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Performance analysis and economic evaluation of thermosyphon paddy bulk storage

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Abstract

Performance and economic analyses of a prototype paddy bulk storage with R22 thermosyphon for self-heat rejecting have been studied. The unit has a steel cylindrical bin with diameter of 1250 mm and length of 1500 mm that contains 1000 kg of paddy. The evaporation section of the thermosyphon embedded in the paddy bulk is a set of copper tubes with the total heat transfer area of 8.5 m^2. The condenser section with the total area of 12.2 m^2 is exposed to the ambient air. The analyses have been compared with the unit having a conventional aeration.

The experiment shows that there is a high potential for using thermosyphon to control the paddy bed temperature. It could be found that for the paddy with moisture content of 26.9% and 13.5% wet basis, the thermosyphon can maintain the paddy bed temperature at 37–38 °C and 28–29 °C, respectively compared with 62 °C and 31–32 °C for the unit without any control. Moreover very small temperature difference in the bed is also observed in the unit with thermosyphon.

The paddy quality in term of head rice yield (38.06%), percentage of brown (72.7%) and white rice (60.14%) for the unit with thermosyphon is very close to those (40.16%, 72.37%, 60.43%) of the unit with aeration. The mathematical model developed could be used to predict the paddy bed temperature accurately and the evaporator area should not be less than 16 m^2 for 1000 kg of paddy (Condenser area of 12.2 m^2) at Chiang Mai, Thailand. The economic analysis indicates that the payback period of the storage with 16 m^2 evaporator area is shorter and higher IRR obtained with the percent of annual fan operation. The payback is about 8 years when 20% of annual fan operation is taken.

Keywords: Paddy storage; Thermosyphon; Economic evaluation; Paddy quality

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Nomenclature

C_{pw}	specific heat of paddy (kJ/kg °C)
dt	storage time interval (s)
DML	dry matter loss (decimal)
i	discount rate (decimal)
IRR	internal rate of return (%)
m	mass of paddy (kg)
n	life cycle (year)
M_w	moisture content (decimal wet basis)
$\dot{Q}$	heat liberated from paddy respiration (kW)
T	storage temperature (°C)
t	storage time (h)
ΔT	increment of paddy bed temperature from respiration process (°C)
T_{b2}	paddy bed temperature of the unit without thermosyphon (°C)
T_{b1}	paddy bed temperature of the unit with thermosyphon (°C)
T_a	ambient air temperature (°C)
T_v	working fluid temperature (°C)
T_b	paddy bed temperature (°C)
U	overall heat transfer coefficient between paddy bed and working fluid (kW/m^2 °C)
SPWF	series present worth factor
ε	reduced temperature ratio

1. Introduction

In Thailand, deterioration of paddy during storage due to heat liberated from respiration process is normally controlled by ventilating cooled air or ambient air throughout the bed (aeration process) to reduce the bed temperature. However, vapor recondensation on the cold surfaces of the paddy or walls of the storage might occur which transfers moisture back to the paddy. Moreover, the fan runs for a very long period that results in high electrical energy consumption. Maier et al. [1] studied ambient and chilled paddy aeration under Thai conditions. The study showed that continuous ventilation of cooled air decreased paddy temperature down to 15 °C in 110–144 h. While continuous ventilation with ambient air could not decrease paddy temperature down to 25 °C neither in summer nor rainy season. Intermittent ventilation with ambient relative humidity control (<75%RH), the paddy temperature was higher than 26 °C. The simulation had been carried out incase of aeration operation, it was found that the fan should operate 1650–1836 h in dry seasons (November–February), and 1062–1680 h in wet season (July–October). The total operating time is about 30–40% of a year. The energy consumption was 38–64% lower than the continuous ventilation.

In Thailand, one-ton thermosyphon paddy bulk storage could serve for Thai family scale in rural area which has no electrical grid. Moreover, small scale could use to store seed paddy and other grain crops.