SOME EXPERIENCE IN THE TESTINGS OF A HEAT PUMP AIR DRIER AS APPLIED TO RUBBER SMOKING

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SUMMARY

Previous study found that rubber smoking process can be accelerated by employing dry inlet air to the system. A heat pump air drier (HPAD) assembled from air conditioner parts was used to supply dry air to the rubber smoking furnace. Two sets of experiments were conducted with different loading densities (kg rubber/m^3 room), air flow rates and relative humidities. It was obvious in one experiment that the smoking time was shortened. HPAD had little effect on the other experiment and explanation was given based on insufficint air flow and relatively high loading density, Comparison of results with conventional operation showed that the two HPAD - assisted smokings actually accelerated the smoking process as they resulted in higher water removing rate from the rubber sheets, but the HPAD did not help saving firewood as the specific firewood consumption was not changed.

KEY WORDS Heat pumps Driers Rubber smokings

INTRODUCTION

Thailand is one of major natural rubber producing countries. As 80% of the rubber production is ribbed smoked sheet (RSS), Thailand becomes the word largest RSS rubber producer and exporter (Reutaitananond, 1991). In 1989 Thailand exported 920 x 10^3 tons of RSS compared to 278 $\times$ 10^3 tons and 152 x10^3 tons for Malaysia and Indonesia, respectively. During 1980-1989 Thailand increased her RSS export by 168% (Reutaitananond, 1991).

RSS is one of the solid forms of rubber products. Ribbed unsmoked rubber sheets are produced from chemically-treated coagulated latex, normally by small holders. Rubber smoking factories acquire the unsmoked rubber through local dealers to be processed in smoking rooms. The smoking room is just a rectangular room constructed from brick having wood furnace at the back. Hot gas and smoke obtained from wood burning are conveyed into the room to dry and cure the rubber sheet. Drying rubber sheets at 65-70°C until obtaining a moisture of 0.3-0.4% will result in transparent sheets known as cured rubber sheets. Smoke impeded in the rubber acts as a disinfectant which render the rubber less liable to mould attack. Since smoke generated from wood burning is essential to the proces, the rubber smoking industry cannot adopt other kinds of fuel and is a major firewood consumer. Rubber trees cut down from rubber replanting plantation are the only source of the firewood for many local industries including the rubber smoking.

A research project aiming to reduce firewood consumption by the rubber smoking industry was formulated in 1991. Monitoring of rubber smoking process have shown that energy saving measure, although economically feasible, does not draw interest from the factory owners (Prasertsan et al., 1992) because firewood contributes only 1-2% to the production cost. The smoking process can possibly be accelerated by employing dry firewood and dry inlet air (Prasertsan et al., 1991, 1993). Firewood supplied to the factories is usually green (newly cut) wood (Prasertsan et al., 1992).

Dry firewood can be obtained by leaving the stock pile of firewood outdoor for a cartain period. Natural solar drying is usually sufficient. But in the rainy season keeping the stock pile undershed is required and may not be cost effective for such indoor storage since substantial investment is needed for a roof-covering space.

Moisture of inlet air was found to have an important role in rubber curing time (Prasertsan and Kirirat, 1993). Laboratory -scale experiment revealed that the lower the relative humidity the rubber was exposed to, the shorter was the curing time. If the ambient relative humidity is 40% (before heating up to 65-70°C to cure the rubber) the curing time is only 60% of that needed for 80% RH. Smoking a batch of about 45 tons of rubber takes only 5 days in dry season and can be 9 days in rainy season which eventually indicates the adverse effect of moisture in ambient air. Monitoring of the smoking process (Prasertsan et al., 1992) showed that 2.0 tons out of 4.2 tons of moisture in the exhaust air (from smoking room) were the moisture admitted by the furnace inlet air. Since nearly half of the water in the process comes from the inlet air humidity, shorter processing time could possibly be achieved by dehumidification of the inlet air. Research and development for a viable air drier is necessary then.

Many air dehumidification methods were examined. Wet air can be treated chemically with water absorbent substances such as silica gel and lithium chloride. Preliminary study on water absorption capability of granular silica gel found that the gel could absorb water up to 27% of its own weight. Thus, substantial amount of gel is required if the gel is used in an air drier apparatus. Furthermore, heat is needed for the gel regeneration. The commercially available air dehumidifying apparatus appears in a form of rotary sorption wheel, which is traversed by two air streams separated by seal. The part of the wheel which is exposed to process air absorbs moisture from the air while the area exposed to reactivation air (hot air) releases the moisture from the gel. More importantly, the unit cost is about 500,000 Bahts (U$ 20,000) (1992 price) which is unacceptably high (Tirasarnvong, 1993). Problems in long-term maintenance and poor performance due to repeated regenerations and deposit of particulate on the gel are other factors that make the silica gel-based apparatus very doubtful and not so attractive. Lithium chloride is an interesting substance as it can absorb water up to three times of its own weight (Perry and Green, 1984). But the price of the chemical is very high and problems similar to those of silica gel still exist.

Limitation of the chemical method has led to an idea that applies air conditioning principle; resulting in an apparatus called "heat pump air drier" -HPAD. The HPAD is an equipment that adopts (with modification) air conditioning cycle. The cycle consists of cooling, dehumidifying and heat recovering processes.

HEAT PUMP AIR DRIER (HPAD)

Principle of air conditioning cycle can be employed to dehumidify the air by cooling the air to a temperature that the predetermined

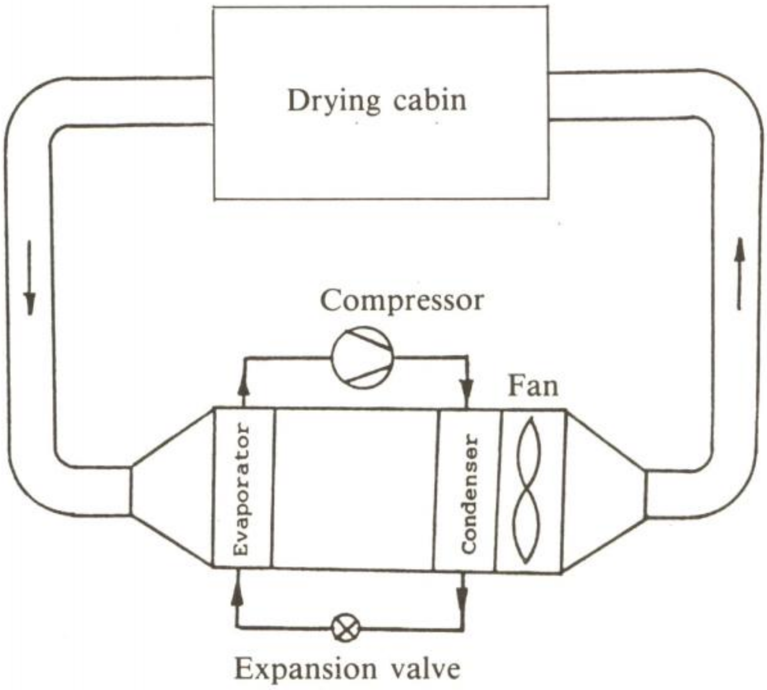


Figure 1. Closed cycle heat pump air drier.

amount of water vapor in the air is condensed. The cooled air passes through the condenser to recover heat. This kind of air drier is sometimes known as heat pump air drier because, due to its main application in close -cycle drying process, it recovers heat and as a consequence dehumidifies the air as shown in Figure 1. The close-cycle system is very efficient because it can extract more water from the incoming hot and humid air (Moser and Schnitzer, 1985).

Close-cycle HPAD cannot be adopted to the rubber smoking room because of suspended particle in the smoke will deposit on the components and reduce heat transfer effectiveness. Fin damaged by corrosive vapor is another undesirable consequence. Therefore, an air drier implemented in this project was limited to an open-cycle type.

Air at ambient condition (typically 32-35°C and 70-90% RH) is sucked through a series of evaporator, compressor and condenser. As the air passing through the evaporator, its temperature is reduced below dew point causing condensation. Air leaving the evaporator is at low-temperature saturation condition (100% RH but low moisture ratio). Its temperature is raised by recovering heat from the condenser. The air leaving the system is, therefore, warm and dry (low RH and low moisture ratio).

Research works on heat pump applications in ASEAN countries, especially Indonesia (Suwono 1992) and Singapore (Chou et al. 1994) are very active. Suwono (1992) developed a heat-pump assisted dryer for the air-dried rubber sheets (drying without smoke). The capacity of the dryer was 2 tons which was substantially small in comparison to the smoking rooms in Thailand. Surprisingly, hot air was obtained from the condenser only without the evaporator dehumidification. Chou et al. (1994) presented a mathematical model of a heat-pump and by introducing parameter called contact factor, a performance chart to guide the selection of the heat-pump dryer components was proposed.

Young et al. (1992) showed that while this basic system works in principle, its operation in practice can be far from effective or efficient. If, for example in the close cycle (Figure 1), the air is emerging from the drier at a temperature of around 50°C and a relative humidity of 50%, it will reach its dew point when cooled to about 37°C. If 20 kJ per kg dry air is removed from the air stream, final temperature would be 36°C, and only 2 grams of water per kg of dry air is removed. Most of the energy withdrawn from the air has been spent in removing the sensible heat from the air stream, and is wasted.

Young demonstrated further that the heat pump air drier can significantly extract moisture if a bypass passage is provided. The drier in Young's report was installed to a drying cabin. A certain portion of warm and humid air exhausted from the cabin was passing through the evaporator. The rest was bypassed and mixed with the cooled air behind the evaporator. Because of low volume flow rate through the evaporator, the after -evaporator air was at very low temperature. Consequently, substantial amount of water was extracted from the air. The mixture behind the evaporator was at lower humidity compared to the process without the bypass. Using the previous example, if 50% of the air is bypassed around the evaporator, the air passing through the evaporator will be cooled to 33°C, removing about 4.5 grams of water per kg of total dry air. Over twice dehumidification effect is achieved for the same rate of energy removal.

MATERIALS AND METHODS

The research and development of the HPAD -assisted rubber smoking consisted of 2 phases :-laboratory-scale HPAD testing and field trial test of a full-scale HPAD. In the laboratory scale experiment a one-ton (cooling capacity) window type air conditioning unit was modified and used for the study. A covering hood coupled with a bypass duct and butterfly valves was used to enclose the unit and form the control volume of the experiment. Air flow rate was measured by sets of pitot tube. Humidity at various locations were determined by wet bulb and dry bulb temperature technique. Twenty one experiments were conducted with percentage of bypass varying from 20 to 50.

A full scale HPAD was designed for field trial test. Details of design, construction and preliminary test are given in Figure 2 and

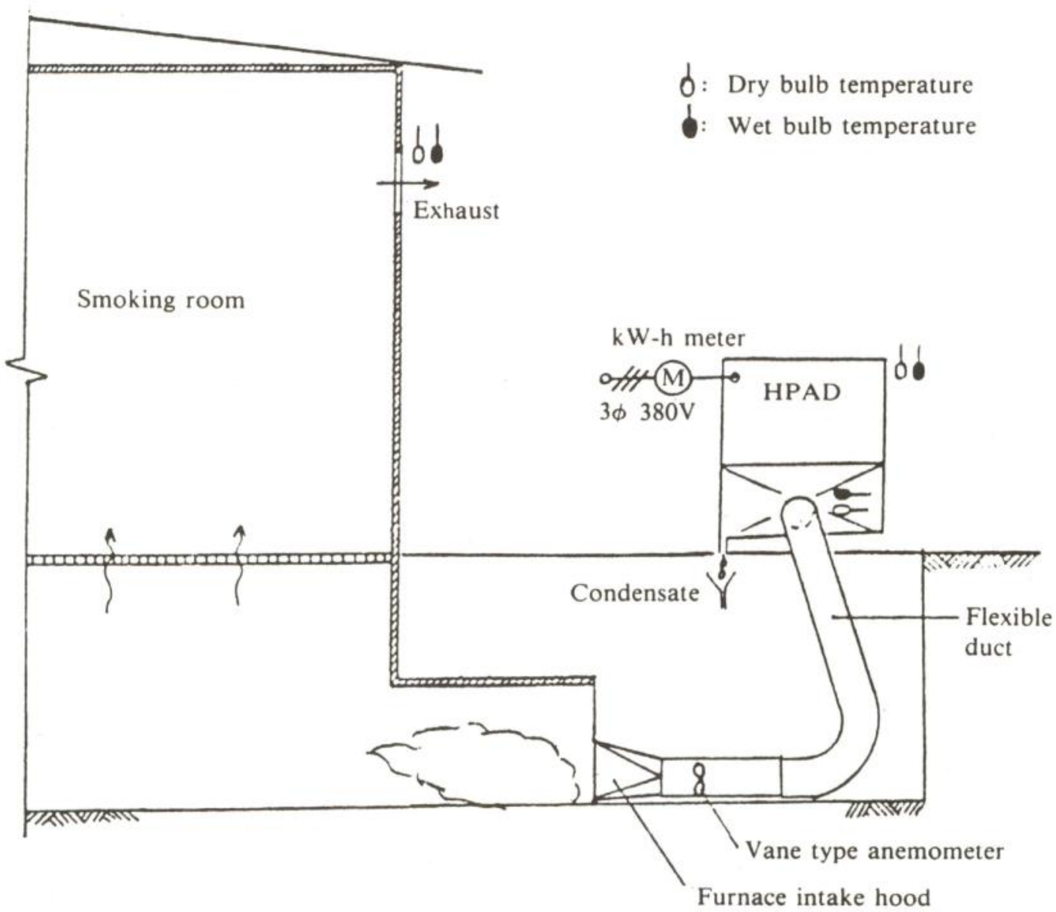


Figure 2. HPAD-assisted rubber smoking setup.

the Appendix. In the full scale field test the unit was installed at the rear of the smoking room near the furnace intake. A flexible duct made from canvas was used to connect the HPAD outlet and the furnace intake hood. A kW-h meter was equipped to the HPAD to record electrical energy consumption. Type-K thermocouple was used to monitor temperatures and wet bulb temperature at the inlet and outlet of the HPAD and the exhaust from the smoking room. Temperature, air flow rate, amount of condensate and firewood consumption were recorded. Air velocity in the duct and hence the flow rate was determined by a vane type anemometer. There were two smokings with different flow rates conducted with the aid of the HPAD.

RESULTS AND DISCUSSION

Experimentation with Laboratory-Scale HPAD

Preliminary observation found that the test with such arrangement is not appropriate for endurance run because the amount of air flowing through the condenser is limited to the amount that flows through the evaporator. In a conventional air conditioning unit the air stream passing through the condenser is at a much higher flow rate in comparison to that of the evaporator. In this experiment although the air entered the condenser at low temperature, the insufficient flow caused a relatively high temperature in the condenser. It was found that the amount of condensation varied insignificantly with the amount of bypass. Average mass of condensation of 50% (5 tests), 40% (8 tests), 30% (5 tests) and 20% (3 tests) bypasses were 0.98 kg/h, 1.03 kg/h, 1.04 kg/h, and 1.16 kg/h, respectively. The difference in condensation might be the effect of the difference in the inlet humidities (the 21 tests were run on different days and time). It is obvious that the bypass technique does not effectively dehumidify the air if it is used for inlet air at room temperature. However, the bypass technique was reported working well at high inlet temperature (50-55°C) (Young et al., 1992). This can be explained by the phenomenon that the absolute humidity of air at a certain relative humidity varies nonlinearly with temperature as appeared in the psychrometric chart. For example of saturated air, reducing the temperature from 50°C to 45°C will extract 0.020 gram of water per kilogram of dry air while the corresponding figure if the air is cooled from 30°C to 25°C is only 0.0065 gram.

Field Trial Tests of Full-Scale HPAD

Results of the field trial tests are tabulated in Table 1. Humidity ratios of air entering the HPAD, entering the furnace and leaving the room of the high and low flow rate tests are presented in Figure 3. Unlike humidity ratios across the HPAD, the exhaust humidity ratio exhibited substantial fluctuation. Ambient humidity ratios of the two tests are about the same figure of 0.02 kg/kg dry air. The lower the air flow rate was, the lower humidity ratio could be obtained from the HPAD.

Practically, the furnace operator, based on his experience, is the one who estimates the smoking time. It was estimated that in normal operation Test 1 and Test 2 should take approximately 120 hours and 155 hours to finish the process, respectively. The application of the HPAD resulted in smoking time of 86 hours and 142 hours for Test 1 and 2, respectively. This implies that at least a significant reduction in the processing time was achieved in Test 1. However, it is not clear that Test 2 processing time was affected by the application of the HPAD. It seems that the HPAD in test 2 did not effectively decrease the smoking time. This could be the result of very high loading density in Test 2 (82.5 kg/m^3 compared to 68.5 kg/m^3 for Test 1). In addition, the rubber sheets in Test 2 contained more water (3.81%) in comparison with Test 1 (2.91%) while the air flow rate for Test 2 (412 m^3/h) was only half of that for Test 1 (881 m^3/h). Drier air of Test 2 was obtained with the expense of lower air flow rate. Although only 16% of water in the exhaust came from the inlet air (Test 2), the flow rate was probably too low to affect the smoking time. This conclusion seems contradictory to previous experiment reported by Prasertsan and Kirirat (1993) which showed that the volume flow rate of air had unnoticeable effect on the curing time. Prasertsan and Kirirat cured rubber sheets in a smoke-free environmentally

Table 1 Results of HPAD-Assisted Smoking

Parameters	Test 1	Test 2
Weight of unsmoked rubber (kg)	39,488	47,555
Weight of smoked rubber (kg)	38,338	45,744
Loading density (kg/m^3, wet basis)	68.5	82.5
% weight loss (moisture, wet basis)	2.91	3.81
% moisture estimated by factory*	2.90	3.90
Smoking time (h)	86	142
Air flow rate (m^3/h)	881	412
Condensate from HPAD (kg)	514.15	725.25
Rate of condensation (kg/h)	5.91	5.07
Humidity ratio of (average value)		
- air entering HPAD	0.0194	0.0194
- air leaving HPAD	0.0133	0.0082
- exhaust from smoking room	0.0410	0.0360
Water inherent in air entering HPAD (kg)	1646	1270
Water inherent in air entering furnace (kg)	1129 (36%)$^+$	537 (16%)$^+$
Water emitted from firewood** (kg)	843 (27%)	1013 (30%)
Water extracted from rubber@ (kg)	1150 (37%)	1811 (54%)
Water consisted in exhaust^{++} (kg)	3122 (100%)	3361 (100%)
Firewood consumption (kg)	2842.3	3413.5
Electrical energy consumption (kWh)	363	588
Specific firewood consumption (kg wood/kg rub)	0.074	0.075
Specific electrical energy consumption (kWh/kg)	0.009	0.013

* *Rubber sheets were visually sorted according to thickness and moisture by an experienced personnel so that the processing time of every sheets in the room was the same (in order to prevent unnecessarily prolonged smoking of some sheets).*

\+ *Figures in bracket represent percentage with respect to water in exhaust*

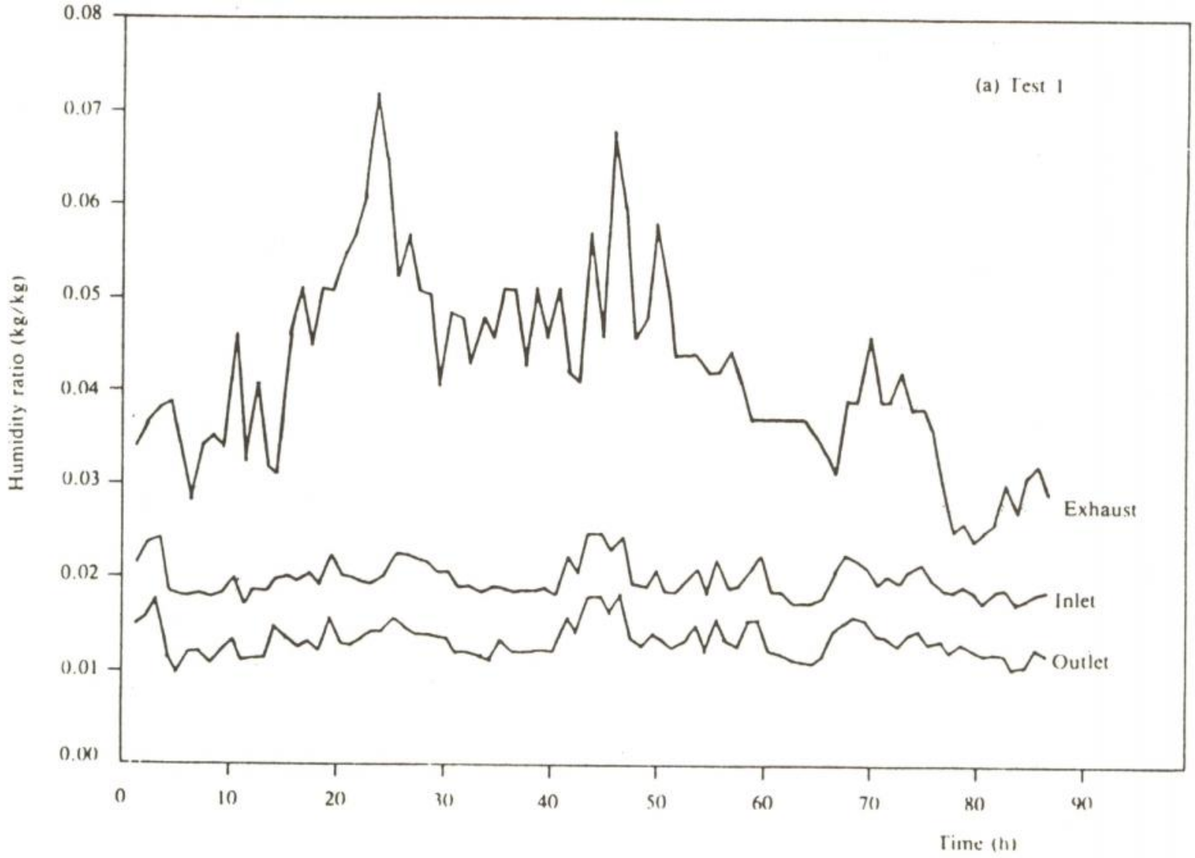
** *Based on 42.2% moisture dry basis (Prasertsan and Kirirat, 1993)*

@ *Calculated from weight loss*

\+ + *Calculated from mass balance*

controlled chamber which has inlet air humidity, inlet air flow rate and loading density (kg rubber/m^3 room) as studied parameters. It must be borne in mind that the specific air flow rate in this case was only 0.0086 m^3/hkg which was lower than the minimum figure of 0.011 m^3/hkg quoted in the previous experiment. Furthermore, the physical size of the environmentally controlled chamber and the absence of smoke might play a certain role in the previous experiment and make the results not comparable. Test 2 gave result of lower humidity in the exhaust because of lower inlet humidity admitted into the furnace. More than 50% of water in the exhaust of Test 2 came from the rubber which is substantially high compared to 37% of that for Test 1.

It is interesting to note that the investment cost of a heavy duty 4 ton capacity HPAD is in the range of 70,000 Bahts Keraticheevanon, 1993) which is only 17.5% of the cost for constructing a new smoking room (ex-



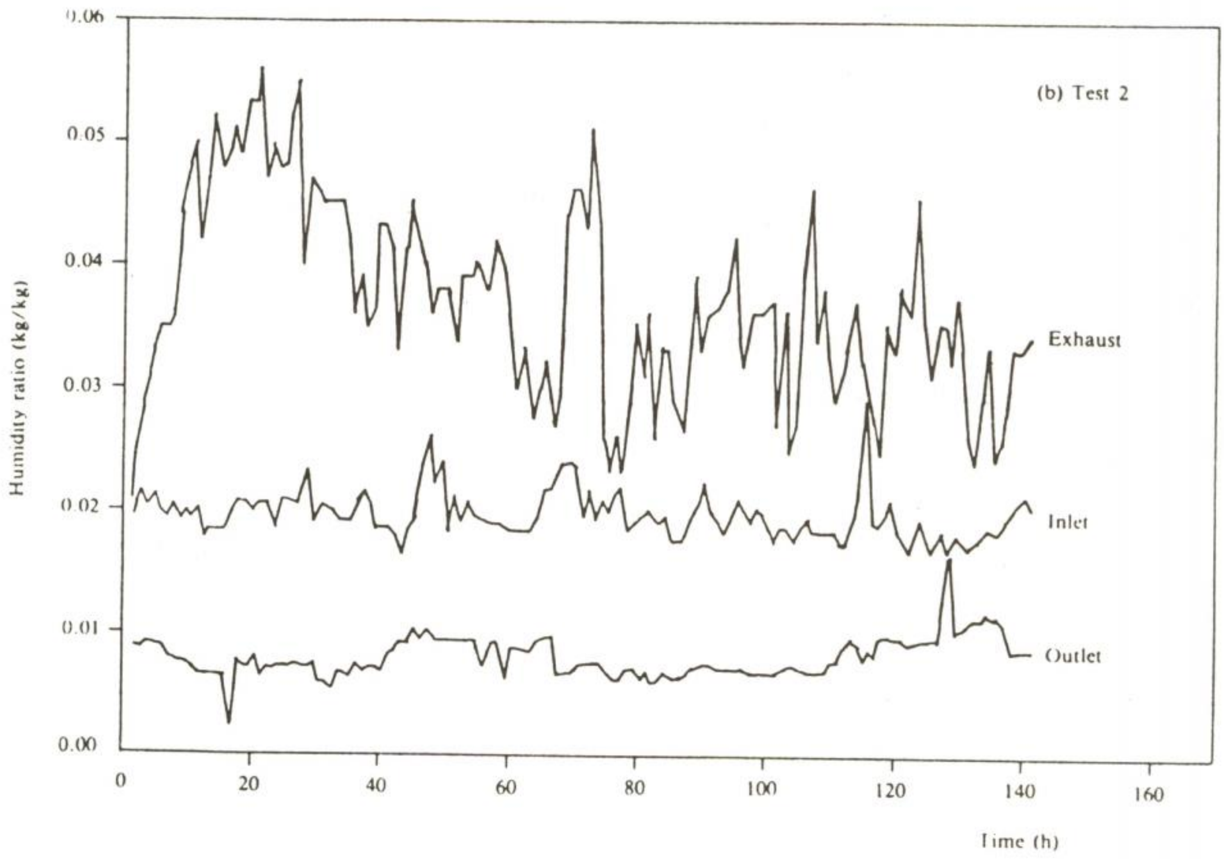


Figure 3. Humidity ratios of inlet and outlet of HPAD and exhaust.

cluded land). Adding a new room means doubling productivity. For 20-25% increase in productivity, an investment of 100,000 Bahts for installation of a HPAD to the smoking room is acceptable (Tirasarnvong, 1993). However, the results in Table 1 show that the HPAD did not affect the specific firewood consumption. Specific electrical energy consumption required to run the HPAD was in the range of 0.009-0.013 kWh/kg. Taking electricity cost of 1.80 Baht/kWh, the specific electricity cost becomes 0.016-0.023 Baht/kg. At present the specific firewood cost is in the range of 0.013 Baht/kg (6 m^3, 100 Baht/m^3 for 45,000 kg of rubber). Therefore, running cost for the HPAD-assisted smoking process is not financially competitive (HPAD-assisted process still requires firewood). Because the cost of electricity is very high in comparison to the firewood, the process with the HPAD cannot compete with the conventional method unless the firewood price increases to a level that the specific firewood cost is about 0.25 Baht/kg rubber (determine from specific firewood consumption, specific firewood cost and specific electrical energy consumption).

Table 2 gives a comprehensive comparison of the role and involvement of water (moisture) when smoked the rubber with and without the aid of HPAD. Previous study (Prasertsan et al., 1992) which monitored the rubber smoking process without the aid of HPAD showed that the smoking time was over 100 hours for the 2.9% moisture category. The corresponding smoking time for the process

Table 2 Effects of HPAD on Rubber Smoking

Parameters	Without HPAD@			With HPAD	
	Test 1	Test 2	Test 3	Test 1	Test 2
Smoked rubber (kg)	45,526	43,850	47,322	38,338	45,744
Loading density (kg/m^3; wet basis)	81.3	78.3	84.0	68.5	82.5
Smoking time (h)	166.5	110.0	122.5	86	142
% of moisture removed from rubber	2.9	2.9	2.3	2.91	3.81
Inlet relative humidity at 30°C (%)	Untreated (≅70-80%)			50	32
Water					
- in exhaust (kg)	4460.9 (100%)*	4180.6 (100%)	4200.5 (100%)	3122 (100%)	3361 (100%)
- extracted from rubber (kg)	1311.9 (29%)	1255.6 (30%)	1096.2 (26%)	1150 (37%)	1811 (54%)
- emitted from firewood (kg)	1154.0 (26%)	1027.3 (24.6%)	935.21 (22%)	843 (27%)	1013 (30%)
- inherent in inlet air (kg)	1995.0 (45%)	1897.7 (45.4%)	2174.0 (52%)	1129 (36%)	537 (16%)
Water removing rate from rubber (kg/h)	7.88	11.41	8.95	13.37	12.75
Firewood effectiveness (kg water extracted/kg wood)	0.486	0.510	0.490	0.405	0.531

@ Prasertsan et al., 1992

** Figures in bracket represent percentage with respect to water in exhaust* with HPAD was only 86 hours. This shorter processing time could be a combined effects of lower loading density and lower inlet air humidity. For the 3.81% moisture rubber, the smoking time using dry air was 142 hours which was shorter than that for the conventional process of 2.9% moisture rubber at the same loading density and higher specific air flow rate (Test 2 with HPAD and Test 1 without HPAD). The effectiveness of the HPAD is indicated by the sources of water in the exhaust. Higher contribution from water extracted from the rubber is obvious when the HPAD was implemented compared to those figures when tested without the HPAD. It is obvious also that water removing rate (from rubber) was significantly improved when the HPAD was employed. Comparison of results in Table 2 when smoked the rubber with and without the HPAD revealed that the HPAD had no effect on the firewood effectivenes. This implies that the HPAD, although accelerated the smoking process, did not save the firewood. Additional electrical energy consumed by the HPAD was just for the benefit of shorter processing time and increasing productivity.

CONCLUSION

An attempt to reduce the rubber smoking time was undertaken based on the principle that the process can be accelerated by introducing dry air into the furnace. A heat pump air drier that cools, dehumidifies and heats the inlet air was assembled from air conditioner parts. It was experimentally verified that the smoking time could be reduced by HPAD-assisted process. Economic assessment found that unless the firewood price is drastically increased and performance of the HPAD is greatly imporved, the HPAD is not suitable for the rubber smoking industry. However, the HPAD is suitable for the factories that want to increase productivity without building a new smoking room or occasionally increase productivity because of fluctuation in order and/or supply of raw material. Research and development should place emphasis on the low operating cost and high performance HPAD. Application of the HPAD in drying energy-sensitive and high-value products should also receive attention.

ACKNOWLEDGMENTS

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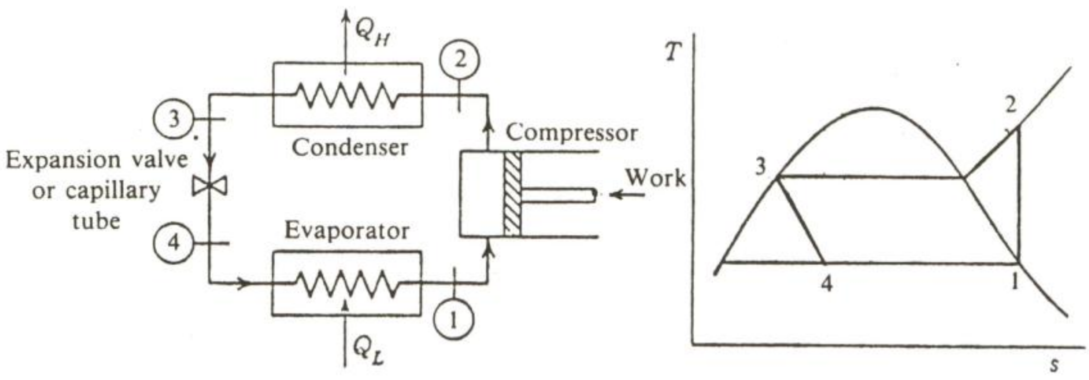

Figure A.1 Vapor compression refrigeration cycle.

Suwono, A. (1992), Development of Rubber Sheets Dryer Using Heat Pump, 3rd ASEAN S&T Proc., Vol IV, pp. 188 -196.

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APPENDIX
DESIGN AND CONSTRUCTION OF HPAD

The ideal cycle for vapor compression refrigeration is shown in Figure A.1 as cycle 1-2-3-4-1. Saturated vapor at low pressure enters the compressor and undergoes a reversible adiabatic compression, 1-2. Heat is then rejected at constant pressure in process 2-3, and the working fluid leaves the condenser as saturated liquid. An adiabatic throttling process follows, process 3-4, and the working fluid in then evaporated at constant pressure, process 4-1, to complete the cycle. Heat absorbed by the evaporator and rejected at the condenser are calculated by equations (A.1) -(A.2), respectively.

$$q_L = h_1 - h_4 \quad \text{(kJ/kg)} \quad \text{(A.1)}$$
$$q_H = h_2 - h_5 \quad \text{(kJ/kg)} \quad \text{(A.2)}$$

For the air (mixture of dry air and water vapor), the cooling through the evaporator can be shown by process 1-2 in Figure A.2. Energy equation by the first law is,

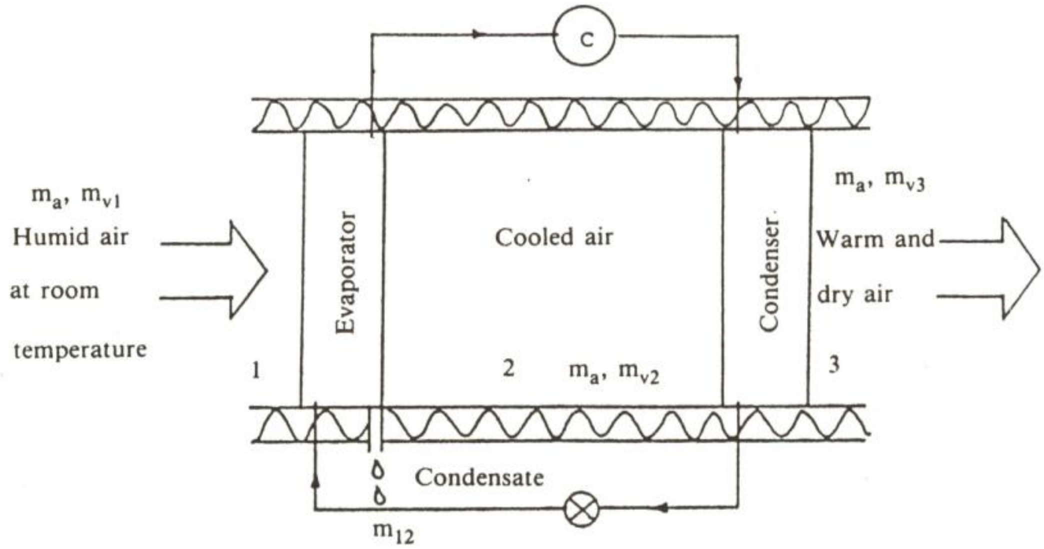

Figure A.2 Principle of heat pump air drier.

$$m_1h_1 + Q_L = m_2h_2 + m_{l2}h_{l2} \quad (A.3)$$

In dealing with air-water vapor mixture at ambient pressure the changes in enthalpy of the water vapor can be found from the steam tables and the ideal gas relations can be applied to the air. Let us consider a steady -state, steady-flow process, the continuity equations for air and water are

$$m_{a1} = m_{a2} = m_a \quad (A.4)$$
$$m_{v1} = m_{v2} + m_{12}$$

Equation (A.3) can be rewritten as,

$$Q_L + m_ah_{a1} + m_{v1}h_{v1} = m_ah_{a2} + m_{v2}h_{v2} + m_{12}h_{12}$$

$$\text{or } \frac{Q_L}{m_a} + h_{a1} + \omega_1h_{v1} = h_{a2} + \omega_2h_{v2} + (\omega_1 - \omega_2)h_{12} \quad (A.5)$$

In the heat recovering process 2-3, the first law yields,

$$Q_H + m_2h_2 = m_3h_3 \quad (A.6)$$

and $m_{a2} = m_{a3} = m_a$, $m_{v2} = m_{v3}$

Hence, $Q_H + m_ah_{a2} + m_{v2}h_{v2} = m_ah_{a3} + m_{v2}m_{v3}$

$$\frac{Q_H}{m_a} + h_{a2} + \omega_2h_{v2} = h_{a3} + \omega_2h_{v3} \quad (A.7)$$

It was reported that dry air of relative humidity of 40% is required for the smoking process (Prasertsan and Kirirat, 1993). Monitoring of rubber smoking process (Prasertsan et al., 1992) found that air flow rate into the smoking room was measured as 700 m^3/h. Hence, the full scale HPAD must be capable of dehumidifying 700 m^3/h of ambient (humid) air so that 40% RH (at ambient temperature) is achieved. Cooling capacity of the HPAD is determined assuming the control volume conditions are,

Inlet conditions $P = 0.1$ MPa, $T = 30°C$, $\phi = 80\%$

Outlet conditions $P = 0.1$ MPa, $T = 30°C$, $\phi = 40\%$

Air flow rat = 700 m^3/h, air density = 1.12 kg/m^3

From psychrometric chart obtains $\omega_1 = 0.0219$, $\omega_2 = 0.0108$

The air leaves the evaporator as saturated mixture which gives partial pressure of vapor (P_v) equivalent to saturation pressure (P_g).

$$\omega = 0.622\frac{P_v}{100 - P_v}$$

$$0.0108 = 0.622\frac{P_g}{100 - P_g}$$

Thus, Pg = 1.705 kPa

From steam tables with P = 1.705 kPa, the saturation temperature just behind the evaporator is 15°C. Water extracted from the air can be calculated as

$$\begin{aligned}\dot{m}_1 &= (\omega_1 - \omega_2)\dot{m}_a \\ &= (0.0219 - 0.0108) \times 767 \times 1.12 \\ &= 9.5 \text{ kg/h}\end{aligned}$$

$\dot{m}_a$ was estimated as 767 kg/h (ρ = 1.12 kg/m^3 ,$\omega = 0.0219$, flow = 700 m^3/h)

Equation (A.5) gives, $\frac{Q_L}{m_a}$

$$\frac{Q_L}{m_a} = h_{a2} - h_{a1} + \omega_2h_{v2} - \omega_1h_{v1} + (\omega_1 - \omega_2)h_{12}$$

$$= 1.0035(15\text{-}30) + 0.0108 \times 2528.9 - 0.0219 \times 2556.3 + (0.0219 - 0.0108) \times 62.99 = -43.02 \text{ kJ/kg}$$

$$\begin{aligned}\text{Hence, } \dot{Q}_L &= -32996 \text{ kJ/h} \\ &= 31296.7 \text{ Btu/h} \\ &= 2.6 \text{ ton (cooling capacity)}\end{aligned}$$

In ideal conditions (e.g. reversible heat transfer) an air conditioning unit of 2.6 ton capacity is required. Conventional air conditioner is not designed for air dehumidification and the condensation of 9.5 kg/h (for 700 m^3/h) could not be possibly obtained for the 2.6 ton unit. Taking into account of irreversibility, it was decided that a commercially available unit of 3.6 ton capacity should be selected for this experiment.

Preliminary study with a modified window type air conditioner revealed that the temperature of refrigerant leaving the condenser coil was very high due to limited flow rate of the air passing through the condenser. Therefore, the full scale unit was equipped with an extra condenser. The cooling fan of the additional condenser was operated only when the temperature of the condenser exceeded the set limit.

The air drier underwent trial test in the laboratory. Calculation for cooling capacity based on equation (A.5) yielded a figure of 2.77 tons which is 77% of the quoted specification. Volumetric flow rate of the inlet air was 759 m^3/h which is enough for the smoking process. In actual practice a higher flow rate can be expected due to additional draught from the furnace. Relative humidities of inlet and outlet were 77% (30°C) and 19.5% (at 46°C or 46% at 30°C), respectively. It was considered that although improvement was needed for a better performance, this HPAD apparatus deserved trial tests in a real situation.