CHAPTER II

REVIEW OF RELATED LITERATURE AND RESEARCH

Chillies

The chillies are fruit of plant belonging to Capsicum genus. They are one of the most widely used as a condiment and vegetable all over the world. They are a short rotate plant which their fruits are consumed fresh, dried or processed as a spice. Chillies originated in a remote area of South America between the mountains of Brazil and the lowlands of Bolivia more than 1,000 years ago. Over thousands of years, the wild chillies that looked much like small, red berries were moved out of this area and disseminated by birds. Through time, a symbiotic relationship between birds and chillies evolved because birds lack the receptors that feel pungency and harbor digestive systems that do not harm the seed of the chilli. Conversely, mammals feel pungency, and their digestive systems crush the seed. People are probably not supposed to eat chillies as the pungency is supposed to deter. But strangely enough, humans started to cultivate this very pungent, wild chilli. Year after year, humans began to select for larger, different colored pods and eventually ended up with a large number of varieties of chilli, very different from their wild predecessors.

Chillies have been carbon dated back to 7000 B.C. at archeological sites in southeastern Mexico. Fossilized chillies much larger than the wild types, have been documented back to 2500 B.C. in Northern Peru, suggesting cultivation at that time. One theory of anthropologist is that Indians of central Mexico cultivated chillies and started to trade chillies with Indians from the North; another is that chillies ended up hundred of years ago in the southwestern U.S. as Spanish explorers collected them along the trade routes. Chillies are a Western Hemisphere crop that got back to the East with some help from explorers. Record books indicate that Columbus, looking for black pepper (piper nigrum), the most expensive spice at the time, came across these fiery pods and returned with returned with these unique fruits because of their pungency. Today, chillies are global, found and cultivated in almost every country in the world. They are staples in many ethnic diets, including Thai, Chinese, Korean, Indian, Hungarian, African, Mexican, and others. Chillies are used in these cuisines in both the dried and fresh forms. They are also considered a spice in many countries because of the extensive use of paprika, which can be pungent or non-pungent. Colour and flavour extracts are used in both the food and feed industry, for example for ginger beer, hot sauces and poultry feed.

Chillies are relatives of other plants in the Solanaceae family, which includes potatoes, tomatoes, and eggplants. There are many different varieties, colors, shapes, sizes and even names. Scientifically, chillies are described by pod type which is the overall shape and size of particular chillies and the specices. In addition to an endless number of wild species, there are five domesticated species of chillies in the world today:

1. *Capsicum annuum*, the species in the *Capsicum* genus,houses more than a thousand different varities, including jalapeno, New Mexican, bell peper, Serrano, cayenne and ancho. All of them are also different pod types, with hundreds of different varieties within those pod types.

2. *Capsicum Chinese*, another popular species, accommodates pod types and also includes some of the worlds hottest peppers. Varieties within these pod types include the 'Red Savina' which is currently the world's hottest scientifically tested chilles, and the 'Red Caribbiean'.

3. *Capsicum frutescens* includes the "Tabasco".

4. *Capsicum baccatum* includes most of the true ajis. A "trye aji" is a pod type within baccatum that includes many different varieties. The distinction is made here because aji is a term used loosely in the U.S. and other parts of the world to describe any types of chilles.

5. *Capsicum pubescens* includes the "Rocoto", a favorite of chillies aficionados around the world for its black seeds.

Chillies have a wide range of pungency (Table 1), which is affected by the environment in which the chillies were grown. Capsaicin which is produced in the placenta of the chilli pod, the "ribs" in the interior of the pod, where the seeds are attached, causes pungency. When chillies are processed, the capsaicin glands burst or break and the oils containing the yellow-orange capsaicin penetrate the seed coat, making it pungent.

Table 1 Pungency and Uses of Chillies [1]

Variety	Pungency (Scoville Heat Units)	Culture most widely used in	Forms used
California Wonder	0	All	Fresh in salads, stuffed
Ancho 101	1,500	Mexican	Rellenos, salsa, mole
Serrano del Sol	4,000	Mexican	Meat marinades, sasas, Fresh
NuMex Joe E. Parker	4,500	Hispanic	Rellenos, enchiladas, sauces, and powders
Aji Escabeche	17,000	Hispanic	Sauces
Santa Fe Grande	21,000	Hungarian	Stuffed, fresh
Mitla	25,000	Hispanic & American	Jalapeno stuffers, salsas
Thai Hot	60,000	Asian	Soups, powers, curries
Tabasco	120,000	American & Mexican	Sauces
Caribbean Red	250,000	Mexican & Jamaican	Fresh, chutneys

1. **Chillies in Thailand**

There are various types of chillies exist in Thailand which has 87.0-90.0 mg/100 g of vitamin C and 140.8 RE of β-carotene. It is good for blood vessels expansion at the intestines and stomach as it can help to absorb the nutrient well. Chillies in Thailand are categorized by their pungency and pod size. Chillies with 1% (by weight) capsaicin are the strongest one in pungency and equal to 100% pungency which is 175,000 in Scoville Heat Unit. There are 3 types of chillies which are categorized by their pungency as follows.

1.1 The strongest pungency chillies which are 70,000-175,000 Scoville with small pod type. Normally, they are used in essential oil extraction. Variety within this type is *Capsicum frutescens* including the "Tabasco".

1.2 The medium pungency chillies which are 35,000-70,000 Scoville. They are used as spice in food in both the dried and fresh forms. Variety within this type is *Capsicum annuum* which are Thai bird chilli pepper (Prik Kee Nhu, Prik Hua Rue, Prik Hauy Si Ton, Prik Chor Morkhor), Jinda (Prik Jinda), chilli spur pepper (Prik chee Fha, Prik Mun).

1.3 The less pungency chilies which are less than 35,000 Scoville with large pod type. Variety within this type is *Capsicum annuum cultivars* which is Bell Pepper or Italian Sweet.

In case of pod size category, chillies are separated into 2 categories [2] as follows.

1. Large chillies

1.1 Chillies within this group are 5-20 cm long with 1-3 cm diameter. groups of large chillies. Chillies in the first group are more than 10 cm long. They are strong in pungency. Varieties within this group are Singapore chillies and chilli spur pepper (Prik Num), chillies spur pepper (Prik Chee Fha), Prik Mun Pichai, Prik Bangchang, Prik Leung, which are grown many in Ratchaburi, Nakhon Pathom, Uttaradit , and Chiang Mai provinces.

1.2 Chillies in the second group are 4-20 cm long with 1-4 cm diameter. Varieties within this group are Prik Youg which are grown many in Ratchaburi, Nakhon Pathom provinces.

2. Small chillies or Prik Kee Nhu

2.1 Chillies within this group are 3-12 cm long with 0.3-1.0 cm diameter which they are very popular in Thailand. Varieties within this group are Prik Hauy Si Ton 1, Prik Jinda, Prik Chon Buri, and Prik Hua Rue which are grown many in Si Sa Ket, Loei, Khon Kaen and Rachaburi provinces.

2.2 Chillies which are not more than 3 cm long. Varieties within this group are Prik Kee Nhu, Prik Karaing, and Prik Keenok which are grown many in Kanchanaburi, Ratchaburi, Prachuap Khiri Khan and Phetchabun provinces.

2. Prik Jinda

Another name in some area is Prik Kaset. Its stem height is about 1.5 m. Its fruit is small in green when immature and in red when mature. As shown in Figure 1, its pod length and width are about 3-4.5 cm and 0.7 cm respectively. It is used in both fresh and dried. Hole pod dried length is about 2.5 cm which is very strong in pungency. Prik Jinda is usually dried in the sun. It is also exported in both fresh and dried form.

Figure 1 Thai Red Chillies Namely Prik Jinda

The consumption of chillies by Thai, Indian, Mexican and American people is about 5.0 g/person/day, 2.5 g/person/day, 20.0 g/person/day and 1.5 mg/person/day respectively. Thailand produces large number of chillies each year but they still need to be improved in their quality from their production in farms to dinning table. In Thailand chillies are popular spice crop for both sale and consumption. Both fresh and dried chillies are consumed. Chillies are also not only important part in Thai food but also one of the cash crops. It is reported that Thailand exports fresh, sauce and dried chillies for about 900 million baht a year [3]. Since 1997, it has been exporting more than 10,000.0 ton each year. In year 2001, the exported quantity was 12,283.0 ton. The exported number increases each year. Dried chillies are also exported every year as 51.0-92.0 million baht. However, Thailand also imports dried chillies from other countries. In year 1997, 4,642.0 ton of dried chillies were imported. This shows that the consumption of chillies will increase whereas the quality is not consistent to them.

To dry chillies is not only to preserve but also change their flavor to be better for the consumers. At present, the production of dried chilli has been processed in both households and medium scale industries. Chillies are dried in both traditional drying method (Figure 2) and drying by LPG method. However, the traditional drying presents certain difficulties such as: there is too much dependence on climate conditions (it is sometimes necessary to gather up the product in case of rain), there is a need for manual labor to move the product during the drying time, and there is difficulty in maintaining hygienic conditions.

Figure 2 Traditional Drying of Chillies

The traditional drying of chillies is difficult to avoid risks of losing the product due to the rain, wind, and action of insects and rodents. From this, the value of dried chillies can be decrease when they will be on sell. The chemical properties of dried chillies which were set up by Thai Industrial Standards Institute (TISI) are shown in the following table.

Table 2 Chemical Properties of Dried Chillies

Properties	Fixture of standard
1. Moisture content (percentage) not to exceed	13
2. All ashes (on dry basis), percent by weight not to exceed	8
3. Acid-insoluble ashes (on dry basis), percent by weight not to exceed	1.25
4. Non-volatile ether extract (on dry basis),percent by weight not to exceed	
- small fruit type	15
- large fruit type	12
5. Crude fiber (on dry basis), percent not to exceed	28
6. Aflatoxins, µg/kg of samples not to exceed	20

To produce large number of dried chillies consumes much energy. Developing drying technology that uses renewable energy can help in producing dried chillies which meet the requirements in chemical properties.

Solar Energy

Most renewable energy sources are derived from solar radiation, including the direct use of solar energy for heating or electricity generation, and indirect forms such as energy from the wind, waves and running water, plants and animals (wood, straw, dung, and other plant wastes). Tidal sources of energy result from the gravitational pull of the moon and the sun, and geothermal energy comes from the heat generated within the earth. Energy from wastes of all kinds is also often included under the heading of renewable energy sources. In their technological development, the renewable energy range from technologies that is well established and mature to those that need further research and development. The use of renewable energy on a more significant scale than at present would be at the very least replace a further significant proportion of fossil and nuclear fuel use, thereby reducing the associated environmental impacts. Most of the renewable sources have to be considered to avoid environmental damage. Renewable sources are secure and inexhaustible, in the sense that there is no problem of reserves being depleted. With some exceptions, proposed renewable energy sources are local and so cannot be turned off by a 'foreign power'. They can also add diversity to energy supply.

Solar radiation incidents on the earth's surface at a rate approximately 8×10^{16} W, which is more than 10,000 times of the present world energy consumption. Obviously, the resource base is there to support a solar-energy-based civilization at the current level of energy use. In order to be useful, however, the solar energy must be collected and brought to the right place at the right time. A more meaningful number is therefore the flux density or radiation per unit surface area. Thailand is located near the equator where sunshine is relatively strong and available all year round. The distribution of solar radiation is influenced by the northeast and southwest monsoons. Highest solar radiation in most parts of the country occurs during April and May, which account for 20 and 24 MJ/m^2-day [1]. The yearly average of daily global is about 14% of the total country area where the highest solar radiation of 19-20 MJ/m^2-day is found in the northeast and central regions. About half of the country receives yearly average daily global radiation in the range of 18-19 MJ/m^2-day. Only 0.5% of the country receives yearly average daily global radiation less than 16 MJ/m^2-day. The yearly average daily global radiation for the whole country is 18.2 MJ/m^2-day.

The acceptance of solar energy will depend on the cost of the equipment needed to collect it. Even though sunlight is free, one must pay a capital charge for the amortization of the collecting equipment. Solar energy is capital intensive. For solar equipment one usually assumes a lifetime on the order of 20 years and a useful rule of thumb is that the annual capital charge in constant dollars is about 10 percent of the initial investment.

Biomass

Due to increase in fuel costs and concerning environmental impact, the utilization of biomass for fossil fuel substitution has drawn attention from people concerned in many aspects, particularly in global warming issue. Crucial reduction of carbon dioxide emission approximately accounts for 75% of green house gases is one of the main reasons.

Biomass is simply defined as the material of plants and animals, which can fix and store solar energy as a part of their growth and breeding. While bio-fuel is the biomass resource that can be used or converted to a fuel. For example, the carbohydrate portion of the lignocellulosic feedstock can be converted into ethanol by biological methods. Moreover, combustion of the lignin component can generate heat as well as electricity. There are three main types of biomass fuel namely solid fuels, gaseous fuels, and liquid fuels. The solid fuels may be divided, according to the properties, into pellet and charcoal. In the same way, biogas, wood gas, and hydrogen are three main kinds of the gaseous fuels. Again, the liquid fuels can be divided into six main groups. Ethanol and methanol are examples of the liquid fuels.

The chemical composition of biomass varies among species, but basically consists of high, but variable moisture content, a fibrous structure consisting of lignin, carbohydrates or sugars, and ash. Biomass is very non-homogeneous in its natural state and possesses a heating value lower than that of coal. The non-homogeneous character of most biomass resources (e.g. cornhusks, straw) pose difficulties in maintaining constant feed rates to gasification units. The thermal properties of biomass are the criteria to determine the performance of this material as a fuel for combustion. The most important thermal properties consist of moisture content, ash content, volatile matter content, heating value, bulk density and elemental composition. It is widely accepted that there are three kinds of basis to state the percentage of these properties, namely, wet basis, dry basis, as well as dry-and-ash-free basis. The moisture content of biomass, which is expressed as a percentage of the biomass's weight, describes the quantity of water in the substance. Next, the ash content generally expressed as a percentage on a dry basis is the amount of ash in the material, which can affect the performance of the high temperature process, such as clogging. Volatile matter content means the part of the biomass that is discharged during the heating process. The heating value indicates the energy chemically bound in the biomass in respect of a standardized environment. Then the bulk density is the ratio of the weight of biomass to its volume. Finally, the element composition mainly comprises carbon, oxygen, hydrogen and nitrogen. Table 3 compares the proximate and ultimate analyses of several potential biomass gasifier feedstock [5]. Wood is the most commonly used biomass fuel. The most economic sources of wood for fuel are usually wood residues from manufactures, discarded wood products diverted from landfills, and non-hazardous wood debris from construction and demolition activities. Fast-growing energy crops (e.g., short hardwoods) show promise for the future, since they have the potential to be genetically tailored to grow fast, resist drought and be easily harvested.

Table 3 Potential Biomass Gasifier Feedstock.

	Ultimate Analysis (wt% dry basis)						Proximate Analysis (wt% dry basis)			
	C	H	N	O	S	Ash	Moisture	Volatiles	Fixed Carbon	Heating Value HHV (Mj/kg)
Agriculture Residues										
Sawdust	50	6.3	0.8	43	0.03	0.03	7.8	74	25.5	19.3
Bagasse	48	6.0	-	42	-	4	1	80	15	17
Corn cob	49	5.4	0.4	44.6	-	1	5.8	76.5	15	17
Short Rotation Woody Crops										
Beech Wood	50.4	7.2	0.3	41	0	1.0	19	85	14	18.4
Herbaceous Energy Crops										
Switchgrass	43	5.6	0.5	46	0.1	4.5	8.4	73	13.5	15.4
Straw	43.5	4.2	0.6	40.3	0.2	10.1	7.6	68.8	13.5	17
Miscanthus	49	4.6	0.4	46	0.1	1.9	7.9	79	11.5	12
Municipal Solid Waste										
Dry Sewage	20.5	3.2	2.3	17.5	0.6	56	4.7	41.6	2.3	8
Coals										
Subituminous	67.8	4.7	0.9	17.2	0.6	8.7	31.0	43.6	47.7	24.6
Bituminous	61.5	4.2	1.2	6.0	5.1	21.9	8.7	36.1	42.0	27.0

Compositions are approximated and may not sum exactly to 100.0%.

Biomass moisture contents reported are for dried feed stocks.

Biomass in Thailand

Agricultural products are one of the most important parts of the economy in Thailand. Approximately, it accounts for 10.7%, 11.2% and 10.1% of the GDP values from 1998-2000 respectively [6]. Examples of the products are paddy, soybean, sugar cane, maize and palm oil. Nonetheless, not only are there the crops itself, there are also large quantities of agricultural residues produced every year.

The majority of indigenous energy resources in Thailand is biomass. In the country, over thirty percent of the indigenous supple is accounted for biomass. Currently, wood fuels and charcoal widely used in the rural areas are the main biomass energy source in the country. However, particularly for small-scale application, large amount of agricultural products dispersed all over the country is considered as a high potential energy resource for Thailand. The energy potential of selected agricultural residues will be discussed in this section.

1. Paddy

One of the most important staple crops in Thailand is paddy. Over 22 Mt (10^6 ton) per year of paddy had been generated in the country for last 5 years, from 1996 to 2001, continuously [7]. Therefore, with respect to the processes in rice mills, paddy husk is generated as residue. Then, it is utilized as a fuel for direct combustion, especially for large rice mills. It is also used as a component for brick production. The paddy to husk ratio varies in a wide range from 1:0.16 up to over 1:0.30. In this paper, the husk proportion of 26.7% of paddy, from experimental data, is utilized for calculation.

Additionally, rice straw is another kind of residues from paddy. The straw may be categorized into 2 main groups. First is the paddy straw, which contains the top portion with 3-5 leaves only. The paddy to rice straw ratio of 0.1999-0.452 was reported. On air-dried basis, 1:0.447 is the value used for calculation. Rice straw cut at about 2 inches above the ground is another type of paddy residue. With moisture content of 12.71%, the paddy to straw ratio of 1.757 was reported [8].

2. Sugar cane

Among the selected agricultural products, sugar cane represents the largest yield of agricultural residue. In 2001, about 49 Mt of sugar cane was generated. The main residues produced from sugar cane are bagasse, leaves and trashier. The crop to residue ratio ranging from 1:0.1 to 1:0.33 was reported for bagasse generation. According to the study of the National Energy Administration, 1:0.291 is the value chosen for calculation. Besides, the value of 0.302 (moisture content 10%) is used for sugar cane to leaves and trashier ratio.

3. Maize

Maize stem and corn cob become available as residues after harvest and milling respectively. More than 4 Mt per year of maize produced was reported for last five years. Thus, it seems that there are a large amount of residues available. However, maize stems are usually utilized as a fertilizer for the land. It appears that losing of soil fertilizer may occur if all maize stems are removed from the field. So, the availability of corn cob will be discussed in this paper only. The maize to corn cob ratio of 0.273 is used for calculation purposes [7].

4. Coconut

Four types of residues are associated with coconut production. Coconut husks, shells, empty brunches and fronds are such residues. In Thailand, there are two kinds of coconut plant viz. tall and short types. About 1.4 Mt per year of coconut generated in the country from 1996 to 2001 was reported [7]. Coconut to husk and coconut to shell ratios are 1:0.419 and 1:0.12 respectively. In addition, 4.9% is the crop to empty bunches ratio while the ratio to generate fond from such a crop is 22.5%.

5. Cassava

After cassava harvesting, cassava stalks are the residues produced. Firstly, cassava plants are topped and then uprooted at the harvesting. Some stalks are utilized as a propagation plant. However, there are a lot of cassavas stalks left in the fields and are burned later. In Thailand, approximately 15 Mt of cassava was generated in 2001. The cassava to stalk ratio ranging from 0.167-2.0 was reported as the most suitable for Asian conditions. At 30% moisture content, 1:0.088, which is utilized for calculation purposes, is the ratio to produce the stalk from harvested cassava root [9].

6. Oil palm

Oil palm residues may be classified into four main groups, namely empty bunch, fiber, shell and frond as well as trunk. However, the last group of the residues is available after the oil palm replanting. From 2.7 Mt in 1996, oil palm productivity was increased to 4.1 Mt approximately. With 40% moisture content, oil palm to fiber ratios ranging from 0.14 to 0.15 was reported [10]. Also, the ratio of 1:0.18 was also utilized for Thailand. Nonetheless, the value used for calculation in this paper is 0.147. Besides, the values in the range of 0.06 to 0.07 for shell production ratio from oil palm were reported. For Thailand, 0.073 is the crop to shell ratio utilized for the calculations. Finally, for empty bunches with moisture of 50%, the values of 0.23 and 0.234 were reported.

7. Soybean and sorghum

In 2001, the productivity of soybean and sorghum are about 0.32 and 0.15 Mt respectively. Leaves and stem are available as residues from sorghum production while stalks and pods are those from soybean generation. For sorghum, the ratio of 1.2 was used in a source. For calculation purposes, 1.252 is the value utilized. Additionally, soybean to pod reported is 2.5 and 1 respectively, however the value of 2.663 from another source was used [4].

The yields of selected agriculture products of Thailand are shown in Figure 3. There are three types of crops with the annual yield over 15 Mt viz. sugar cane, paddy and cassava. Oil palm, maize as well as coconut were produced more than 1 Mt per year while the annual yields of soybean and sorghum were only some hundreds kton. According to the crops to residue ratios, the agricultural products were calculated as shown in Fig 4. It can be seen from the chart that bagasse, leaves and trash from sugar cane; and husk as well as rice straw from paddy represent considerably large quantities of residues. Moreover, from the last five years, the average residues generated from oil palm, cassava and maize production are approximately 2, 1.7 and 1.2 Mt respectively.

Furthermore, as regards residue surplus factors, the surpluses of agriculture residues in Thailand were also computed. The results are shown in Figure 5. There are only two kinds of plant account for the average surplus quantities over 10 Mt per year, namely sugar cane and paddy. The average amounts for the other crops, except sorghum, are in a range of 600-900 kton. Finally, the surplus residues were converted into energy as shown in Figure 6. As can be seen from the chart, the surplus energy of sorghum accounts for some thousands TJ while the others are over 10,000 TJ.

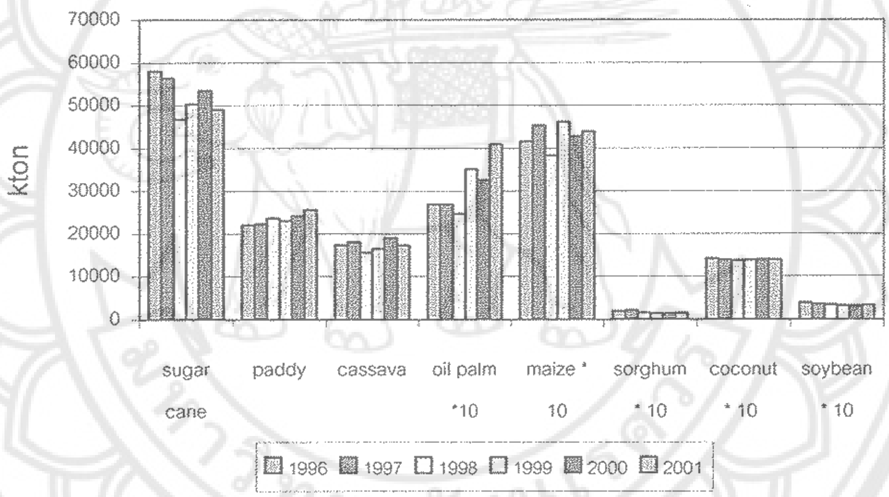

Figure 3 Annual Productions of Selected Agricultural Products in Thailand (1966-2001)

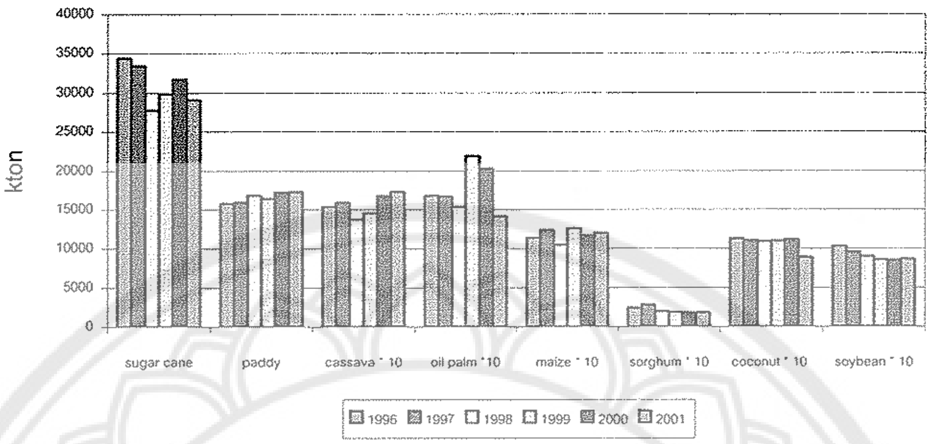

Figure 4 Annual Residues of Selected Agricultural Products in Thailand (1996-2001)

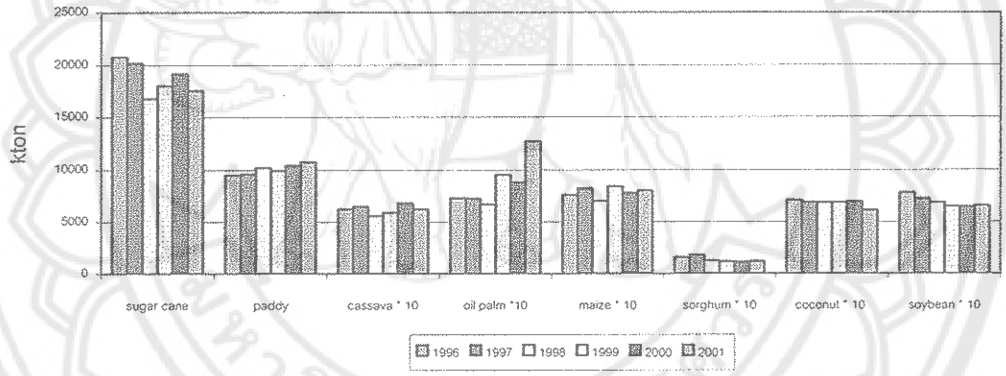

Figure 5 Annual Surpluses of Selected Agricultural Residues in Thailand (1996-2001)

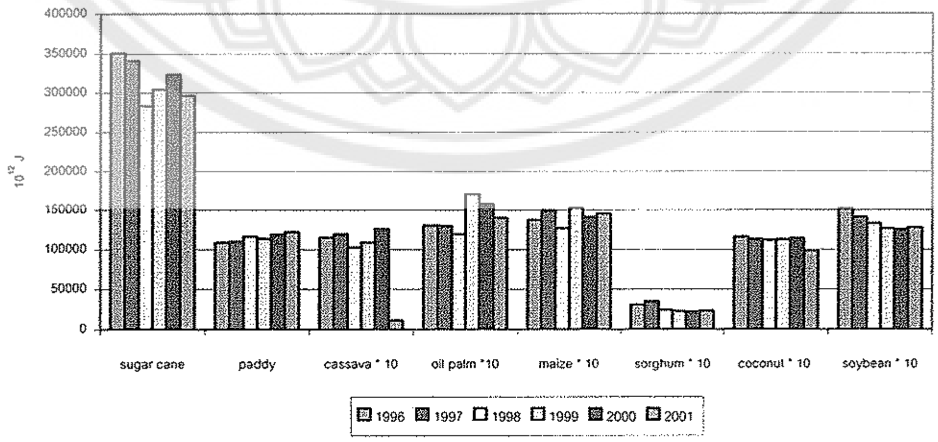

Figure 6 Annual Surplus Energy of Selected Agricultural Residues in Thailand (1996-2001)

Gasifier

Worldwide, it seems that gasification technology represents an alternative to produce heat, electricity or the combination of both. Particularly, for biomass application, it is widely accepted that using the gaseous fuel from gasification, which is called producer gas, has many advantages in composition with raw biomass utilization. An example of the advantages is that it is rather cleaner than using raw biomass, as the contaminants are removed from the gas during the processes. It also appears that the producer gas utilization is easier in respect to handling and transportation. Biomass gasification may be defined as a partial oxidation of biomass at elevated temperature, which converts lignocellulosic materials into a combustible gas. The heating value of the gas is considerably low when compared with natural gas. There are three main sequential steps, which happen in a gasifier, namely drying, pyrolysis and gasification processes. Drying is a process to evaporate the moisture in the material. Then, the gas, vaporized oils including tars and char are produced by the pyrolysis process. Finally, the gasification is a partial oxidation of the remained char and tars, as well as gasses vaporized by the pyrolysis process. The gaseous fuel produced from these processes can be utilized for thermal applications.

Fixed bed reactors can be divided into two main groups i.e. counter-current (updraft) and co-current (downdraft) reactors. However, there are other kinds of reactors hardly found, for example, crosscurrent reactor.

1. Counter-current reactor

For the counter-current or updraft gasifier, the movement of feedstock, which flows down slowly due to gravity and the reactive material, are in the opposite directions. The biomass is fed to the gasifier at the top and it flows through all zones in the gasifier to produce the combustible gas, which exits at the top of the gasifier. The biomass, which descends through the gasifier, is dried by the up-flowing hot producer gas. After that, the volatile gases are separated from the char in the distillation zone. Many reactions, such as carbon conversion, take place in the reduction zone. The combustion of the remaining char occurs in the hearth zone. Finally, at bottom of the gasifier the ash, which is normally completely oxidized, is discharged.

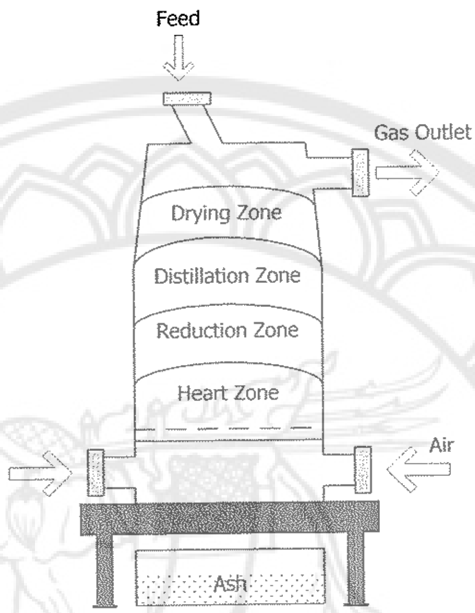

Figure 7 Updraft Gasifier

The outlet temperature of the producer gas is considerably low, which leads to high thermal efficiency of the system, as the direct heat exchange between biomass and hot producer gas recovers the sensible heat from the hot gas. Furthermore, the gas product is suitable for direct combustion, for example, using as a boiler fuel, due to its high heating value. In addition, the biomass of moisture content up to 50% can be used as a fuel for the gasifier. With regard to heat generation, the updraft system has the lowest cost, and there is rather low level of dust content in the producer gas. This is due to the low rate of producer gas filtration effect of the feedstock within the gasifier. On the other hand, it contains very high proportion of tars deemed to be up to 20% of the pyrolysis gas. This can be a problem for the internal deposition in the system. Therefore, for power generation via engine or turbine generator the counter-current reactor system is not economically competitive because there is a need for an extensive tar removal system.

2. Co-current reactor

By the way of contrast to the counter-current reactor, the flow of feedstock and that of the reactive material are in the same direction for the co-current reactor (or down draft gasifier). The biomass is also fed to the gasifier at the top of it. However the reactor material, such as air, is taken into the gasifier at the top or the sides of the reactor, then. The producer gas leaves the gasifier from the bottom.

The biomass descending flows through the gasifier, where it is dried in the drying zone. Then the volatile gasses are decomposed from biomass in the distillation zone. These two zones are generally heated by the radiation and convection produced by hearth zone. Next, the char and the volatile gases are combusted in the hearth zone. Finally, carbon monoxide and hydrogen, which are the major component of the product, are generated in the reduction zone, where the remaining char is also burn.

Generally, there is a constriction to support the biomass bed, which is known as the throat, within the gasifier. For such a reactor, uniform and close size specification, as well as low moisture content of the feedstock is required. So, fine materials, which can obstruct the flow of the air and gases, have to be handled separately to avoid and reduce agglomeration. This problem can be eliminated by the removal of fine material from the biomass. Nonetheless, with regard to open-core downdraft reactors, the gasifiers without throats are designed for fine material gasification to avert the fuel bridging.

The biogas exit temperature is considerably high; hence the thermal efficiency of such a reactor is lower than that of the updraft gasifier. Moreover, the productive gas high dust content but the problem can be resolved by an extension dust-cleaning filter system. Conversely, the gas produced from this kind of reactor constrains low levels of tar.

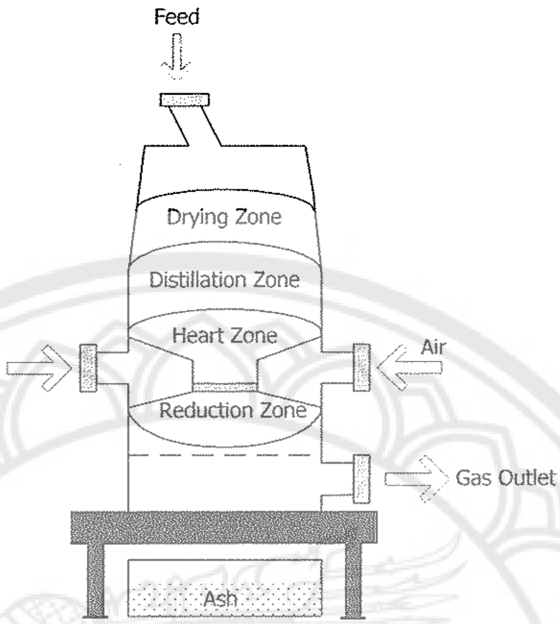

Figure 8 Downdraft Gasifier

3. Gas cleaning system

Producer gas produced from a gasifier contains a number of contaminants, such as sulfur, tars and dust. Typically, the level of sulfur in the gas is very low so sulfur removal equipment is not required. It seems the two main contaminants in producer gas that is needs to be removed are tars and dust. Cyclones and baffle separators, fabric bag filter are examples of the dust cleaning systems. Using this equipment, dust content less than 0.1 mg/Nm^3 (immeasurable amount) was reported. One type of tar and dust removal system is a wet scrubber. This is an effective tar and dust removal system, however the gas produced is not clean enough. Nevertheless, tar and dust content below 50 mg/Nm^3 can be obtained from a good designed system of this type.

There were many researches that involved in an application of solar drying for agricultural product. Detail of some researches will be described as the following.

Wirat Arunluksanadumrong [12] conducted that 2-3 cm long of fuel and 0.44-0.51 kg/minute mass flow rate was appropriate for up-draft gasifier 175 cm height, 65 cm outer diameter. This gasifier can produce more than 28.7 % of carbon monoxide.

S.C. Bhattacharya and N. Shah [13] used producer gas from up-draft gasifier to dry maize by using rice husk and corncob as a fuel. Heating value and fixed carbon of rice husk were about 15.8 MJ/kg and 16.12 %, respectively whereas corncob has 19.7 MJ/kg of heating value and 11.7 % of fixed carbon. There was water cool down at gasifier wall. The producer gas went pass water scrubber. Then passed through risk husk filter in order to reduce high heating and tar. This dryer system can reduce moisture content from 22 % wb to 14 % wb.

Chanakan Asasutjarit et al. [14] studied chilli drying by using energy from producer gas. The drying system consisted of an up-flow gasifier, gas cleaning system, combustion room, heat exchanger, drying chamber and blowers. The combustible gases from producer gas were CO, H_2 and CH_4 with a total heating value of 4.95 kJ/m^3, approximately. 0.6 m^3 volume with 8 trays cabinet dryer was used in the experiment. Drying time and air flow rate were investigated. It was found that at 63°C of drying air temperature with 0.082 kg/s air flow rate could reduce the chilli moisture content from 615.24 %db to be 17.82 %db within 19 hours. The efficiency of combustion room, heat exchanger and dryer were 48.92 %, 7 %, 9.2 % respectively. By using 17.18 kg of chilli total energy consumption was about 33.46 MJ/kg H_2O evaporated. Also, the total product cost was about 54.25 Baht/kg H_2O evaporated.

Rattanachai Pairintra et al. [15] studied and designed a pilot dryer using the combination of solar energy and producer gas for garlic drying. During sunshine, the solar energy was preferably used by passing air through a 2.5 m^2 solar collector which was located on the top of the dryer, while during no sunshine, the producer gas which was generated from charcoal gasifier is preferably used. The appropriate condition of garlic drying from 67 %wb to 60 %db was investigated. The average drying temperature was 55.6 $^{\circ}$C within 14 hours drying time of using producer gas only. On the other hand, the average drying temperature was 45.4 $^{\circ}$C within 15 hours drying time by using the combination of the solar and producer gas energy. The drying air flow rate was 0.17 kg/s in both cases

Beck M. and Ribouni K. [16] determined performance measurements on large-scale solar drying plants. Two projects with large-scale systems with an overall collector area of 140 m^2 and 165 m^2 were monitored. The result showed that collector efficiency was 57% at increase of ambient air temperature of 30-50 ^{o}C. At a solar radiation of 800 W/m^2, the heating power of the solar plants is 70 kW. The effects of a high albedo and ground reflection lead to a solar irradiation higher than 1000 W/m^2. The maximum required temperature is 60^{o}C. The maximum drying temperature was reached over a time interval of 5 hours a day. A normal drying stage at this plant lasts 4 hours in average. Actual additional heat supply was done by a conventional oil fired water heating system that will be replaced by the local district heating system. The air to water heat exchanger has a thermal performance of about 65 kW. The efficiency of the additional heating system is 80%. A grand total of 171 ton of grain, oilseed and maize was dried in 29 days of operating the drying plant. The amount of dried products depends very strongly on weather conditions during harvesting period. The plant was designed for an annual amount of 500 ton of crop.

Sukruedee Nathakaranakule and Sirinuch Jindaraksa [17] studied the parameter for analysis of mango glace. The density, the specific heat, the equilibrium moisture content, the drying rate was determined at different moisture contents and temperatures. The empirical equations were shown to predict the parameter. From the results show that the density was increased linearly when the moisture content decreased. And the specific heat of mango glace depends linearly on its moisture content. From the experiment results at the temperature range of 41, 51 and 68 ^{o}C and relative humidity range of 11.1-87.4 %, it was found that the equilibrium moisture content models could be predict by Chung and Pfost model and Halsey model while Henderson model was suitable to predict the equilibrium moisture content for 10-50 % of relative humidity condition. In addition, for 30-50 % of relative humidity prediction at low temperature, Modified Henderson model could predict equilibrium moisture content accurately. For the drying rate at 40,50,60,70 and 80 °C, the air velocity of 1 and 4 m/s showed that the effect of temperature was significant. It was found that the empirical models were in polynomial equation forms.

Esper and W. Muhlbauer [18] indicated that the reduction of food losses is particularly a problem for small farmers in developing countries who produce more than 80 % of the food. Since the traditional sun drying is a relatively slow process considerable losses can occur. A reduction in the product quality takes place due to insect infestation, enzymatic reactions, microorganism growth and myctoxin development. The technology used in industrialized countries or even at large scale plantation in developing countries for food preservation is neither technically nor economically feasible for smallholders. In contrast, numerous investigations have shown that solar drying can be an effective means of food preservation since the product is completely protected during drying against rain, dust, insects and animals. But still some obstacles have to overcome that solar drying will become a technology with a broad dissemination. Although a lot of research work has been conducted during the last decades, only a small number of appropriate solar dryers which can be used by farmers or small scale industries in developing countries are commercially available. There is still a lack of knowledge how to process fruits, vegetable, fish, etc. in a proper way to ensure a high quality product and to minimize post-harvest losses.

Akwasi Ayensu [19] studied the dehydration of food crops using solar dryer with convective heat flow. The results indicated that based on local weather conditions and thermal process based on psychrometric analysis, a low cost, low temperature and simple to operate solar dryer was constructed to dehydrate farm produce. It took nearly 2 times longer to dehydrate crops in the open air-sun drying as compared to the solar dryer. An empirical drying equation of the form $M(t) = M_0 exp(-kt)$ could describe the dehydration process fairly well; and can be used to model and simulate drying of common tropical farm products.

S. Janjai, Wongpromchai and A.Esper [20] developed a solar dryer named as Silpakorn-Hohenheim type. The dryer consisted of a plastic-covered flat plated collector and a drying tunnel. The dryer could be used to dry 200-300 kg of bananas. It was found that the drying time was 2.5-3 days. The final moisture content was between 30-40 % w.b.

Da-Wen Sun [21] studied the comparison and selection of EMC/ERH isotherm equations for drying and storage of grain and oilseed. It was found that the Modified-Chung-Pfost, Modified-Oswin equation, Strohman-Yoerger equation and Modified-Halsey equation are identified as the most appropriate equations for describing the EMC/ERH sorption isotherms for wheat, shelled corn, rice and rapeseed, respectively. No single equation has the ability to describe accurately the EMC/ERH relationships for all crops over a board range of relative humidity and temperature. The modified-Henderson equation is among the least successful equations for wheat, shelled corn, rice and rapeseed.

O.V. Ekechukwu and B. Norton [22] presented a comprehensive review of the various designs, details of construction and operational principles of the wide variety of practically realized designs of solar-energy drying systems. They also evolved a systematic classification of solar-energy dryers. This classification illustrates clearly how these solar dryer designs can be grouped systematically according to either their operating temperature ranges, heating sources and heating modes, operation modes or structural modes. Two board groups of solar-energy dryers can be identified, viz, passive or natural-circulation solar-energy dryers and active or forced-convection solar-energy dryers. Three sub-groups of these, which differ mainly on their structural arrangement, can also be identified, viz, integral or direct mode solar dryers, distributed or indirect-modes and the mixed-modes. Properly designed forced-convection (active) solar dryers were agreed generally to be more effective and more controllable than the natural-circulation (passive) types, the requirement of electricity or fossil-fuel driven fans and/or the use of auxiliary heating sources, however, renders the former clearly inappropriate for remote rural village farm application in most developing countries and makes both their capital, maintenance and operational cost prohibitive for small scale farming operations. For large-scale applications in rural locations, the "ventilated greenhouse dryer" has the advantage of low cost and simplicity in both on-the-site construction and operation.

Hayati OlGun and Sevim Kose [23] determined that the pre-treated fish samples were dried at 33-36°C with about 1.8 m/s air velocity in 3 days. Results showed that the samples dried very quickly in the first 15 hours of drying then a slow process occurred. The drying process was completed in about 75 hours. It was concluded that fish drying is possible in the North East Black Sea region or other areas with a similar climate by a solar energy system if an additional heater is used. This technique was found to be safe for changeable weathers as well as simple. This system has economical advantages compared to other methods applied alone, and can also be used for other drying applications.

Arun K., P.V.R. Iyer and Tara Chandra Kandpal [24] indicated that a unit cost of thermal energy for biomass gasifier-based institutional cooking systems worked out to Rs 0.37/MJ for a 29 kW_{th} (25000 kcal/h) biomass gasifier system while for a 291 kW_{th} system was Rs 0.23/MJ. Biomass gasifier-based institutional cooking systems were always financially more attractive than corresponding coal based systems and were even better than LPG-based systems for capacities over 58 kW_{th}.

S.Phoungchandang and J.L Woods [25] determined mathematical model of solar drying of banana by using the temperature rise and moisture loss during solar drying. The model demonstrated that banana can be dried to low-moisture contents in humid tropics because the RH at the heated banana surface is substantially below ambient. The laboratory experiment was performed in a heated building giving a relatively low RH. The model indicated that this will not produce results significantly different from those under tropical RH values.

Yahya M. Gallali, Yahya S. and Faiz K. Bananani [26] indected that the mix and indirect modes of drying were more effective than natural drying, since the final moisture contents for grapes were 12.5, 20.05 and 68.45 %, respectively. The figs moisture was reduce to 23.5 % using mixed mode drying and 46.8 % in case of natural drying for the same period. No significant difference was noted in the case of tomatoes, while there was little significant difference between the two drying methods for onions, but the drying was higher for slices than lobes. There was a highly significant difference for percent ash between the solar dried grapes and naturally dried samples (2.95 and 12.1 %, respectively). The temperature inside the dryer was 80.5 ^{o}C, which induce the sugar determination higher than drying outside.

Osman Yaldiz, Can Ertekin and H. Ibrahim Uzun [27] investigated thin layer drying of Sultana grapes. The solar grapes drying process occurred in the falling rate period, starting from the initial moisture content to the final moisture content of 0.16 kg water per kg dry matter. In order to explain the drying behavior of Sultana grapes, eight different thin layer drying models were compared according to their coefficient of determination and reduced chi-square values. The two term drying model could adequately describe the thin layer solar drying behavior of sultana grapes. When the effect of the drying air temperature and velocity on the constants and coefficient of the two-term model were examined, the resulting model gave an r of 0.979 and X^2 of 4.11 x 10^{-3}. This final model described the drying behavior of Sultana grapes with the drying air temperature range of 32.4 to 40.3 ^{o}C and velocity of 0.5 to 1.5 m/s.

Kil Jin Park, Zdenka Vohnikova and Fernando Pedro Reis Brod [28] determined the desorption isotherm of mint leaves at tree temperature. Experimental curves were fitted to three two-parameter equations, three three-parameter equations and one four-parameter equation. All BET, GAB, Oswin and Peleg models could be used to describe the mint desorption isotherm. Experimental data for the drying of mint was obtained at three different temperatures and two different air velocities. The drying process was interpreted through the diffusion model in order to obtain effective diffusivity values, which proved to range from 4.765 x 10^{-13} to 2.945 x 10^{-12} m^2/s. Activation energy was calculated as 82928.5 J/mol assuming an Ar-rhenius-type temperature reliance. The empirical Page model has shown a better fir to the experimental mint drying data as compared to Fick's model, except for the 50^{o}C-1.0 m/s curve.

Wattanapong Rukwichian et al. [29] determined the performance of the vegetable drying system that got energy from solar energy and steam. And also, the financial analysis, advantages and disadvantages of the system were described. The results showed that the efficiency of drying system was between 27.5 – 58.5 % depending on type and quantity of the fresh product. And the final moisture content of product was between 10-15 % whereas the initial moisture content was between 60 - 90 %. It was found that internal rate of return was 57.8 % and the benefit-cost ratio was 1.17. From this study, it has indicated that the system has many advantages. However it also has some disadvantages that should be improved in the aspect of auxiliary heat in order to save more money.

From the literature reviews indicate that the solar drying is one of the good methods that can preserve foods. Moreover, biomass gasifier might be used to supply supplementary source of energy of drying system. This states clearly that an appropriate drying process with dryer system using biomass and solar energy should be investigated.