

Energy- and Emission-Based Performance of an Experimental Tobacco Bulk-Curing Barn

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ABSTRACT

Energy conservation and efficiency of small tobacco curing industry in Northern Thailand was investigated. Traditional, flue-curing barn as well as a modern, bulk-curing, experimental barn were used as case studies. Firewood and lignite were used as fuels. The energy consumption, temperatures and CO, CO₂ and O₂ emissions were monitored during curing process. Performance analysis in terms of energy utilization index, thermal efficiency and emissions for both types of barn was carried out. The results indicated that the existing traditional rural barn consumed more energy and produced more emissions than the modern barn. This was largely due to greater energy loss through walls and ceiling of the barn and poorer combustion in a furnace. A new curing barn with improved energy efficiency and better emissions was demonstrated.

Key words: Energy efficiency, Flue curing, Tobacco curing barn, Emissions

INTRODUCTION

Tobacco is one of the major cash crops and commonly grown in almost all provinces in Northern Thailand. Tobacco grown in Thailand can be divided into two categories: foreign tobacco such as Virginia, Burley and Turkish and native tobacco. Virginia tobacco is by far the most popular, accounting for over 60% of the total market volume. Around 30-60 million tons of dried tobacco are produced each year, earning approximately US\$ 37 million annually (Boonlong et al., 1992). During the past several years, the production is approximately 20 million tons a year. The products are either sold to the Thailand Tobacco Monopoly or exported. About 50% of the total tobacco output is produced by about 50,000 small individual households while the other half is produced by large commercial curers and their associates. Typically, individual household utilizes from 5 – 10 rai (one rai = 1,600 m²) of land for growing tobacco.

Traditionally, Virginia tobacco crop is flue-cured by individual farmer in the field. Traditional method is based on natural convection where fresh tobacco is hung loosely inside a curing barn and heat is provided from a hot flue pipe connected to a furnace. Its thermal efficiency was reported to be very low, being around 10 – 15% or even less (Boonlong et al., 1987, 1994, Siddiqui and Rajabu, 1996, Siddiqui, 2001). This highly energy-intensive process consumes enormous quantities of firewood with serious ecological implications.

It was estimated that more than 200,000 tons of firewood was used in this industry in Thailand each year, contributing significantly to the severe deforestation problem (Boonlong et al., 1994). In the past, energy conservation and ecological consideration in tobacco-curing practice have not been emphasized sufficiently, or in some cases, neglected. In view of the adverse environmental effects of traditional tobacco-curing practice, there is an urgent necessity to improve efficiency of the curing process by improvements in the barn structure, the furnace and flue-pipe system design. With respect to this connection, a continual research effort in the Department of Mechanical Engineering, Chiang Mai University has been made over the recent decade to introduce a number of energy- conservation measures to the tobacco-curing industry in Northern Thailand (Boonlong et al., 1987, 1994; Tantakitti and Thavornun, 1998, 2003). The method of bulk curing was introduced which is based on forced convection by the use of an appropriate fan to force hot air through densely-packed leaves. Thermal efficiency of up to 45% can be achieved by this new system. Demonstration of a new multi-room commercial bulk-curing system with central hot-water heating has been successful. To date, over 100 units have been installed by large commercial curers (Tantakitti and Thavornun, 2000, 2003). However, initial investment for the new system is exceedingly high, preventing individual farmers to adopt and so only large commercial curers use it. It is apparent that investigation into a cheaper, yet effective system to reduce energy consumption in traditional tobacco-curing practice for small individual farmers is urgently needed.

In this paper, a modern tobacco-curing barn is introduced, based on bulk- curing principle. Experimental data obtained from the modern curing barn are presented and analysis of its thermal performance and emissions are conducted and compared with those from a traditional barn.

TOBACCO-CURING PRACTICE IN NORTHERN THAILAND

Tobacco is normally grown around late August and harvested for their leaves between November to April. Immediately after harvesting, the leaves should be cured. Curing of Virginia tobacco is an energy-intensive process with precise controlled conditions of temperature and humidity. In general, tobacco curing is classified into four steps, involving a coloring process, a color-fixing process, a leaf drying process and a stem drying process. Typical curing processes are shown schematically in Figure 1. During the first two steps, heat applied to the tobacco leaves produces chemical and enzymatic changes which condition and fix the color of the tobacco leaves. These processes start around 35°C at a relative humidity of 85% and gradually increase to between 40 – 43°C. The coloring and color-fixing steps last from 36 – 72 hours when all the leaves' color is considered to be uniformly brownish-yellow. Afterwards, the temperature is gradually raised to accelerate drying of the leaves. The drying processes are usually conducted at a vicinity of 70°C with diminishing humidity and end when the midrib or stem of the leaf is dried. A softening process is performed at the end of the cure in which golden-brown leaves are obtained. The curing period varies with local conditions, positions of leaves in a curing barn and quality and ripeness of the fresh tobacco leaves. One curing cycle lasts approximately 120 – 150 hours.

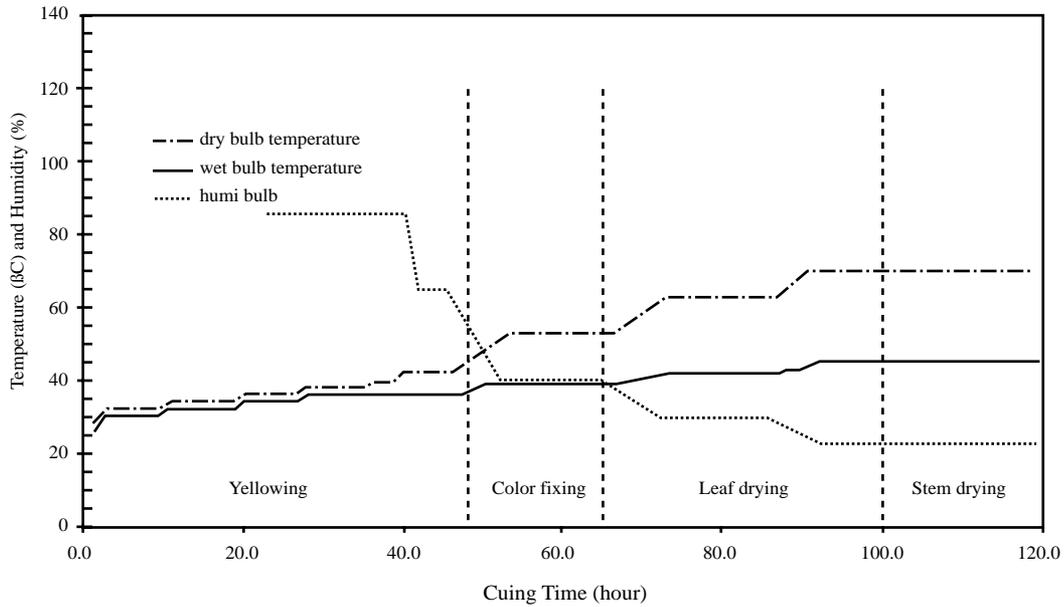


Figure 1. Typical process of tobacco curing.

Thailand’s flue-curing tobacco barns are mostly of traditional type with no standard dimensions for the size of a barn. The most commonly-used barns have floor areas of 6 m x 6 m, shown in Figure 2, with a loading capacity of about 3,000 – 6,000 kg of fresh tobacco leaves per curing batch, depending upon sequence of leaf picking. The barns usually have gable roofs of galvanized iron sheets. The roof height ranges between 6 – 9 m. The walls are about 100 mm thick and made of concrete or baked bricks. There is no extra insulators installed on the roofs or the walls of the traditional barn. Air vents are provided in the walls near the floor and the roof to control humidity and induce fresh air flow. One or two open-burning furnaces are used. The furnace is usually made of bricks and is partly protruding inside the barn. The furnace has varying dimensions but is normally small in overall combustion volume. The flue gases are circulated through a long, 300 mm in diameter flue pipe, made of galvanized iron sheet and laid near the floor and out to stack above the barn.

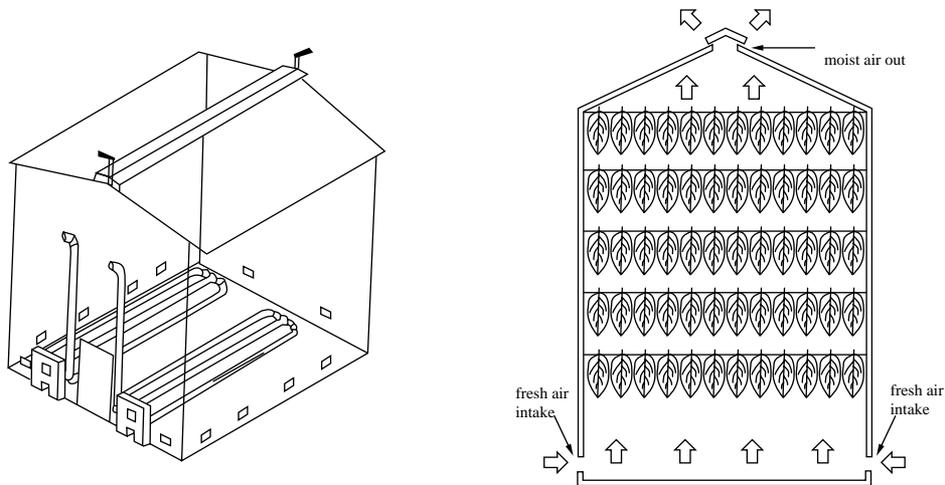


Figure 2. Structure and airflow inside a typical traditional flue curing barn.

METHODOLOGY

A modern loose-leaf experimental barn was constructed as shown in Figure 3. It is a forced-draft bulk curing system, similar to that in a commercial curing barn used by large commercial curers. The prototype barn has a reinforced concrete floor area of 3.6 m x 10.2 m and its height is 3.3 m at one end, sloping up to 4.0 m at the other with two tiers for loading the leaves. The barn has a capacity of about 3,000 – 6,000 kg fresh tobacco leaves. Air plenum above the loading floors is tightly insulated. The barn has gable roofs of galvanized iron sheets with 50 mm-thick fiber glass insulator attached to them. The walls are made of 75 mm-thick concrete bricks and covered with acrylic paint in the inner wall to minimize moisture absorption. No insulation on the walls was implemented because they were expensive. The curing section is separated by an iron-sheet partition from the gas-to-air heat exchange section where a 2.0 kW motor-driven axial fan, a staggered tube-type heat exchanger and a furnace are accommodated. This furnace-flue gas system is a novel feature for this type of tobacco barn. Hot air circulation is through the openings at the top and the bottom of the partition. Fresh air intake is located just above the fan while there is an opening at the side of the barn to allow exhaust air out. The furnace, made of firebrick, was built partly inside the heat exchange section to reduce heat loss to the surrounding air outside. Primary air vent is located at the front door of the furnace via an adjustable aperture. A grate was provided to collect ash with an access through the front at the bottom. The furnace was designed in such a way that (i) it has large volume to ensure a sufficient gas residence time of at least two seconds for combustion, (ii) it was fully insulated to ensure higher temperature inside the furnace due to less heat loss, (iii) it enables better mixing of fuel and air.

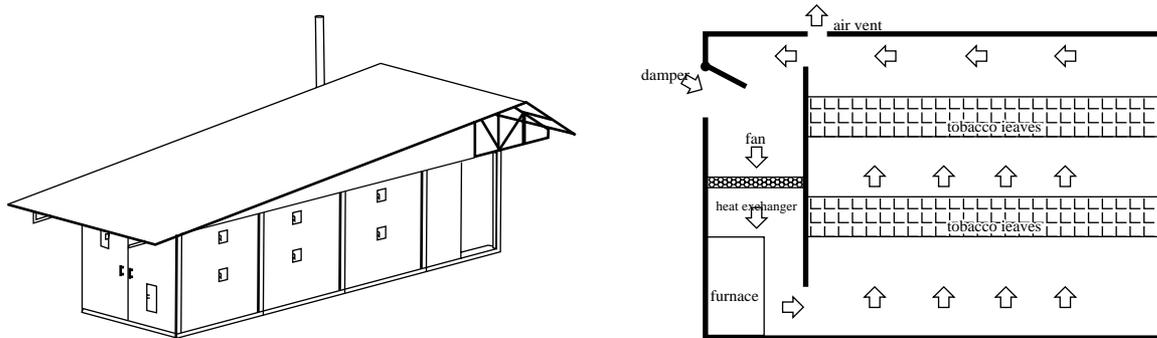


Figure 3. Structure and airflow inside a modern bulk curing barn.

In all, seven batches of actual curing were conducted between December 2003 – March 2004. Over 28,000 kg of fresh leaves were cured, yielding about 4,000 kg dried leaves. Only data from four batches were used because of their completeness. Type k thermocouples were used to measure temperature of the flue gas, the barn wall temperatures and furnace door and wall temperatures as well as ambient temperature. Dry- and wet-bulb thermometers were used to measure temperature and humidity inside the barn. CO, CO₂ and O₂ in the flue gas were measured, using a Testo 350XL flue gas analyzer. Circulated curing air was measured, using a sensitive anemometer. Pressure drop across the fan, the heat exchanger and in the curing section were monitored, using manometers. All measurements were taken at intervals

of about 3 – 6 hours throughout the curing cycle. Firewood with average weight of 2 – 5 kg was used with crushed lignite coal. Amount of wood and lignite used was noted. Previously-obtained data from a number of flue-curing experiments were used to compare with this study.

The internal heat transfer coefficient inside a tube was calculated, using an empirical formula in Incropera and DeWitt (2002),

$$Nu_d = 0.027 Re_d^{4/5} Pr^{1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14} \tag{1}$$

where Nu is the average Nusselt number; Re_d , the Reynolds number based on pipe diameter; d , Pr , the Prandtl number; L , the length of the pipe; and μ , the viscosity at the mean bulk gas temperature, while μ_w is evaluated at the wall temperature. Equation (1) is valid only for $Re_d > 10000$, $L/d > 10$ and $0.7 < Pr < 16700$.

The external heat transfer coefficient was calculated, using the relation for a tube bank in cross flow in staggered arrangement given in Incropera and DeWitt (2002),

$$Nu_d = 0.294 \left(\frac{S_T}{S_L} \right)^{0.2} Re_d^{0.6} Pr^{0.36} \left(\frac{Pr}{Pr_s} \right)^{0.25} \tag{2}$$

where S_T and S_L are the transverse and longitudinal pitches, respectively; and Pr_s is the Prandtl number evaluated at wall temperature while other properties are evaluated at the mean bulk gas temperature. Equation (2) is valid only for $Re_d > 1000$ and $0.7 < Pr < 500$.

These coefficients were used to calculate the overall heat transfer coefficient, U , which was subsequently used to calculate heat transfer from the heat exchanger to the curing air. Conductive heat losses from the walls of the barn were also calculated. Thermal or fuel conversion efficiency is defined as a ratio between heat used to remove water content from the leaves to heat input from fuels. Energy utilization index is defined as equivalent energy used in terms of fuel mass divided by mass of dried tobacco leaves after curing. Labor requirement for curing was also monitored.

RESULTS

The flue gas temperatures and barn space temperatures are shown and compared in Figure 4. It can be seen that heat requirement increases as curing process proceeds. Heat lost to the surroundings through the walls and the front side of the furnace and heat lost to the atmosphere in the form of hot flue gas escaping through the chimney during the running period of the barn were calculated. Flue gas loss was small as a result of effective heat exchange between the circulated air and the hot flue gas. Heat lost through the barn's walls was around 10% and it was in similar order of magnitude to that from the traditional barn. This was reasonable because similar wall material was used and temperature of curing air was identical. It is noteworthy that wall insulation was not implemented due to economic reason. With furnace partly inside the barn, heat loss from the furnace to the surroundings was relatively small, unlike the traditional barn's furnace. Better results could be expected if the furnace was completely inside the heat exchange section.

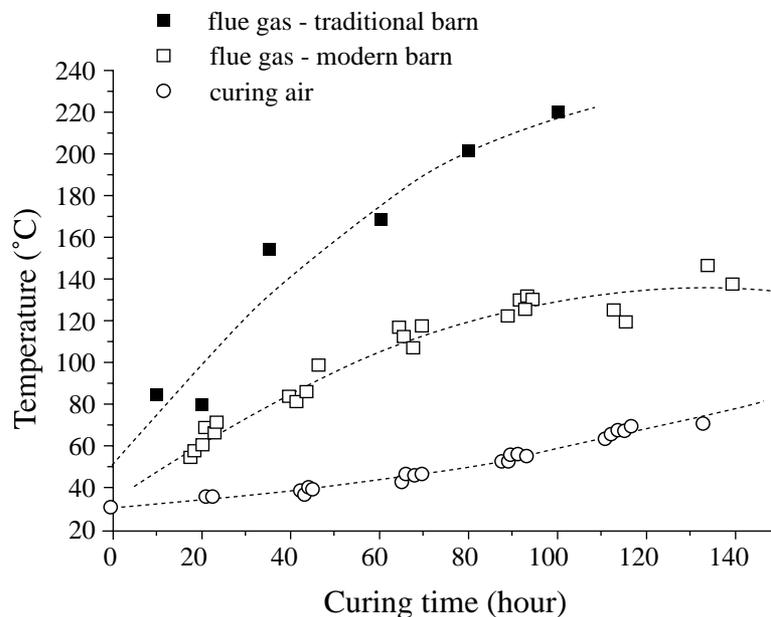


Figure 4. Average air and flue gas temperatures in modern and traditional barns.

Percentages of CO, CO₂ and O₂ emissions in the flue gas, emitted from the chimney for both types of curing barn are plotted in Figure 5. Generally, CO was high in the early stage of curing but exhibited a gradual drop towards the end of the curing process. The reason may be that during the yellowing and color-fixing stages, heat requirement was low, just enough to maintain 35 – 43°C in the barn. For a fixed volume of the furnace at low heating, hence fuel requirement, it was likely that inadequate combustion air and its distribution or low combustion temperature due to radiation loss would occur, leading to incomplete oxidation (Tillman, 1991). Whereas, during leaf and stem drying stages, heat requirement was high, less CO emission was observed. The average value of CO for the modern barns was around 700 ppm by volume. Comparison of emission profiles indicated that CO from the modern barn was, on average, a factor of magnitude lower than from the traditional barn even though O₂ measurements from both barns were in similar range. This was a direct result of a better furnace design in which combustion time, temperature and gas turbulence in the modern barn's furnace were superior than that of the traditional barn. It should be noted that the emission level of CO was observed to increase when fresh fuelwood or lignite was introduced into the furnace. This was one of the reasons why fluctuation in emission value was observed. CO₂ and O₂ exhibited moderate variation with time and were found to be in the range between 1 – 7% and 11 – 19% by volume, respectively, for both barns.

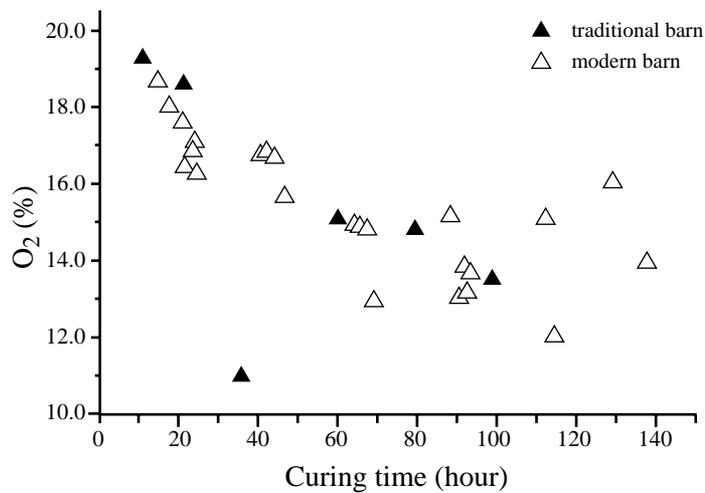
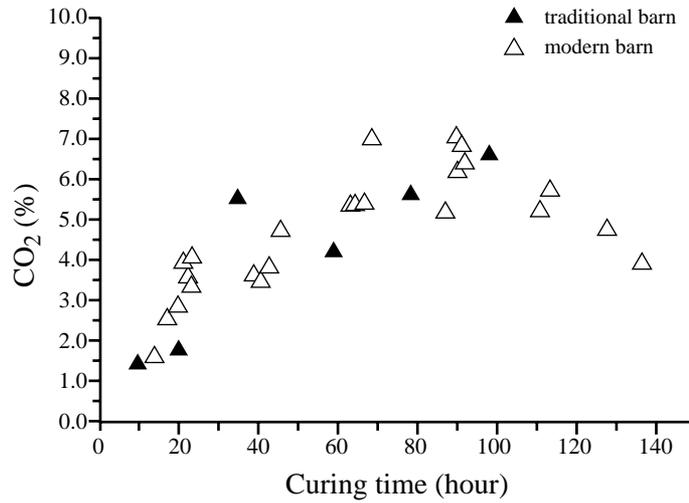
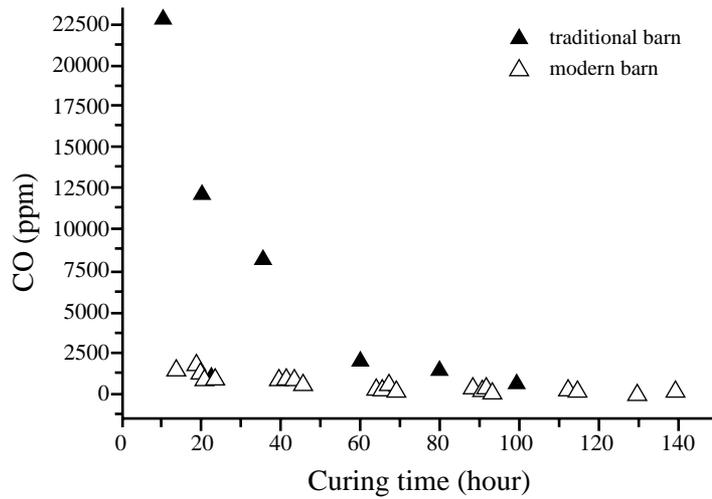


Figure 5. CO, CO₂ and O₂ emissions in the flue gases during typical curing periods.

Experimental tobacco curing trials carried out in the instrumented research barn showed that the fuel used per kilogram of tobacco leaf cured was lower as compared to a traditional flue-curing barn. With an average fresh leaf to dried leaf ratio of 7.5, energy utilization index was found to be 45 MJ per kg dried leaves or 2.53 kg lignite per kg cured leaves for the modern barn. Fuels as well as electricity were included. With reference to a traditional barn, typical values would be 197 MJ per kg dried leaves or 10.7 kg lignite per kg cured leaves (Tantakitti and Thavornnun, 2003). The thermal efficiency was improved from 10 – 15% for the traditional barn to about 30 – 40% for the modern barn.

DISCUSSION AND CONCLUSION

Tobacco curing is one of the biggest consumer of firewood and lignite coal among the agro-industrial processes in Northern Thailand. Experimental results from previous studies underline the urgent need to improve traditional tobacco-curing practice. This can be done via adoption of forced-draft bulk curing system, better insulation installation and modification of furnace – flue system design. The modern bulk-curing system in this study proved to have advantages over the traditional flue curing barns in energy saving and reduced labor requirement. With insulation, heat losses through the roof were virtually eliminated, wall loss was reduced. Dasgupta et al., (1991) reported that a well-insulated system resulted in a much narrower vertical temperature spreads inside the barn, and the day-night cyclic variations, as well as inversion of temperatures, were either totally suppressed or greatly reduced. It is suggested that the more stable temperature profiles contributed to fuel economy and also to the quality of the cured leaf. In this experimental study, a significant improvement in energy efficiency and marked reduction in pollution emitted were demonstrated with a better furnace – flue system. Even though data reported here reflect general overall results well, further investigation is still required. There exists variation and scattering of data, mainly because of difficulty in controlling various parameters during curing, variation of local conditions and practices. Therefore, it was felt necessary to obtain statistically-significant and reliable results derived from greater amount of data collection and refinement of experimentation via further research ongoing.

On the basis of experimental results from this study in comparison with those from existing traditional barns, it has been established that, on average, a reduction of 50% of lignite per one batch was achieved. The current consumption of lignite and firewood for tobacco curing in Thailand is estimated at 200,000 tons per year where half of this is used by small individual households. If all small holders' curing is done with this modern system, this means that an equivalent of approximately 50,000 tons of lignite will be saved and 4,000 tons less SO₂ and 70,000 tons less CO₂ will be emitted to the atmosphere annually. It should be pointed out here that curing was undertaken by an experienced farmer who was familiar with the traditional system. With some training and supervision, he will be able to operate the modern barn satisfactorily well in a relatively short period of time. With reference to the authors' limited discussions with several individual farmers, there is a very promising prospect that this system will be widely accepted. Adoption of this new system in place of old traditional barns should therefore be encouraged. From a preliminary cost estimate, it is financially viable for potential individual curer to invest in the system. Nonetheless,

governmental incentives in terms of low-interest loans may be made available to interested farmers to help speed up this development.

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REFERENCES

- Boonlong, P., A. Hirun, P. Rerkkriangkrai, T. Siratanapanta, N. Sitthipong, T. Sucharitkul, and P. Terdtoon. 1987. Energy conservation in tobacco curing for Northern Thailand. A Final Report submitted to ASEAN Working Group on Non-Conventional Energy Research and ASEAN-Australia Energy Cooperation Programme Phase I. Project no. T2,EC15(T)-Tobacco Curing, January 1987. 136 pages.
- Boonlong, P., C. Tantakitti, P. Ingsuwan, T. Sucharitkul, N. Sitthipong, W. Kiatpakdee, A. Promwangkwa, and P. Rerkkriangkrai. 1992. Energy conservation in tobacco curing in Northern Thailand. p.21-23. In Proceedings of the 3rd ASEAN Science and Technology Week on Non-Conventional Energy, September 1992, Singapore.
- Boonlong, P., C. Tantakitti, P. Ingsuwan, T. Sucharitkul, N. Sitthipong, W. Kiatpakdee, A. Promwangkwa, and P. Rerkkriangkrai. 1994. Energy conservation in tobacco curing. A Final Report submitted to ASEAN Working Group on Non-Conventional Energy Research and ASEAN-Australia Energy Cooperation Programme Phase II. Project no. ECI-6, February 1994. 36 pages.
- Dasgupta, D.J., T. D. Prasada Rao, P. S. R. V. S. Vithal, and P. C. Kapur. 1991. Flue curing of Virginia tobacco by a tube-in-basket burner using rice husk as fuel and barn insulation, Resources, Conservation and Recycling 5(1): 47-60.
- Incropera, F.P., and D.P. DeWitt. 2002. Introduction to heat transfer. John Wiley & Sons, New York.
- Siddiqui, K.M. 2001. Analysis of a Malakisi barn used for tobacco curing in East and Southern Africa. Energy Conversion and Management 42: 483-490.
- Siddiqui, K.M., and H. Rajabu. 1996. Energy efficiency in current tobacco-curing practice in Tanzania and its consequences. Energy 21(2): 141-145.
- Tantakitti, C., and S. Thavornun. 1998. Energy conservation in tobacco curing. A Final Report submitted to the National Energy Policy Office. Project no. 0239-01-02 Phase I., April 1998. 184 pages. (in Thai).
- Tantakitti, C., and S. Thavornun. 2000. Energy conservation in tobacco curing. Asian J. Energy & Environment 1(3): 213-222.
- Tantakitti, C., and S. Thavornun. 2003. Energy conservation in tobacco curing. A Final Report submitted to the Energy Policy and Planning Office, Ministry of Energy. Project no. 01-008-41-02 Phase II., April 2003. 150 pages. (in Thai).
- Tillman, D.A. 1991. The combustion of solid fuels and wastes. Academic Press, San Diego.