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A Biomass-Fuelled Ice-Making Machine*

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ABSTRACT

A prototype intermittent ammonia-water absorption refrigerator has been designed, manufactured and tested at the Asian Institute of Technology (AIT), and for the past year has been undergoing field operations on a remote rural island in the south of Thailand. The system can be fuelled by any biomass residue, and apart from this source of energy is completely energy-autonomous. The system has no rotating parts and does not involve the opening or closing of any ammonia valves, features which would be detrimental to the long life of any machine of this sort. The unit can produce about 25 kg of ice per cycle, and two cycles can be run during a single day.

After a brief description of the operating principles and the novelties of the ice-making machine, the paper presents the attractiveness of this machine from both an economic and social point of view. Feedback from actual operation has led to a certain number of technical modifications and, more important, has enabled the socio-economic impact of such a machine to be evaluated. These aspects are also discussed in the paper.

BACKGROUND AND HISTORY

In developing countries, and especially in remote rural areas, there is a need for cold storage for purposes of food preservation and storage of medecines and vaccines. Although thermodynamically it is easier and more efficient to design cold storage units in the range of 0° to 10°C, ice-making units, which require evaporator temperatures of $-15°$C to $-8°$C, have certain practical advantages (relating to transportation, storage and versatility in usage) which led Merriam (1972), among many others, to advocate the use of ice-making units.

The basic objective of this project was to develop an ice-making machine which would not require the use of conventional sources of energy (such as electricity, oil, or coal) and which would be simple to operate and maintain, long lasting and amenable to indigeneous manufacture. The two promising sources of non-conventional fuel are solar energy and biomass residues. In view of the fact that the solar option is much more expensive than the latter (by almost a factor of two),

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*For complete details concerning this project, the reader may refer to the Final Report on 'Multi-Fuel Ice-Making Machine', AIT Research Report No. 190, July 1986.

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that in Southeast Asia biomass residues are to be found in plenty, and that the monsoonic climate renders entire reliance on solar energy unwise, it was thought more appropriate to go in for a biomass-fuelled ice-making machine. Consequently this project limited its attention to this source of energy. However, as later studies (albeit of theoretical nature only) showed, an ice-making machine almost identical (except for the heat input portion) from the thermodynamic and practical point of view could be designed to operate equally on solar energy in locations where waste biomass residue are not abundant.

An experimental unit of 20 kg of ice per cycle was initially constructed in order to evaluate the feasibility of the basic working principle on which the biomass-fuelled ice-making machine was to be operated. No attempt was made to optimize this unit, and the heating was done by electric heaters since this was more convenient and more controllable than heating by biomass residues. Experiments and modifications done to this initial system spanned a period of two years and yielded valuable information concerning system layout considerations and magnitude of heat transfer coefficients in the various components. This eventually permitted a rational and a more or less optimized system design which led to the construction of a prototype machine to produce 25 kg of ice per cycle.

After a brief testing period, this prototype version was dismantled, transported to Khau Yai, a remote rural island off the southern coast of Thailand (near Phuket), and re-erected in the premises of a local fisherman. This island has no continuous electric supply, except during 4 p.m. to 10 p.m. when the government-run diesel generator set is operated to supply basic electricity needs in certain sections of the island. The unit has been operating on this island for the last year, and certain technical and social drawbacks have been identified. A final version of this unit has been designed and is being constructed to overcome its deficiencies.

SYSTEM DESCRIPTION

The principle of operation of the ice-making machine is the absorption cycle, and a combination of ammonia and water was selected since this combination is widely used in the refrigeration industry and its thermodynamic properties, chemical behaviour and technical characteristics are well-known. Moreover, an intermittent operation was deemed more suitable in view of the relatively small size of the machine and the fact that the unit should be very simple to operate and have low maintenance and replacement costs.

Studies relating to intermittent ammonia-water absorption ice-making machines have been reported in the literature, notably Chinappa (1961) and Swartman et al. (1973). Since these systems involve the opening and closing of hand-operated valves on the principal circuit, leakage of ammonia is a potential source of malfunction, and for remote rural areas its use is extremely inadvisable. This has led Exell and Kornsakoo (1981) to suggest the use of a hydrostatic non-return liquid seal on lines similar to those suggested by Chung and Duffie (1964), a concept which has also been used in this project, albeit in a slightly modified manner. Though the resulting system configuration gets much more complex, practical considerations impose this necessity.

The operation of the ice-making machine (which, it will be noted, has no rotating parts) is best described with reference to the schematic shown in Fig. 1.

During the generation process, the biomass stove heats up water in a primary water loop, which by thermosyphon flows into the generator (piping k-l indicates the heating coil which is

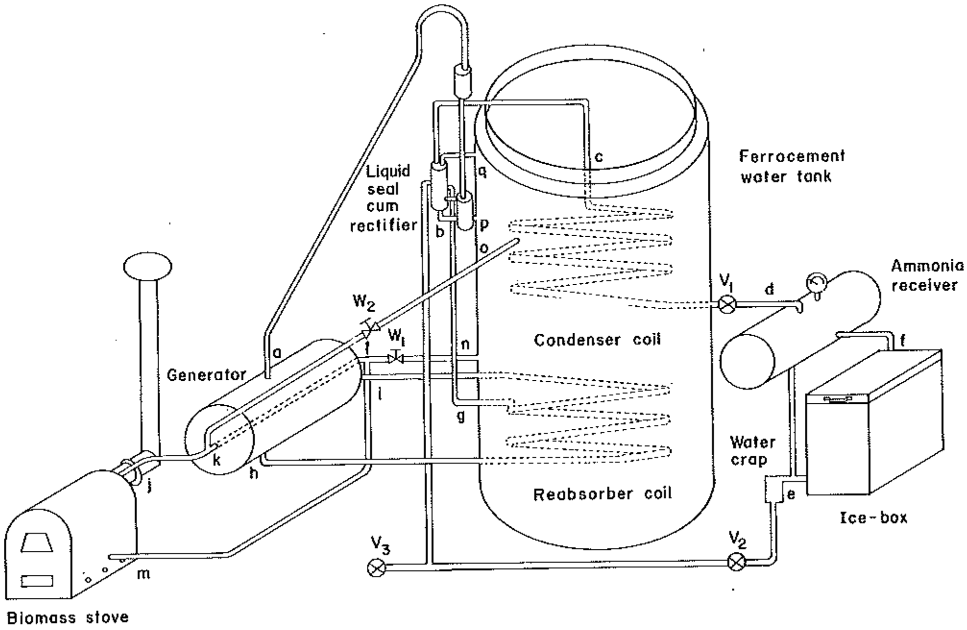

Fig. 1 Schematic diagram of biomass-fuelled ice-making machine.

immersed in the ammonia-water solution). Water valves W_1 and W_2 are kept closed during the entire generation process so that the primary water loop can be pressurized, and consequently working temperatures higher than 100°C can be achieved without water boiling over. The higher the generator temperatures attained, the better the cycle efficiency, since the initial quantity of ammonia-water can be reduced, and so can the size of the generator.

Once the initial sensible heating process is complete, the cycle enters the ammonia generation process. Ammonia, along with small quantities of water boils off, leaves the generator at point a, and enters the liquid seal. The liquid seal is basically a non-return valve which allows ammonia to pass from the generator to the condenser coil, but does not allow the flow to occur in the reverse direction (which will tend to take place during the reabsorption process). This is essential in order to prevent the formation of a rich solution at the top of the mixture in the generator, which subsequently would result in high reabsorption pressures and consequently high ice-box temperatures as well.

One of the novelties of the present ice-making machine is that the rectifier is incorporated into the liquid seal, and whatever amount of water is removed serves to replenish the requirements of the liquid seal in terms of the desired minimum water content. The rectification is done by cooling water from the reservoir, which automatically flows by thermosyphon from point p through the liquid seal and back to the tank through point q.

After rectification, the vapour ammonia enters the cooling water tank through point c, gets condensed, and is collected in the ammonia receiver. Ammonia valve V_1 is always left open, while valve V_2 is kept closed. These valves are only operated occasionally during the discharge of water from the ice-box, and due to their infrequent usage should not cause any leakage or jamming problems as mentioned earlier.

Since the ammonia receiver and the ice box are coupled, the liquid ammonia fills the ice box first and only then starts filling the ammonia receiver. The ice box is thus of the "flooded type" design. For more efficient use of the latent heat of vaporisation of the ammonia (which consequently produces cold), it is our opinion that one should attempt to minimize the amount of liquid ammonia volume in the ice-box. This is because ammonia vaporisation occurs in the form of bubbles at the inner surface of the evaporator wall, and these float up through the ammonia liquid in the evaporator. During this process, its dryness fraction increases, and with less liquid in the evaporator, the dryness fraction of ammonia vapour as it leaves the ice box will tend to be low, thereby leading to a more efficient use of the latent heat of vaporisation.

The operator keeps on checking a simple dial thermometer which indicates the generator temperature, and once it reaches 120°C, the generation process is considered to be complete and the firing of the stove is stopped. Water valves W_1 and W_2 are then slowly opened. After depressurization of the circuit, which results in steam production, cooling water from the ferrocement reservoir rushes in and displaces the hot water in the primary water circuit. Cold water continues to circulate by thermosyphon, and the solution in the generator starts cooling. The same coil k-l which was used to heat the solution thus also serves as the cooling coil.

Thermosyphon maintains the cooling of the generator until reabsorption can start. The ammonia which is evaporated flows back through d to c into the liquid seal where subsequently it flows down to g and is reabsorbed in the absorber coil. It will be noted that the generator is cooled not only by means of the coil k-l but also due to flow occuring from h upwards to i. This flow, which is contrary to the natural thermosyphon flow direction, is set in motion by the ammonia vapour which is made to enter the reabsorber coil somewhere midway in the coil. Rapid generation of bubbles of pure ammonia vapour gives rise to a "bubble pump" operation causing the fluid to circulate from h to i. By the time they reach point i, the bubbles of pure ammonia have been absorbed in the bulk of the weak ammonia-water solution stream. The heat of reabsorption is thus more or less entirely dissipated by the reabsorber coil to the surrounding cooling water.

The present ice-making machine and the stove have been so designed that the ammonia generation process takes up to 4 hours while the reabsorption is complete within 8 hours, thus adding up to a total cycle period of less than 12 hours. Thus if properly adjusted to the living pattern of the user, two cycles per day should be possible. Since each cycle yields about 25 kg of ice, the total ice quantity production for a day should be around 50 kg, which a preliminary survey showed to be sufficient for half a dozen households, or for a small shop selling refrigerated drinks, or for freezing the fish caught by a small group of fisherman.

The ice box has been designed so as to consist of several cylindrical units, as shown in Fig. 2. Each unit is made up of concentric cylinders, in the annular space of which pure ammonia is made to evaporate (Fig. 3). The outer cylinder is made of mild steel while the inner cylinder is of stainless steel in order to withstand the corrosive action of the salt solution. A third cylinder of thin gauge stainless steel sheet is introduced inside the inner cylinder and a small quantity of saturated salt solution assures a proper thermal bond between the evaporating ammonia and the water inside the third cylinder. The water to be subsequently transformed into ice is poured inside this third cylinder. Once this water has frozen at the end of the reabsorption cycle, the third cylinder is lifted out and placed for a few minutes in water at ambient temperature. This is enough to loosen the ice from the cylinder walls, and can be subsequently removed.

In spite of rectification, traces of water are carried over by the ammonia vapour into the ice box. Thus after a number of cycles (typically around 20-25), the water accumulation gets important and this effects the ice formation since the evaporating temperature tends to increase. Consequently the operator has to intervene and perform an operation by which this water is

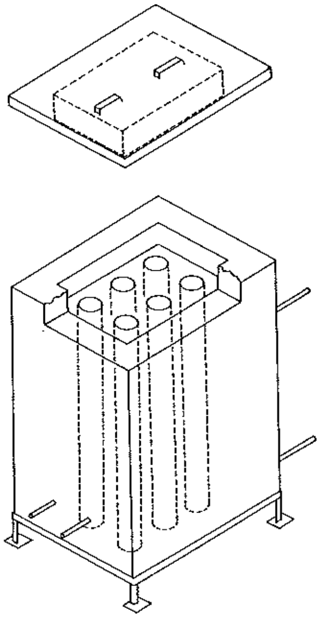

Fig. 2 Sketch of the ice-box.

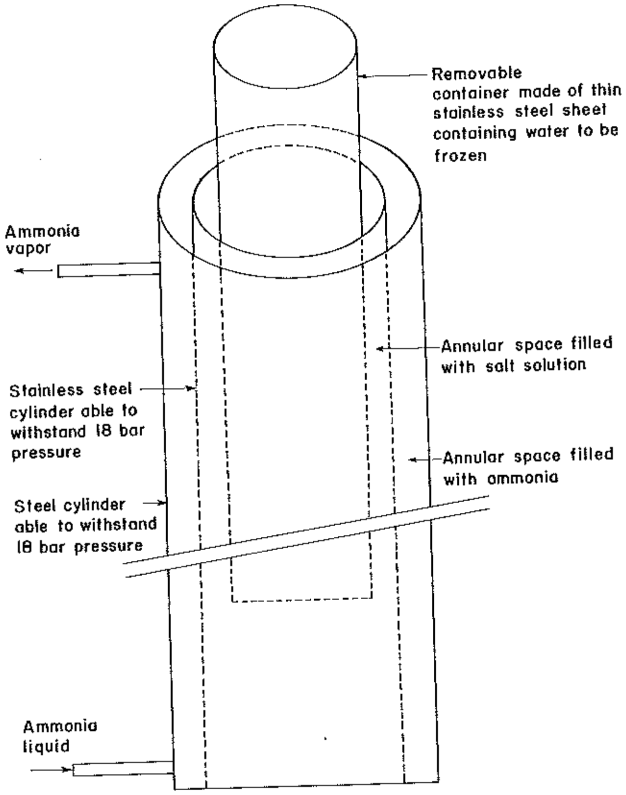

Fig. 3 Sketch of concentric cylinder units of the ice-box.

pushed back into the generator.

A final design consideration still needs to be mentioned. For proper operation of the liquid seal, certain hydrostatic constraints need to be respected. Fig. 4 gives a sketch of the entire ice-making machine, with particular emphasis on the liquid-seal placement. The pure ammonia liberated from the solution in the generator leaves the pipe, bubbles up the liquid in the liquid seal, and goes on to the condenser coil. During reabsorption, the evaporated pure ammonia vapour from the ice-box goes to the receiver, then through the condenser coil and to the liquid seal. Since the pressure in the generator section is very slightly lower than that in the receiver-ice box section, the evaporated ammonia vapour will push down on the liquid in the liquid seal. This liquid will subsequently get into the vertical section of the pipe, and by preventing any ammonia vapour getting into the generator from the top will force reabsorption to take place through the overflow pipe and down to the reabsorption coil .

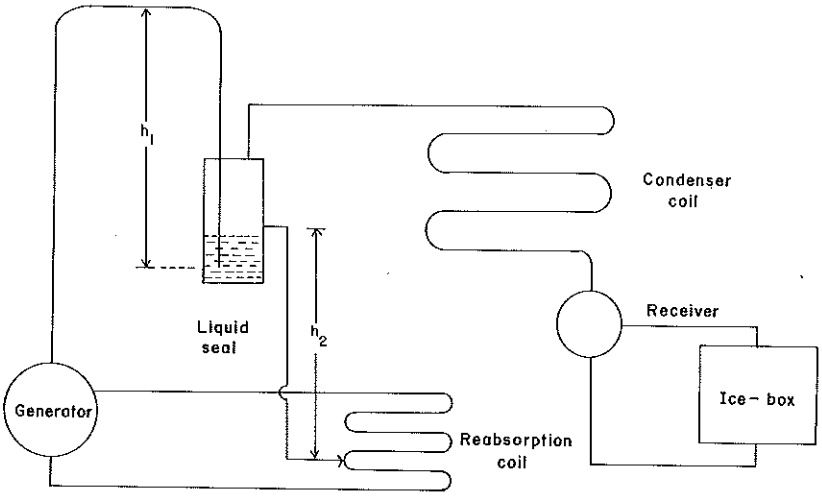

Fig. 4 Sketch indicating system configuration for proper operation of the liquid seal. The height $h_1 > h_2$.

For the above phenomenon to occur, the following hydrostatic constraint should be respected, namely $h_1 > h_2$.

Moreover, the liquid seal should be designed so that it contains enough liquid which when pushed up the vertical pipe does give the required vertical height h_1. Finally, it should be noted that due to dynamic effects during the operation of the system, it is safer to design the vertical height larger than the minimum static height h_1.

Figure 5 gives typical variations of the generator, receiver, and ice-box (i.e. of the water in the freezer) versus time. It can be seen that the generation time takes approximately 4 hours and that the entire reabsorption is complete within 8 hours. Thus an entire cycle takes about 12 hours. The times at which the ammonia generation process and the ice production in the freezer start are also shown in the figure. It will be noted that the receiver temperature starts to increase gradually, from its minimum value of about –8°C, at about 11 h from the starting of the cycle. This indicates that the pure ammonia has become more or less reabsorbed in the solution in the generator, and subsequently, the receiver temperature gradually increases as a result of heat gains

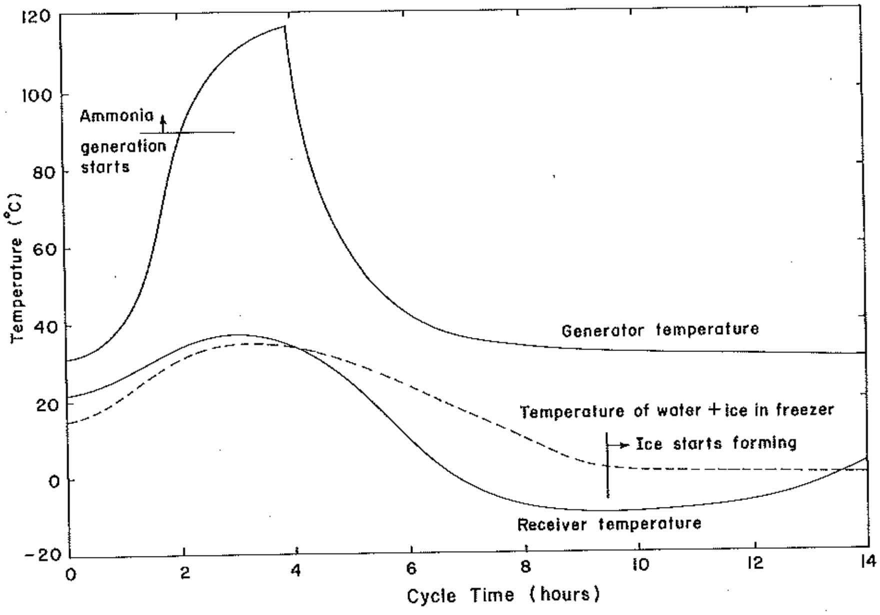

Fig. 5 Typical variation of generator, receiver and ice-box temperatures versus cycle time.

Table 1
Some typical test results obtained in field conditions

Run	Qty of coconut husk burnt (kg)	Qty of liquid NH_3 generated (litres)	Qty of ice produced (kg)
1	32	22	22.0
2	37	24	23.6
3	45	27	24.0
4	40	27	25.5
5	40	28	23.4
–	–	–	–
–	–	–	–
–	–	–	–
–	–	–	–
–	–	–	–
–	–	–	–
24	38	26	20.0
25	38	22	19.5
26	39	27	18.4
27	43	27	20.2
28	–	24	12.7
29	–	28	15.5

from the ambient air. The freezer temperature, on the other hand, continues to remain at 0°C due to the presence of ice, and any heat gains result in the melting (and consequently a loss) of ice.

Table 1 gives some typical results obtained in field conditions. It will be noted that the quantity, by weight of coconut husk consumed, is approximately 1.5 times that of ice produced, while a certain volume (in litres) of liquid ammonia generated results in roughly the same quantity of ice generation (in kg). Note the decreasing values of ice production due to water accumulation in the ice-box.

Table 2 gives the overall dimensions of the principle component parts of the biomass ice-making machine while Table 3 lists the various auxiliary equipment needed. Details concerning the construction materials of the absorption unit and procedures for ammonia installation and handling are similar to the requirements for a solar fuelled ice-making machine, and can be found in the report by Exell & Kornsakoo (1981).

Table 2
Specification of component parts

Part	Dimension			Insulation		Remarks
	ID (cm)	Length (cm)	Thick (cm)	k (W/mk)	Thick (cm)	
1. Generator	38.0	110.0	1.0	0.0375	10.0	2 Tanks
2. Exchanger	1.5	110.0	0.3	–	–	8, 1/2" tubes, one pass
3. Condenser	1.5	5000.0	0.3	–	–	1/2" tube coil
4. Receiver	38.0	55.0	1.0	0.0375	10.0	
5. Ice box	10.0	65.0	0.6	0.0375	10.0	6 cylinders, 25 kg water
6. Absorber	1.5	2000.0	0.3	–	–	1/2" tube coil
7. Water Tank	235.0	270.0	5.0	–	–	total vol. 3.5 m^3

Table 3
List of auxiliary equipment required

	No.
1. Valves	
– for ammonia (18 bar)	3
– for water (3 bar)	2
2. Pressure gauge for ammonia (0 to 20 bar)	1
3. Dial thermometers for water (20° to 150° C)	2
4. Safety valves for steam (blow off: 2.5 bar)	2
5. Ammonia sight-glass with corresponding valves – 30 cm long (20 bar pressure)	1
6. Expansion tank for water	1
7. Balance (upto 30 kg, accuracy of 50 gm)	1

ECONOMIC EVALUATION

A detailed economic evaluation of the ice-making machine would be premature at this stage since the system has yet to reach a form suitable for commercial production. However, a preliminary assessment can be made by comparing the cost of constructing and running a biomass-fuelled ice-making machine with the revenue that would be obtained by selling the ice produced (at the price in the local market).

The various costs which figure are:

a) Initial cost (C'_I) involve equipment, labour and transportation costs.

b) Running expenses include taxes, insurance, repairs, maintenance and wages. Since they are calculated on a yearly basis, they have to be discounted to the beginning of the first year. The influence of annual recurring expense C_E, interest rate i and inflation rate j have to be explicitly accounted for while computing the total discounted present value C'_E.

c) Income is gained by selling the ice produced. The annual income C_S is the product of the price of ice per kg (P) times the amount of ice produced per day (W) times the number of days (N) per year during which the machine is operated. The total discounted income C'_S depends on C_S, i and j, the annual inflation rate of the price of ice.

d) The payback period is the number of years for which the present value of the total income equals the initial cost plus the present value of all expenses, namely:

$$NPV = C'_S - C'_I - C'_E = 0$$

e) The cost of ice per kilogram during the entire life of the machine can be evaluated as follows:

$$P = \frac{C'_I + C'_E}{W.N.n}$$

The effect of the following parameters on the payback period can be investigated:

- annual maintenance cost (C_E);
- interest rate ($i = 0.10$ and 0.18);
- initial investment (C'_I = ฿ 75 000 and ฿ 100 000); and
- cost of ice (P = ฿ 1/kg and ฿ 2/kg)*.

Fig. 6(a) and (b) illustrate the variation of the payback period with the above parameters. It will be noted that C_E has been drawn on the X-axis since it is a parameter to which a realistic value is difficult to assign. From the figures it is clear that C_E has relatively less effect on the payback period if the cost of ice is high. The reader must realise that what is most important is probably the cost of ice, i.e. the parameter P. For P = ฿2/kg, irrespective of variations in C_E, i and C'_I, the payback period is of the order of 4 to 5 years which seems fairly attractive.

The effect of the following parameters on the production cost of ice has also been investigated:

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*US$ 1 = ฿ 26

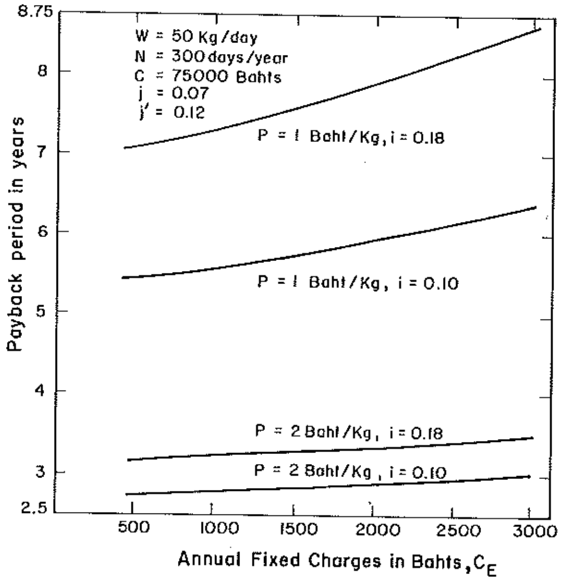

Fig. 6a Payback period versus annual fixed charges.

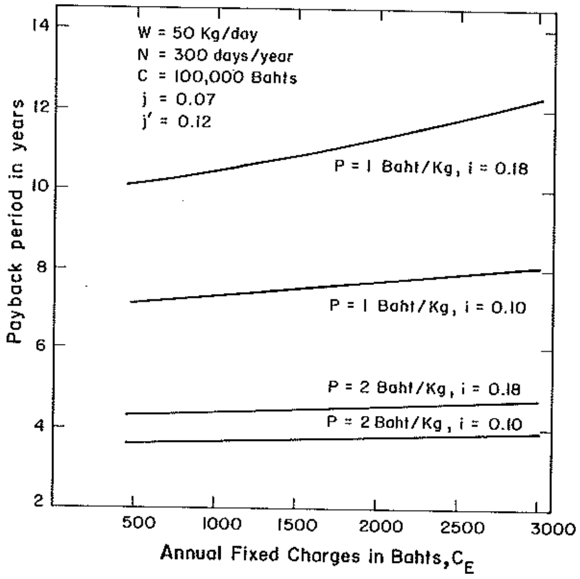

Fig. 6b Payback period versus annual fixed charges.

- life of machine; and
- interest rate ($i = 0.10$ and 0.18).

It can be seen from Figs. 7(a) and (b) that the interest rate does not play a significant role, nor is C_E particularly significant. For a machine life of 4 years, it can be seen that the production cost of ice is around ฿1.2 to ฿1.4/kg, which also goes to show the economic attractiveness of the biomass-fuelled ice-making machine. (Note that commercially produced and transported ice

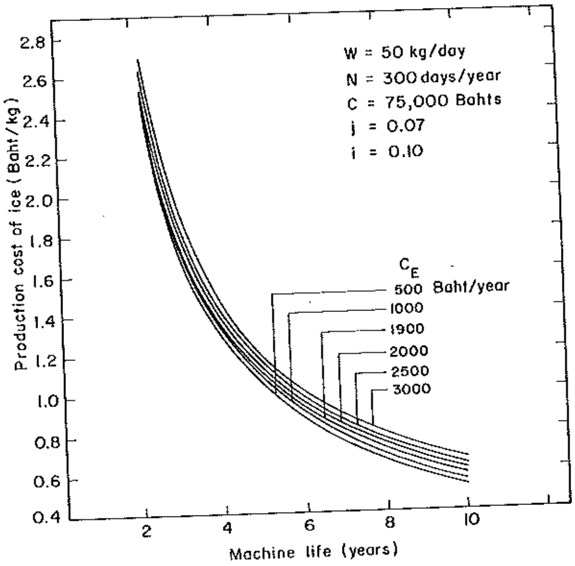

Fig. 7a Production cost of ice versus machine life.

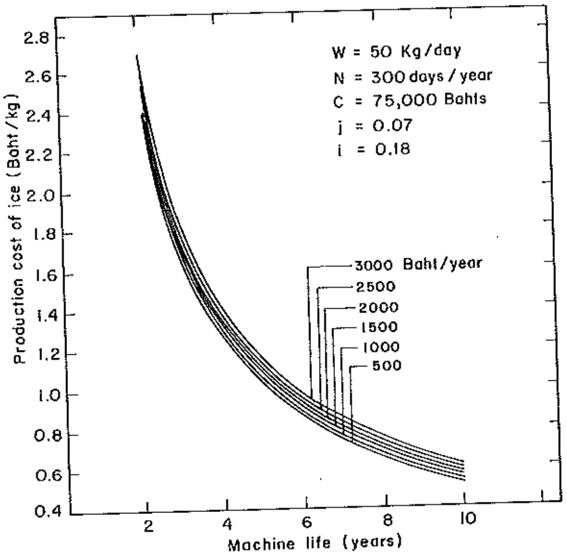

Fig. 7b Production cost of ice versus machine life.

presently sells at ฿2/kg on the island).

It must however be realised that the cost of the biomass fuel has not been included in the analysis. It has been assumed that such fuel is available free of charge, which may or may not be a valid supposition if the situation should arise that several such units were being used in a relatively small area. Problems like scarcity of biomass fuel and neighbours selling their biomass fuel to ice machine owners have not been considered in the above analysis.

FEEDBACK FROM FIELD OPERATION

The unit was installed about a year ago. The feedback from actual field operations has not been as important as we had anticipated. This is primarily because of socio-economic factors, and to a lesser extent due to technical reasons.

Technical modifications required

a) **Stove**

The firing of the stove during the generation process requires approximately 4 hours. The initial stove design was along conventional lines, which required that an attendant be present almost all the time to keep on feeding coconut husk. It was initially thought that this was not a problem, since a child (who would otherwise be idle) could do this operation, thus not requiring the services of a grown-up person. However in this particular instance, it was found that no child was available to do the firing. Consequently the lady of the house had to perform this activity, which obviously hindered her other duties. Consequently she would tend to neglect the firing, either by not running it for the required duration of 4 hours, or not keeping the stove fully loaded. These factors tend to drastically affect ice output, consequently enhancing the lady's feeling of wasting her time.

In order to circumvent this continuous attendance, a novel type of stove has been designed in which a sufficient amount of coconut husk can be stored, and this enables the stove to burn for over 1/2 hour. The person need then to come only every half-hour or so, charge the stove (which would take her less than 5 minutes), and go back to her daily duties. Such a stove has been already installed, and the impact which this modification has made on the acceptance of the ice-making machine is being studied.

b) **Quality of ice**

Once the reabsorption process is complete, the ice produced is freed from the stainless-steel cylinders and stored in an insulated box. As and when ice is required, this box is opened and the required amount of ice removed. Thus the ice generated is consumed not instantaneously but over a period of several hours.

The person to whom the ice-making machine was given, reported back saying that the ice produced tended to liquefy much more quickly than the ice purchased from the local market. Subsequently it was realised that the temperature of –8°C which had been selected as the design evaporator temperature of the ice-making machine was not low enough to give us the right "quality" of ice. By this is meant that ice which has to be stored after it is produced needs to be undercooled to assure that the ice is formed in a properly compacted form and does not melt away too soon. Thus it is felt that the design evaporator temperature needs to be further lowered, to –15°C or so, in order to assure the right quality of ice. (Note that evaporator temperatures of the order of –30°C are used in conventional ice-making plants).

c) **Removal of parasitic water from the ice-box**

During the generation process, traces of water from the solution in the generator are carried away by the evaporating ammonia. In spite of the rectifier, traces of water (which can be termed 'parasitic' since they are unwanted) do find their way to the ice-box section of the ice-making machine. Over several repetitive cycles, this parasitic water keeps on accumulating, which gradually increases generation pressures and evaporation temperatures, consequently adversely affecting ice production (refer to Table 1).

Thus a special run should be undertaken once every two weeks or so to drain this parasitic water back to the generator. This run involves operating the ammonia valves V_1 and V_2. Though written instructions had been provided to the operators, they seem to be having difficulty with this operation. Consequently it seems wise to incorporate three modifications in subsequent ice-making machine designs:

(i) a better rectification unit, which would require that this process be done once in say, one or two months;

(ii) a parasitic water container, which is not only larger but is designed so as to keep the contact between this water and the generated ammonia to a minimum;

(iii) a simplified draining procedure which would involve the opening or closing of only one valve and not two as in the present design. Moreover, a mechanism by which the operator would not forget to reset the valve to the normal operating position once this special water draining run is completed is also advisable.

d) Corrosion

The quality of water found in many remote areas is poor. Due to impurities, either dissolved or in suspension, the condenser and evaporation coils as well as the insides of the generator heat exchanger pipes get coated with slime which decreases heat exchange rates. Moreover, corrosion in certain spots of the heat exchanger coils (for example, in welding joints) has been found to be important, which leads us to suspect electrolytic pitting. Ammonia leakage, especially due to the high generation pressure (13-14 bar) could be a serious problem in a few years unless some device (like cathodic protection) can be incorporated to suppress the pitting. This aspect is presently being studied.

Socio-economic Feedback

Many difficulties are associated with social acceptability at a family level. Unlike the frequently voiced opinion that in remote rural areas, plenty of idle labour could be found, this is not necessarily true of all remote rural areas. Normally the head of the family leaves the house in the early morning to look after his work and cannot take the responsibility of firing the stove each and every day. The housewife, who remains at home, is not only reluctant to operate the machine for 4 hours every cycle, but is intimidated by the simplest of mechanical operation. Children normally go to school while the grandparents are either too old and frail to look after the operation of the machine or to pursue the activities which they used to do when they were younger. As a result, acceptability is strongly dependent on the trade-off between the advantages brought by the ice-making machine and the activities which ought to be abandoned to keep it running.

A second difficulty is that though the machine has been designed so that one cycle takes less than 12 hours, people may be reluctant to run the machine twice a day, i.e. perform two cycles per day. This may be due both to the inability to synchronize the machine-operating time with their present living habits, and to the fact that operation of the machine in the late evenings (as the second cycle of operation requires) has to be done in darkness (since no electricity supply exists) and very often in rain (which is a non-negligible factor in monsoon-prone tropical locations).

A third difficulty is that though the biomass residues may be free and available in plenty, they are spread over a large area. In the particular case of the Khau Yai ice-making machine, the coconut husk around the ice-making machine has long been consumed, and the operator is having to go over 50 m to collect fresh husks. Though this distance is not great she may have to do such trips several times for each run and this distance will keep on increasing, and consequently the necessity of collecting waste biomass may well turn out to be a laborious chore. In certain locations, a small tricycle trolley could be used, but in places where the ground is uneven or even sandy, this would not prove to be the best solution.

The final, and probably the most important, consideration is the economic benefit which may accrue to the owner of such a biomass ice-making machine. In the present field experience, the island of Khau Yai has bountiful natural resources and the people are consequently well-to-do, either by living off the land (for example growing rubber or coconut trees) or by fishing. The financial incentive to operate the ice-making machine (which requires 4 h attendance per cycle) does not seem to be too strong, especially in view of the fact that only about ฿50 worth of ice is generated per run. Though the economic attractiveness of the ice-making machine from the point of view of the pay-back period is certainly promising, the aspect of getting used to the idea of owning, operating and earning from such a machine seems to be much more important.

OVERALL EVALUATION AND CONCLUDING REMARKS

The feedback from field operation of the ice-making machine has revealed certain technical flaws in the initial design of certain components of the system which could be overcome by relatively minor modifications. Some of these have already been made and a newer version of the ice-making machine, presently being built, will incorporate the necessary modifications.

The acceptability of the ice-making machine has to be viewed with regard to both the location and to the purpose of owning the machine. Let us discuss each of these two issues in turn.

Remote rural areas, without an electricity supply, can either be situated in hot humid locations or in dry and arid locations. In dry locations, sources of waste biomass fuel may not be abundant and a solar-fuelled ice-making machine may be the most approppriate option. In hot and humid locations (as in monsoon-prone areas), waste biomass fuel may be found in plenty, and a biomass-fuelled ice-making machine may be more appropriate. (Note that not only is a biomass-fuelled ice-making machine cheaper by almost a factor of 2 as compared to the solar-fuelled machine, but it is more reliable than a solar machine).

The ice being produced in a multi-fuelled ice-making machine may be sold either commercially on a profit-making basis, or used for essential services in medical centers for vaccine or medicine preservation.

Let us consider each of the four possible combinations which drive from the type of remote rural area and the purpose of generating ice. In hot remote areas, people are generally poor, and it looks unlikely that operating a solar-fuelled ice-making machine on a profit-making basis will prove attractive, since consumption of ice by individuals may be a low-priority need. Moreover the purchasing power of individuals for such a luxury will be low.

In areas where waste biomass fuels are abundant, selling ice generated in ice-making machines may prove to be attractive since normally the living standard of people in such regions is above the subsistent level. This, however requires that the people be made familiar not only with the method of operating such a machine but also with the financial benefits which may accrue. This is probably best done by installing half a dozen units or so in a relatively small area, staying in this area for a few months, and getting the users to slightly modify their living patterns so as to synchronize them with the operation schedule of the machine. Installing one machine and spending a couple of weeks at the site, as was done in the present project, does not seem to be the best way of introducing such a new technique into the already established rural way of life.

Since such a procedure is expensive, we are trying another method. In the Khau Yai field project, we have set into motion a mechanism whereby we pay the fisherman a certain nominal sum of money each month as salary to operate the ice-making machine every day. The payment is to be discontinued at the end of six months. It is deemed that this time period should be sufficient to convince the fisherman, one way or another, as to the attractiveness of the machine as a commercial enterprise. As matters stand at present, it is our conjecture that the multi-fuelled ice-making machine does have the potential of being a source of financial gain to individuals, provided due care and effort is taken to introduce it appropriately into the rural way of life.

If we view the multi-fuel ice-making machine as a means of providing non-commercial services, in hospitals for instance, its relevance and usefulness must be compared with ice-making machines employing other technologies; for example, solar/thermal or photovoltaic systems. It should be kept in mind that for such applications, a unit much smaller than the present 25 kg of ice cycle, would suffice. Though at present, the thermal option looks more economical, it seems likely that photovoltaic systems of comparable magnitude will become competitive in the near future. Moreover photovoltaic systems seem to require much less material, labour, transportation and maintenance expenses, while at the same time they can be more easily integrated into the living habits of rural people. However, complete reliance on an intermittent and unreliable source of energy, such as solar energy, is inadvisable, especially in monsoon-prone areas. It remains to be seen which of these technologies (biomass/thermal, or PV) will prevail in the long run.

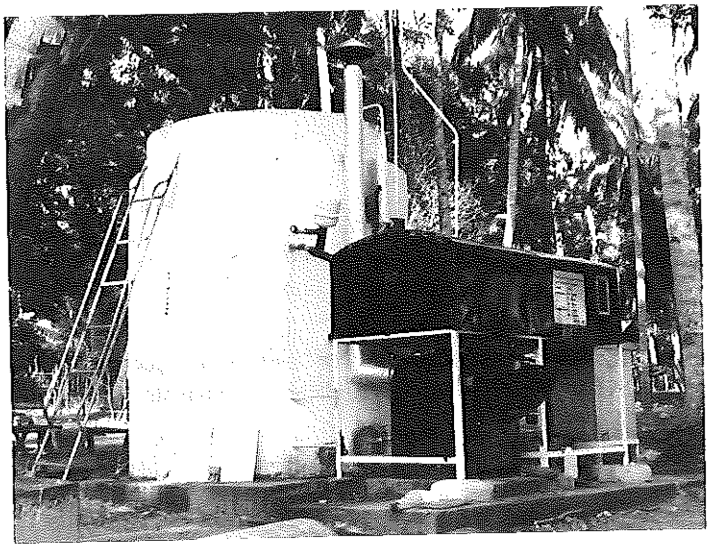

Photo 1: Front view of machine as installed in the island.

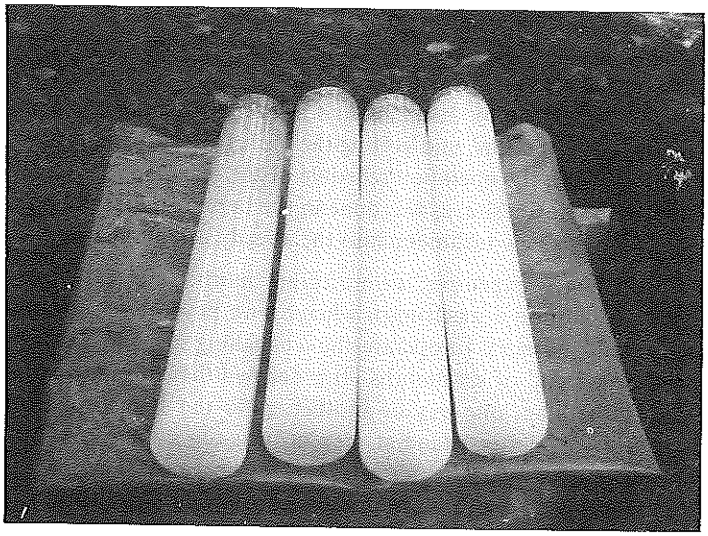

Photo 2: Four of the six cylindrical ice blocks made by the machine.

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