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Rationalization of Materials and Thermal Recovery System for Non-woody Agricultural Wastes

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Research activities associated with non-woody agricultural wastes management is insufficient in comparison with researches involving woody wastes. Lignocellulosic wastes; such as wheat and rice straws, bagasse, maize stalks, etc., which are annually renewable, can be utilized in various ways with multiple benefits based on cost effectiveness, renewability, environmental compatibility, etc. A systematic approach towards utilizing these wastes rather than fragmented approach is strongly desired. This study is aiming to maximize the utilization of these renewable fibrous wastes by developing a sustainable and more reasonable recycling system. Dual approaches are adopted in this study; (1) materials recovery to develop value-added new materials, and (2) thermal recovery to produce fuels, oils and chemicals of industrial importance, and heat. In the present report, a more sophisticated materials and thermal recovery system will be proposed by reviewing and discussing the possible methods for optimum utilization of these abundant resources focussing mainly on the tropical non-woody agricultural wastes.

Key words: Non-woody Agricultural Wastes, Materials Recovery, Thermal Recovery, Value-added New Materials, Advanced Recycling System, Waste Management

1. INTRODUCTION

Future materials technology will feature the need for resource conservation, development and utilization of environmentally conscious materials, economics, etc. through groundbreaking researches in areas including composites, hybrids and re-use/recycling of both developed and wastes materials. One of the most promising methodologies is by combining mutually different sorts of low-value materials such as wastes, or alternating by combining with other high-value materials, in order to yield value-added products with improved properties. This method will definitely form the backbone of materials technology in the coming 21st century, which clearly signifies the eminent use of low-grade materials such as annual crop wastes. Annually renewable resources are especially attractive these days because more concerns about environmental, endangered animal and plant species, destruction of ecosystems, etc. are expressed and legislated[(1)]. However careful attention will be given to cereal straws since researches involving such materials are grossly inadequate. The straw of cereal crops and stalks of corn and sorghum are considered the largest, mainly untapped, reserves of fibrous raw materials [(1)].

Available statistics [(1)] suggest an estimate of more than 2 billion metric tons of potentially available agro-based raw materials from crop residues. Also, **Table I** shows the total cereals production in 1997 and 1998[(2)], which represents approximately 25% increases in total production as compared to 15 years ago. Although it is difficult to quantify exactly the total wastes resulting from agricultural practices, different researchers adopt some factors for calculating different waste materials. It has been shown that, for rice straw wastes, a factor of 0.6 may be used in relation to total rice production, while a factor of 1.6 should be used for wheat [(3)]. However, the resulting waste in the table is lumped for cereals, and hence based on a conservative estimate, that for every ton of cereal crops produced, an equivalent quantity of wastes should be generated (a factor of 1). This suggests a tremendous source of raw materials available for

Table I Statistics of total cereals production in 1997 and 1998[(2)]

World average cereals production per year (1997 and 1998): 2,077,858 (10^3Mt*)

	Country	Production (10^3Mt)		Mean Value/ Year (10^3Mt)	Wastes (10^3Mt)**
		1997	1998		
Africa	Egypt	17, 492	17, 047	17, 270	17, 270
	Nigeria	21, 949	21, 621	21, 785	21, 785
	South Africa	13, 236	10, 026	11, 631	11, 631
North America	Canada	49, 526	51, 150	50, 338	50, 338
	USA	336, 486	349, 703	343, 095	343, 095
South America	Argentina	35, 824	35, 928	35, 876	35, 876
	Brazil	47, 321	40, 471	43, 896	43, 896
Asia	China	445, 968	443, 874	444, 921	444, 921
	India	223, 615	224, 027	223, 821	223, 821
	Indonesia	58, 148	58, 530	58, 339	58, 339
	Japan	13, 326	11, 942	12, 634	12, 634
Europe	France	63, 432	68, 446	65, 939	65, 939
	Italy	19, 912	20, 636	20, 274	20, 274
	UK	23, 519	22, 781	23, 150	23, 150
Oceania	Australia	30, 829	32, 129	31, 479	31, 479

* 1 Metric ton (Mt) = 10^3 kg ** 1 ton of straw per ton of grain[(4)]

developing new materials; otherwise it can be thermally transformed directly into heat for power generation, or indirectly into fuel and/or chemical for other industrial uses.

In this paper, optimization of such recycling system for the more sophisticated utilization of these massive raw materials, namely of the non-woody agricultural wastes, will be discussed on the basis of reviewing the up-dated research works.

2. RESEARCH METHODOLOGY

Like the petroleum refinery, agro-based residues (as raw materials) should be manipulated by applying various techniques based on a systematic and closed recycling system as shown in **Fig. 1**, which was obtained through reviewing and discussing several recent research articles [(5)-(7)]. As shown in the figure, a number of uses are already in place for the utilization of the wastes. Apart from the other re-utilization of agricultural waste and residues, bioconversion (biorefinery) for biofuels is gradually coming to focus, while composting for organic fertilizer is steadily increasing especially in the United States[(8)]. Despite the use of these wastes in such areas, a substantial quantity is still being left unutilized, major part of which is often burned directly in the field. From the review, it has been identified that developing a recovery system that will capitalize on materials recovery, preceding thermal recovery for these abundant wastes is lacking. Therefore, the present study is aimed at bridging the gap existing between the re-utilization and the development of value-added materials by establishing an efficient recovery system to gainfully handle the unutilized portion in an integrated manner. The proposed methodology is depicted in **Fig. 2**, while the approaches should be classified into two phases as outlined below:

2.1 Materials recovery

As the major aspect of the efficient recovery system,

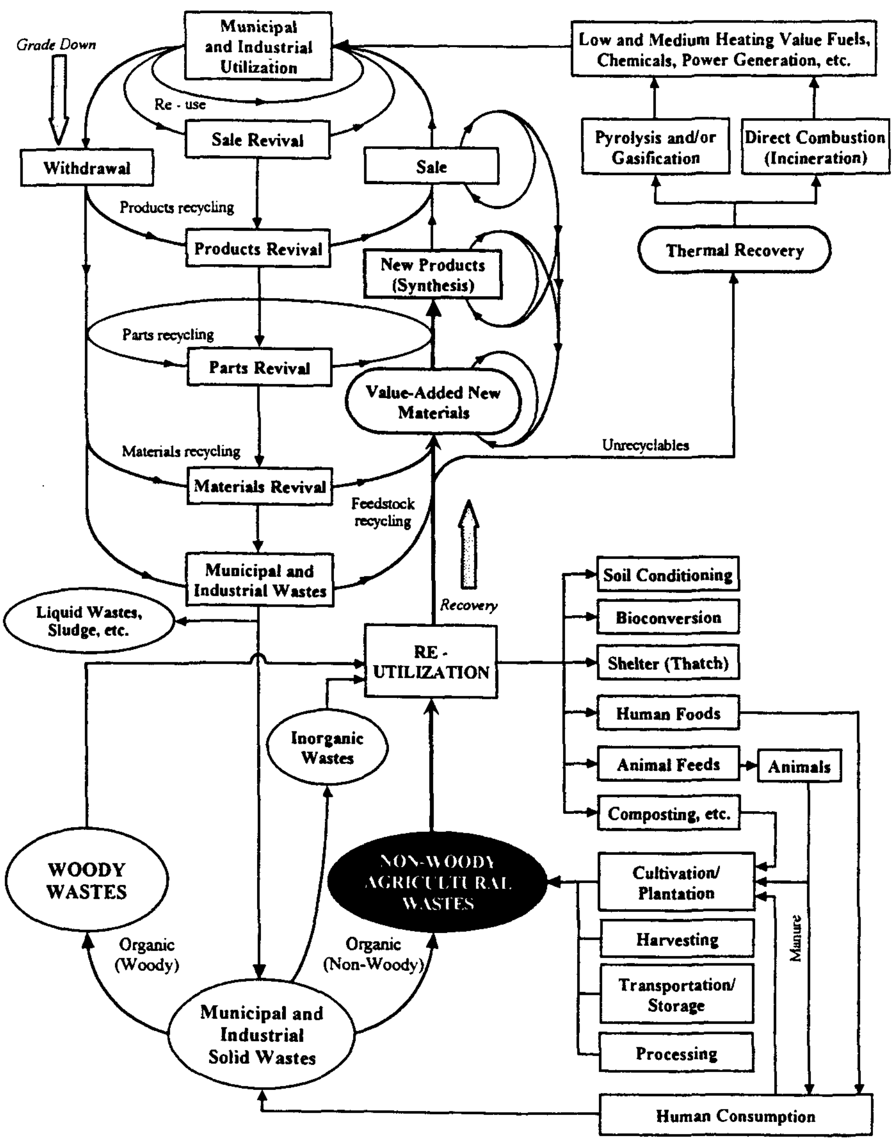

Fig. 1 Flow chart for the efficient and sustainable re-utilization of municipal and industrial wastes.

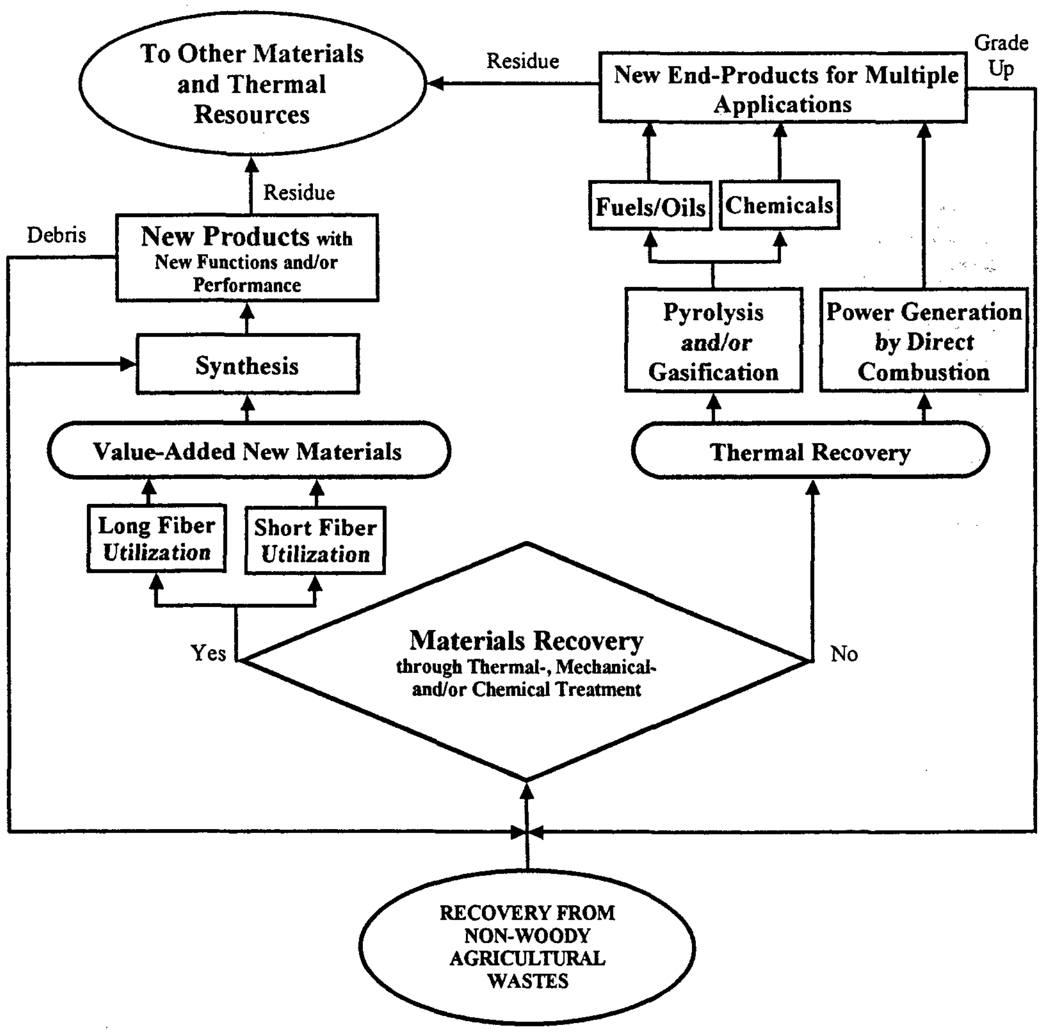

Fig. 2 Flow chart of the proposed materials and thermal recovery system for non-woody agricultural wastes.

priority is attached to materials recovery dominatingly over the thermal recovery. Lignocellulosics will be used to produce a wide spectrum of products ranging from the inexpensive and low-performance materials to much expensive and high-performance ones. Much more researches are necessary to find suitable methods for combining lignocellulosics with other materials such as metals, glass, plastics, and synthetic fibers to produce new materials to meet end use requirements(9). The main focus is to combine two or more materials so that the synergism between the materials results in composites with much improved properties better than the individual components. Available literatures on the utilization of lignocellulosics as construction materials indicate promising results, even though its greatest use is perhaps the use of its fibers in making pulps for quality papers. Evidence exists that houses built using straw panels are especially earthquake resistant(10). However, its use as reinforcing filler in thermoplastic composites is still under-developed(11), and is often associated with problems that require further studies. **Table II** shows the approximate property comparison of lignocellulosics together with some other engineering materials, which is modified from the original reference(12). From the table, lignocellulosics possess some properties that are advantageous which suggest the possibilities of exploration of new processing techniques, new applications, new markets in diverse areas, etc. In the present study, some approaches will be adopted for developing such kinds of highly functional new materials by combining;

(i) homogeneously (nature wisely) different kinds of agricultural wastes,

Table II Properties of engineering materials

Property	Performance				
	Lignocellulosics	Metals	Plastics	Glass	Concrete
Dimensional change	Yes moisture, temp.	Yes temp.	Yes moisture, temp.	Yes temp.	Yes moisture, temp.
Rotting	Yes organisms	Yes oxidation	No	No	Yes moisture
Thermal degradation	Yes fire	Yes melt	Yes melt	Yes melt	No
Thermal insulation	Good	Very poor	Poor - good	Poor	Fair
UV degradation	Yes, surface	No	Yes - no	No	No
Acid degradation	Yes, strong oxidation	Yes	Yes - no	No	Yes

(ii) homogeneously (origin wisely) different sorts of wastes such as agricultural wastes and agro-fiber based products e.g. waste papers,

(iii) heterogeneously, renewable organic wastes and wastes resulting from non-renewable sources such as artificial plastics.

To achieve these, strategy based on fiber utilization which entails the use of fibers without physico-chemical modification should be considered, i.e. the fiber in its natural state, thus;

(1) The use of long fiber (unaltered original length, high aspect ratio) is preferential in this study.

(2) Fiber orientation/stacking; longitudinal, transverse, etc., achieving optimum properties by carefully manipulating the fiber orientation will be highlighted.

2.2 Thermal recovery

Thermal recovery should be considered the final resort (second phase) in the efficient recovery system; hence must attract equal importance. Energy production from agricultural wastes is perhaps the oldest surviving method of its use. However, attention is being re-focussed on it again because of the current realities associated with the global environment, economics and resource conservation, population explosion, etc. Alternate fuel technologies must be applied to reduce dependence on fossil fuels by converting some portions of the agricultural wastes to energy. Energy from renewable sources, such as agricultural residues, must ultimately play a key role in obtaining a world energy equilibrium [13]. The most current popular methodology of converting wood wastes and to a small extend, cereal straws into energy is direct combustion. Controlling and reducing the high moisture contents, densification to increase the bulk density of the loose straw to enhance its handling capacity and combustion uniformity are the major subjects associated with this methodology. Other methods, which should be rather approved in the future, are fuel cell, pyrolysis and gasification for conversion to fuel. By-products in either pyrolysis or gasification are to be finally processed into medium or high heating value fuels and chemicals of industrial importance. However, to improve the quality of the fuels, uniform combustion, etc. in thermal recovery process, feedstock preparation such as drying and densification prior to combustion is strongly required.

In preparing the feedstock, refuse-derived fuel (RDF)/straw-derived fuel (SDF) from straw, bagasse, corn stalks constitute the primary raw materials that will be singly used or in combination with each other. Although used papers from the municipal solid waste (MSW) stream will also be used as secondary raw materials in combination with the aforementioned. Several techniques are available for densification, most of which are originally meant for coal and peat, namely pressing manually or by means of piston, screw, pellet, etc. In the present study an attempt will be carried out to establish the optimum conditions to produce the high-quality fuel by densification through determining the actual relationships between the various variables that affect the quality as fuel, and the relationships between individual fibers as related to a bundle of fibers under compressive forces.

3. CONCLUSION

Non-woody agricultural wastes are great source of raw materials that must be fully exploited. With the appropriate technology, these abundant waste materials should be used to replace a part of non-renewable petroleum-based materials, thereby reducing over-dependence on raw materials accruing from exhaustible sources. Fundamentally, recycling these wastes will yield dual benefits with a single act, i.e. creating a source of raw materials for new materials development, fuels and chemicals, as well as a means of disposal. However, a highly integrated recycling system is desperately required to derive maximum benefits from the utilization of these wastes. An integral part of the proposed recovery system is to capitalize on materials recovery, otherwise thermal recovery. In this study, non-woody agricultural wastes of tropical origin are given preference, and the study will examine in detail the possibilities of achieving a peak recycling system as outlined above. The experimental work is still on progress towards realizing such beneficial effects.

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