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APPENDIX

Uncertainty analysis:

Errors in the experiments can result from the choice of the instrument, the state of the environment, the observations and the readings. The purpose of this analysis is to find mistakes in the estimated amounts derived from the measured values. The uncertainties in the dependent value (*Y*) are calculated by using Eq.(A.1).

$$\Delta Y = \pm\sqrt{\left(\frac{\partial Y}{\partial X_1}\Delta X_1\right)^2 + \left(\frac{\partial Y}{\partial X_2}\Delta X_2\right)^2 + \ldots\ldots\ldots\ldots\ldots\left(\frac{\partial Y}{\partial X_n}\Delta X_n\right)^2} \qquad \text{(A.1)}$$

where, ΔY is the uncertainty in the estimated value and ΔX_1, ΔX_2, ..., ΔX_n are the errors in the independent variables.

Sample calculation for the estimation of uncertainty in solar air heater efficiency:

The thermal efficiency of a solar air heater depends on mass flow rate, solar radiation intensity, area of the solar air heater, temperature of air entering and leaving the collector.

$$\eta_{SAH} = f\left(I_S, T_o, T_i, A_S, \dot{m}_{air}\right) \qquad \text{(A.2)}$$

$$\eta_{SAH} = \frac{\dot{m}_{air}\, C_p (T_o - T_i)}{\alpha\tau I_S A_S} \qquad \text{(A.3)}$$

$$\Delta\eta_{SAH} = \pm\sqrt{\left(\frac{\partial\eta_{SAH}}{\partial\dot{m}_{air}}\Delta\dot{m}_{air}\right)^2 + \left(\frac{\partial\eta_{SAH}}{\partial T_o}\Delta T_o\right)^2 + \left(\frac{\partial\eta_{SAH}}{\partial T_i}\Delta T_i\right)^2 + \left(\frac{\partial\eta_{SAH}}{\partial I_S}\Delta I_S\right)^2 + \left(\frac{\partial\eta_{SAH}}{\partial A_S}\Delta A_S\right)^2} \qquad \text{(A.4)}$$

The sensitivity coefficients are-

$$\frac{\partial\eta_{SAH}}{\partial\dot{m}_{air}} = \frac{C_p \times (T_o - T_i)}{\alpha \times \tau \times I_S \times A_S}$$

$$\frac{\partial\eta_{SAH}}{\partial T_o} = \frac{\dot{m}_{air} \times C_p}{\alpha \times \tau \times I_S \times A_S}$$

$$\frac{\partial\eta_{SAH}}{\partial T_i} = \frac{-\dot{m}_{air} \times C_p}{\alpha \times \tau \times I_S \times A_S}$$

$$\frac{\partial \eta_{SAH}}{\partial I_S} = \frac{-\dot{m}_{air} \times C_p \times (T_o - T_i)}{\alpha \times \tau \times I_S^2 \times A_S}$$

$$\frac{\partial \eta_{SAH}}{\partial A_S} = \frac{-\dot{m}_{air} \times C_p \times (T_o - T_i)}{\alpha \times \tau \times A_S^2 \times I_S}$$

The uncertainty in thermal efficiency is estimated from the measured parameters at a particular time of the day as shown in Table-A.1. Specific heat of the air is constant (C_p = 1.005 kJ/kg-K) and transmissivity (τ) and absorptivity (α) of the solar air heater are taken as 0.95 and 0.85 respectively.

Table-A.1. Sample experimental data

Time	I_S (W/m^2)	T_o (°C)	T_i (°C)
12.30 pm	759	49	35.2

$$\frac{\partial \eta_{SAH}}{\partial \dot{m}_{air}} = \frac{C_p \times (T_o - T_i)}{\alpha \times \tau \times I_S \times A_S} = 16.05; \qquad \frac{\partial \eta_{SAH}}{\partial T_o} = \frac{\dot{m}_{air} \times C_p}{\alpha \times \tau \times I_S \times A_S} = 0.046;$$

$$\frac{\partial \eta_{SAH}}{\partial T_i} = \frac{-\dot{m}_{air} \times C_p}{\alpha \times \tau \times I_S \times A_S} = -0.046; \qquad \frac{\partial \eta_{SAH}}{\partial I_S} = \frac{-\dot{m}_{air} \times C_p \times (T_o - T_i)}{\alpha \times \tau \times I_S^2 \times A_S} = -8.46\times10^{-4};$$

$$\frac{\partial \eta_{SAH}}{\partial A_S} = \frac{-\dot{m}_{air} \times C_p \times (T_o - T_i)}{\alpha \times \tau \times A_S^2 \times I_S} = -0.45$$

Uncertainty in thermal efficiency of the SAH is estimated by using Eq.A.4 and found as ±0.16% at the specified condition. The average uncertainty is determined by following the same procedure. Similarly, the uncertainties in the exergy efficiency of the SAH and the drying chamber are estimated.

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Chapter-1

Introduction

1.1 History and significance of tea

Tea is a refreshing drink. Aroma and taste of a cup of tea brings freshness to every one's mind. It is accepted as one of the highly sought after drinks in the world and has become an intrinsic part of daily life. Tea was first introduced to the society in China in 2737 BC by Emperor Shen Nong when a leaf fell accidentally in a pot of boiling water from an unknown shrub. In India, it was discovered in Assam by Robert Bruce in 1823 among the Singpho tribes. Tea plant was scientifically named as *Camellia Sinensis* in 1833. India produces around 1350 M kg of tea annually and is the second largest tea producing country after China. Around 20% of the tea production is exported to other countries. The remaining amount is used for domestic purposes. India exported 201 M kg of tea in the financial year 2021-22 [15]. However, around 18% decline in the export quantity occurred in 2020 primarily due the corona virus outbreak. The total area for tea plantation covers 579350 hectares of land. More than 1.5 million people are associated with the tea industry in India. It provides indirect employment in the machinery, chemicals and transportation sector in addition to being directly associated in the tea production. The tea industry contributes immensely to the overall economy of the country. Out of the total tea production in India, about 50% tea is produced in Assam [102]. The special feature of the Assam tea is recognized worldwide. Thus, it becomes crucial to emphasize on the development of this industry to sustain these benefits. Incorporation of novel and efficient machinery in the tea sector may help in achieving the goals. Moreover, tea manufacturing being an energy intensive operation, steps may be taken to involve energy conserving economic practices in the process. The process of tea manufacturing is discussed briefly below.

1.2 Tea processing

After harvest, the fresh tea leaves undergo five primary operations before the production of made tea- withering, maceration, fermentation, drying and grading or sorting. Fig. 1.1 shows the flow chart of the tea manufacturing process. Tea-leaf withering and tea drying are the operations which primarily consumes energy in tea manufacturing. Drying consumes the highest amount of thermal energy. Coal, natural gas, oil and wood are the generally used sources of thermal energy in the tea industries. The first three fuels are mainly used in Assam and the latter is used in the

1

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