content (mass %) | 0.04 |
| Coking ability (%) | 0.98 |
| Acidity (KOH/100 cm$^3$ fuel) | 55.1 |
| pH | 4.95 |
| Sulfur content (mass %) | None |
| Open cup flash point (°C) | 10 |

| | |
|---|---|
| Pour point (°C) | -27 |
| Density at 20 °C (kg/m$^3$) | 1070.5 |
| Fractional composition (°C): | |
| Initial boiling point | 98 |
| 5% distilling | 101.0 |
| 50% distilling | 235.0 |
| 95% distilling | 280.0 |
| Final boiling point | 282.0 |
| Heating value (low) based on dry fuel (kJ/kg) | 30203 |
| Elemental composition (%): | |
| C | 70.2 |
| H | 8.5 |
| O | - |
| N | 0.2 |

Another type of ultrapyrolysis developed at FTA is thermoliquefaction. Still in its preliminary stages, thermoliquefaction requires significantly less capital investments and less rigid process conditions, such as fractional structure, humidity controls and content of mineral substances of the wood biomass. By varying the character of the solvent, pressure, temperature, catalyst and time of processing, a significant yield enhancement (a nearly 100% conversion) of a wide range of chemical compounds and improved calorific properties may be obtained.

The essence of the thermoliquefaction process involves aqueous/organic solvents mixed with a wood biomass under the pressure of 2.0-15 MPa and temperatures of 250-350 °C. Under these conditions, considerable decomposition of the organic superstructure and its dissolution occur. The extent of dissolution and decomposition depends on the nature of the biomass, the conditions of the process and the properties of the solvent. In Figure 4, for example, the liquefaction of aspen biomass in its own wood oils is presented. The decomposition of the dissolved organic substances leads to the formation of "liquid wood", which can be used for the food-processing industry (preservatives, flavorings, smoke preparations) and as a quality emulsifier for industrial and road building applications. The technology also uses the water medium and the biomass's own liquid products as a solvent. The structure of smoke preparations with different complex components also depends on the processing of the foodstuff, which has not been recognized until now.

**REFERENCES**

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