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FEASIBILITY OF COGENERATION IN A FRUIT CANNING FACTORY

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ABSTRACT

Electrical and thermal energy audits in a fruit canning factory are presented. The specific fuel oil consumption of the factory in 1989 was found to be about 30.0 l/t of products. The specific electricity consumption in the same year was about 41.1 kWh/t of products. The average heat to power ratio of the factory was about 8.

Technical and economic evaluations of cogeneration potential are conducted for the fruit canning process by means of modeling and system simulation. Topping-cycle cogeneration with a back-pressure steam turbine is considered at three steam loads required by the factory and six levels of turbine inlet pressure with dry saturated and superheated conditions. Grade-C bunker oil is assumed for the cogeneration system simulation.

The technical potential evaluation indicated that 432-2171 kW electrical generation would be suitable for factory. From the techno-economic evaluation, installation of a steam turbine at the process steam rate of 17 t/h and inlet saturated steam pressure 82.7 bar gauge gives the highest internal rate of return about 22.3% and a pay-back period of 6 years at an interest rate of 9.5%.

A sensitivity analysis of the effects of two parameters (fuel price and annual operating time) on the rate of return and pay-back period was carried out. It is found that the rate of return increases as the annual operating time increases. A small increase in the fuel price hardly affects the rate of return.

INTRODUCTION

Food industry is one of the major industries in Thailand. The industry covers a wide range of products such as fruits, sea food, cooking oils, flour, alcoholic drinks, soft drinks, animal feeds, etc. From 1989 statistics, 10,262 companies in this industry are scattered all over the country.[1]

This study covers the energy audit and feasibility of cogeneration in a fruit canning factory. The factory purchases electricity from the Provincial Electricity Authority through five 500 kVA transformers. Four stand-by diesel generators are available with a total capacity 2,060 kW.

Steam for various processes in the factory is supplied by two boilers, each with a capacity of 12 t/h and one boiler with a capacity of 6 t/h. The maximum and operating pressures of the boilers are 10 and 8 bars, respectively.

ENERGY AUDIT

In 1989, the factory consumed 4.449 M litres of fuel oil and the annual-average specific oil consumption was about 30 l/t of products. The amount of electricity consumption in the same year was 6.526 GWh and the annual average specific electricity consumption was about 41.1 kWh/t of products.

The average demand of steam in 1989 was about 17 t/h and varied between 25 to 10 t/h. The average electrical power requirement in the same year was 1.63 MWe with the peak demand at about 2 MWe.

The heat to power ratio of the factory in 1989 varied between 6.5 to 10 and its average value was about 8. Hence, cogeneration with a steam topping cycle seems feasible for the factory, see Figure 1.

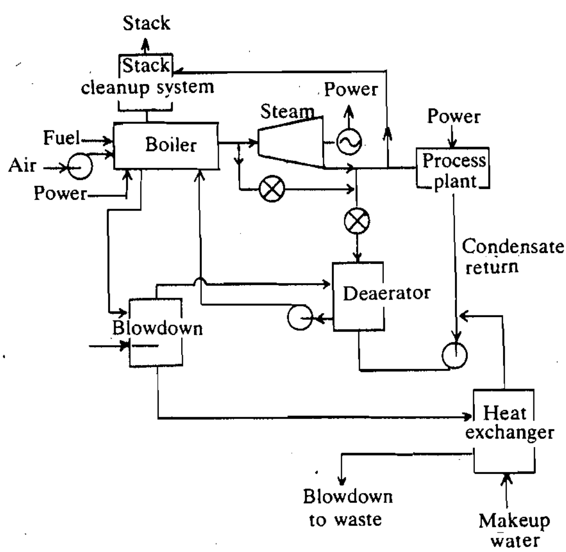


Fig. 1 Proposed cogeneration system

FEASIBILITY STUDY OF COGENERATION

Steam cogeneration is practiced in several Thai industries such as petro-chemicals, foods, oil mills, rice mills, sugar mills, etc. The total generating capacity of these industries exceeds 850 MWe or 10% of the total capacity of the Electricity Generating Authority of Thailand[1].

Detail studies on steam cogeneration systems have been conducted in sugar mills[2,3], palm oil mills[4,5], rice mills[6,7], paper mills[8], oil refinery[9], dyeing factory[10], etc. Most of the studies include system modeling and simulation to determine improvement measures for the cogeneration systems.

To study the feasibility of cogeneration in the fruit canning factory, the following assumptions are made.

Technical Assumptions :

1. A steam topping cycle with a back - pressure turbine and generator is considered.
2. The grade C fuel oil is used to fire the boiler, its HHV is 41.44 MJ/kg.
3. The first law efficiency of the boiler is 85%.
4. Six turbine inlet pressures are assumed at 27.6, 41.4, 48.3, 62.1, 68.9 and 82.7 bars gauge.
5. Three steam flow rates are assumed at 27, 17 and 10 t/h with two steam conditions, namely saturated and superheated at 400°C.
6. The exhaust pressure from the turbine to processes is at 8 bars gauge.
7. The first law efficiency of the turbo-generator is 65%.
8. The number of operating hours of the cogeneration system is 3960.
9. The continuous blow-down is about 5% of the steam production rate.
10. The temperature of the make-up water is at the ambient temperature of 30°C.

Economic Assumptions :

1. The price of the fuel oil is 3.06 baht/l.
2. Economic life time of the system is 25 years with a salvage value of 10% of the system first cost.
3. Annual operating and maintenance cost is 5% of the system first cost.
4. The stand-by electricity rate is 220 baht/kW-yr.
5. The average electricity price is 1.62 baht/kWh.
6. The flat buy-back rate is assumed at 1 baht/kWh.
7. The first cost in 1990 of the cogeneration system in USD is derived from references[11,12] and given as

$$-42071 + 1618.7\ P - 0.1067\ P^2$$

where P = output power in kWe, for a range from 500-5000 kWe.

With the above assumptions, the feasibility assessment of the cogeneration system is conducted by the procedure shown in Figure 3.

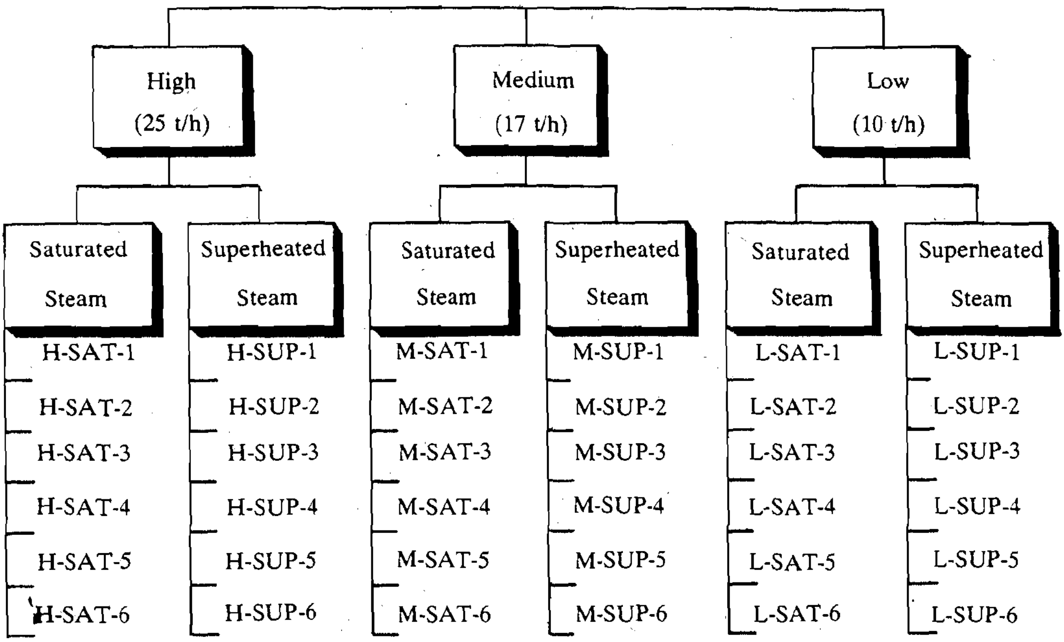


Fig. 2 Cases under feasibility assessment

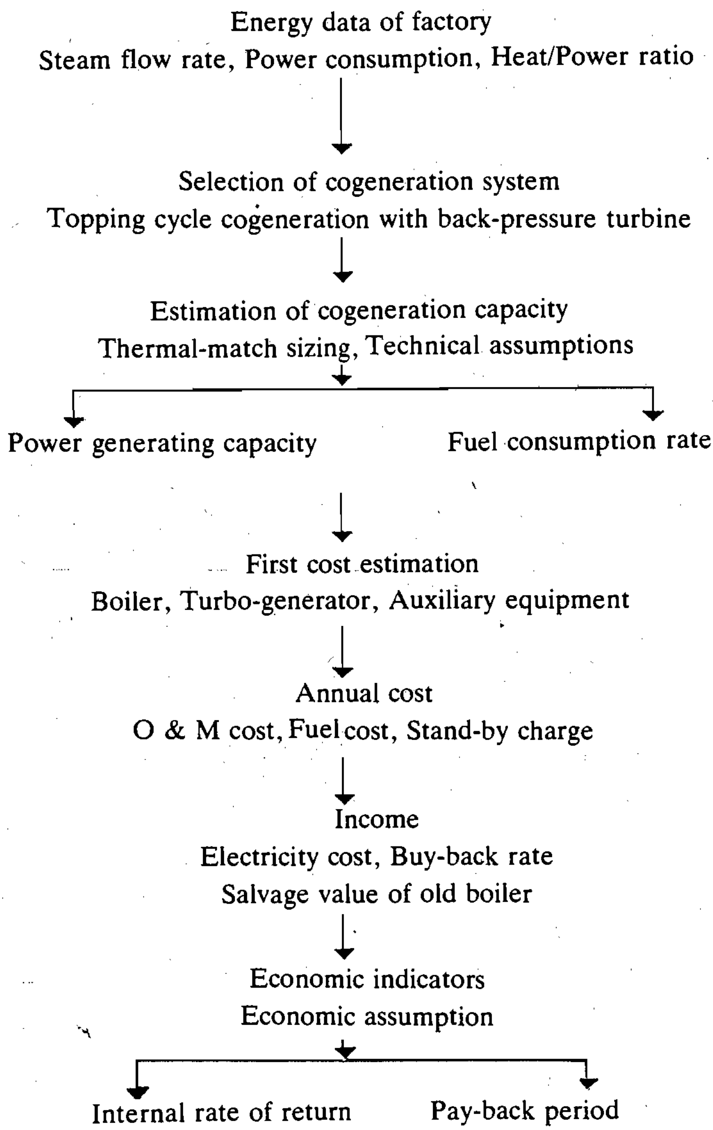


Fig. 3 Assessment procedure for technical and economic potentials

A computer programme is developed for the above assessment procedure and used for evaluating the feasibility of various scenarios of the proposed cogeneration system.

THEORETICAL CONSIDERATION

Capacity of the cogeneration system in this study is selected thermal-match sizing. Process heat in the exhaust steam is the main product and the generated electricity is regarded as the by-product.

The rate of process heat is estimated from

$$m_s (h_e - h_f),$$

where m_s = steam flow rate from the turbine,
h_e = specific enthalpy of the exhaust steam from the turbine,
h_f = specific enthalpy of feed water.

The fuel consumption rate of the cogeneration system, m_f, is determined from:

$$m_f = (h_s - h_f)\, m_s/(HHV.\, \eta_b)$$

where h_s = specific enthalpy of steam from the boiler,
HHV = higher heating value of the fuel,
η_b = first law efficiency of the boiler.

The electric power generated, P, is determined from,

$$P = m_s (h_s - h_e)\, \eta_{tg}$$

where η_{tg} = turbo-generator efficiency

The heat to power ratio, r, is calculated from the definition,

$$r = \frac{\text{rate of process heat}}{\text{electric power generated}} = \frac{h_e - h_f}{(h_s - h_e)\eta_{tg}}$$

The following economic equations are employed for the economic feasibility study:

Income = Total revenue - Total expenses

Total revenue = Displaced electricity +
Excess electricity sold +
Displaced boiler fuel cost +
Displaced boiler O & M cost.

Total expenses = Cost of cogeneration fuel +
Cost of cogeneration O & M +
Stand-by charge.

CONCLUSIONS AND RECOMMENDATIONS

The feasibility study covers three steam flow rates at saturated and superheated conditions and six levels of turbine inlet pressures, see Figure 2. By using procedure shown in Figure 3, ranges of total installation cost and power generating capacity are determined and shown in Figures 4 and 5. Cogeneration systems with power generating capacities between 432 and 2171 kWe seem to be technically feasible. The best case occurs when dry saturated steam enters the turbine at 82.7 bars gauge with the flow rate of 17 t/h. The power output is estimated at 1476 kW. The rate of return on investment is 22.3% and the pay-back period is 6.1 years, see Figures 6 and 7.

The low rate of return and long pay-back period occur as a result of small working hours per year. A sensitivity analysis shows that the economics of the cogeneration system would be more attractive if the annual operating time of the factory is longer. For example, if the operating time is increased by 40%, the rate of return would increase to 31% and the pay-back period would be reduced to about 4 years, see Figure 8.

A cheaper boiler fuel such as lignite will slightly enhance the economic feasibility, see Figure 9. However, some environmental problems from the combustion of lignite may not be acceptable to the food factory.

Feasibility of the cogeneration system using a compression-ignition engine and a waste heat boiler should also be conducted, especially at a low heat/power ratio scenario.

It is also recommended that technical and economic feasibilities of cogeneration in other types of food factories should be assessed in order to obtain the total potential for power generation of the food industry in the country.

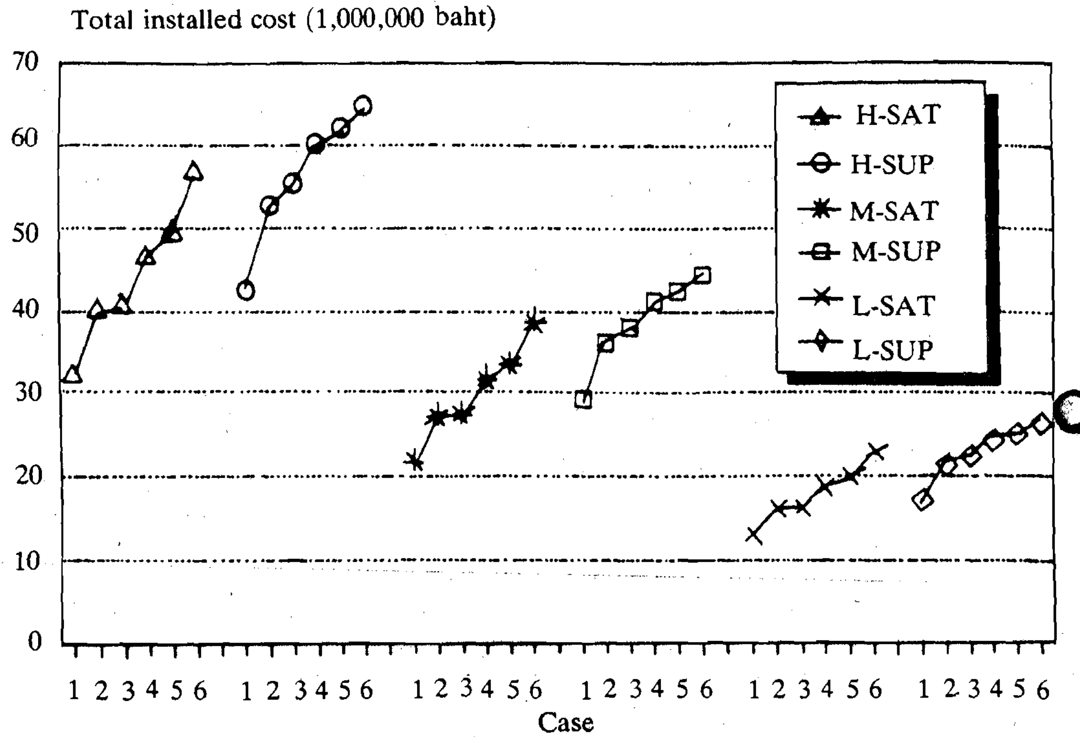


Fig. 4 Total installed cost of cogeneration system

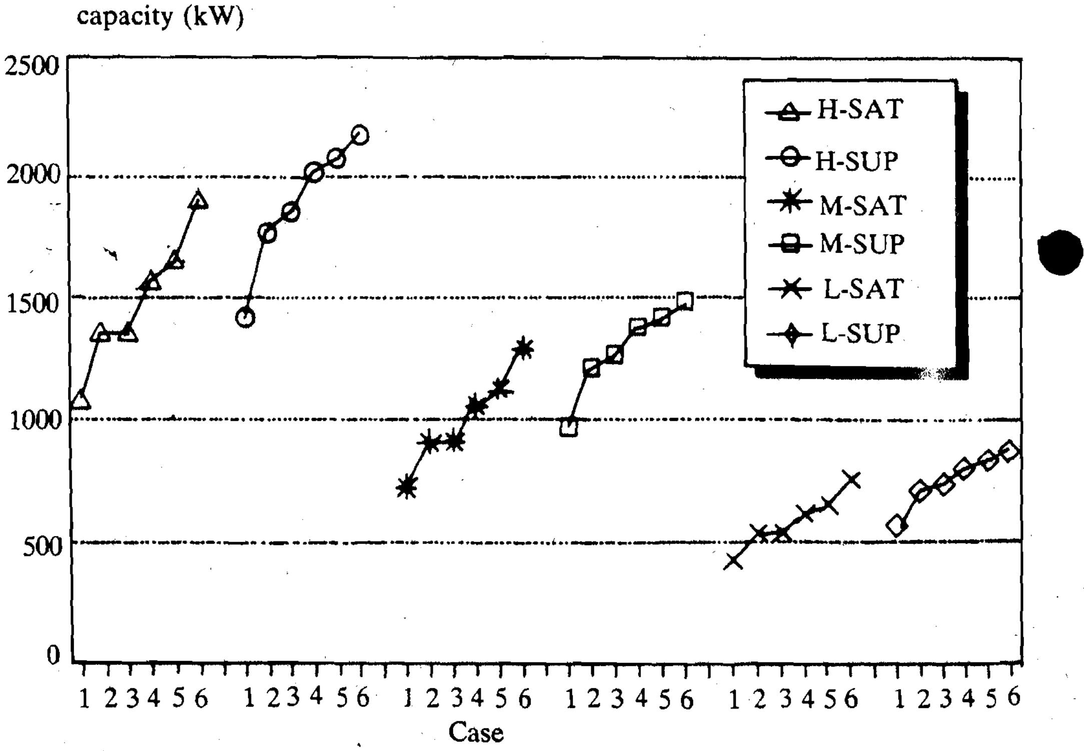


Fig. 5 Estimation of power generating capacity

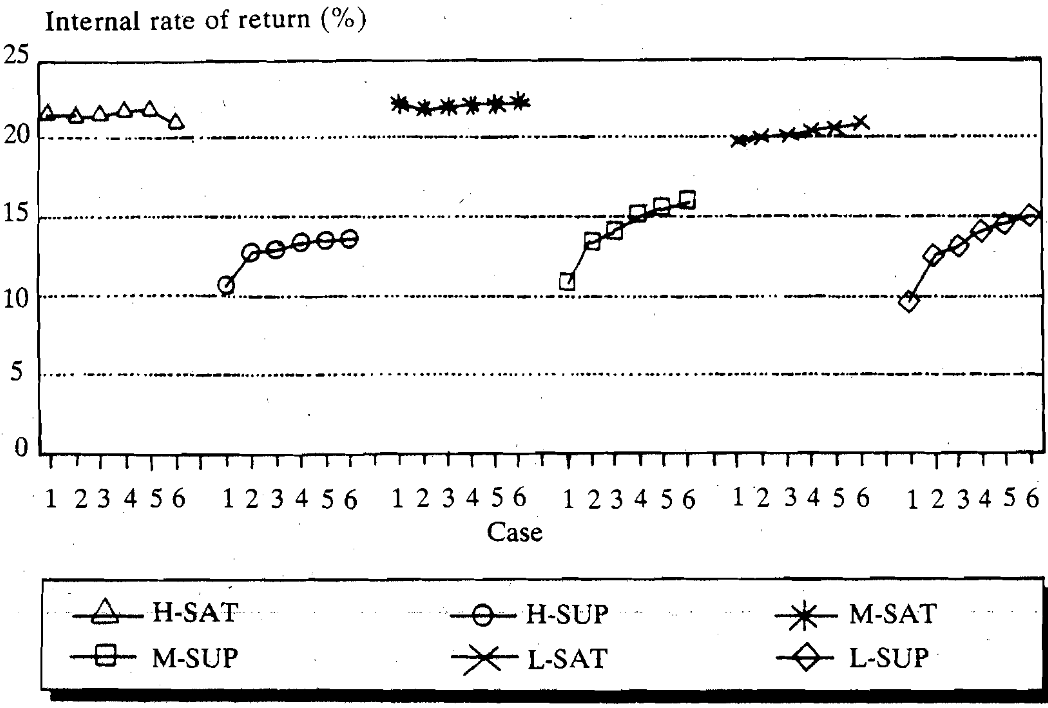


Fig. 6 Internal rate of return of cogeneration system

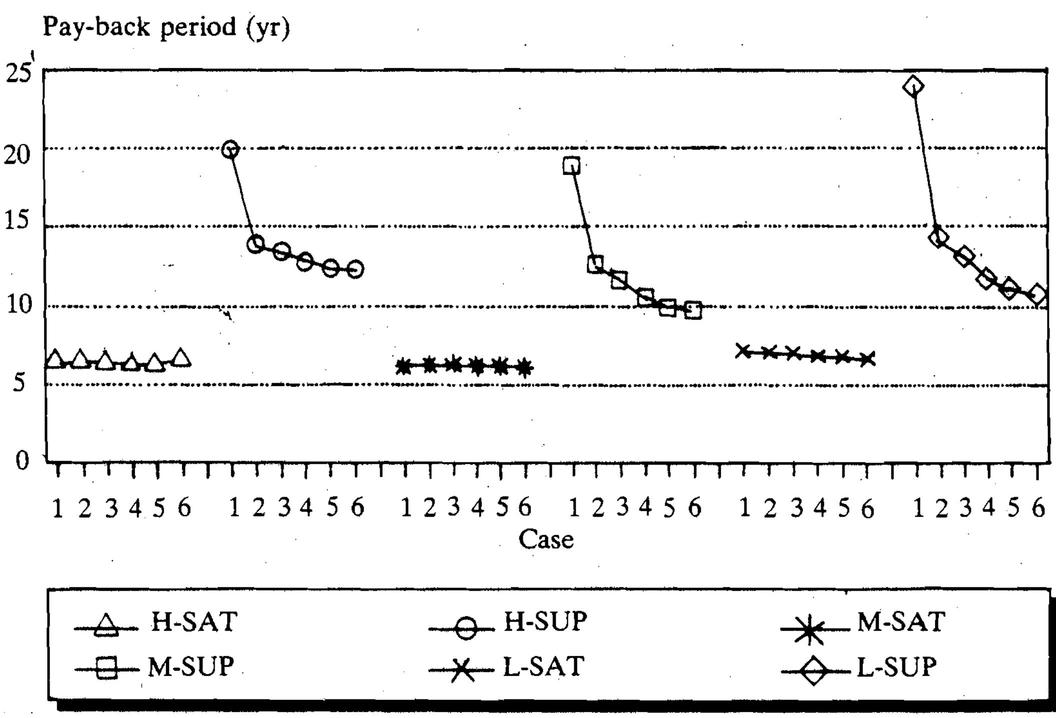


Fig. 7 Pay-back period of cogeneration system

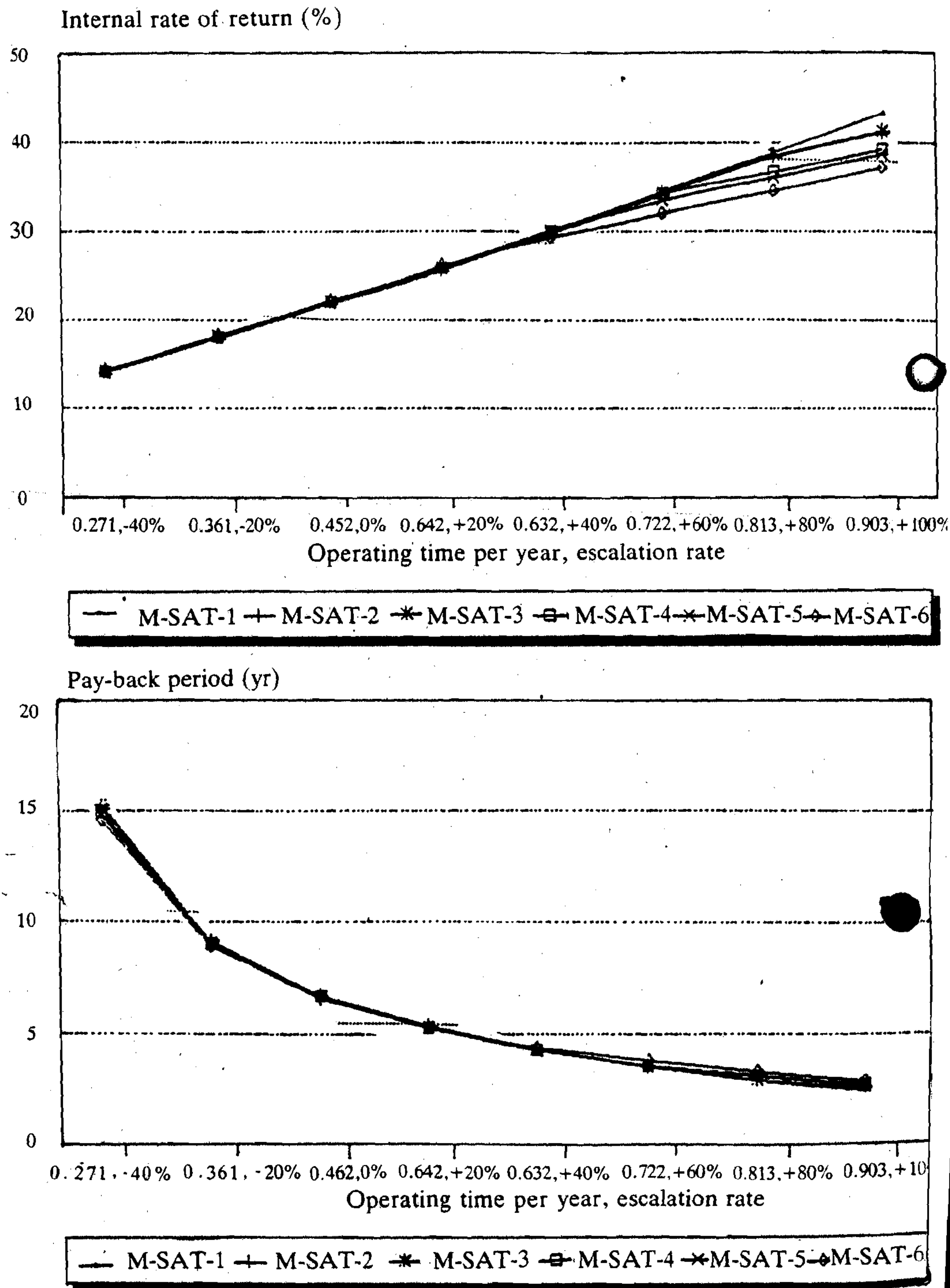
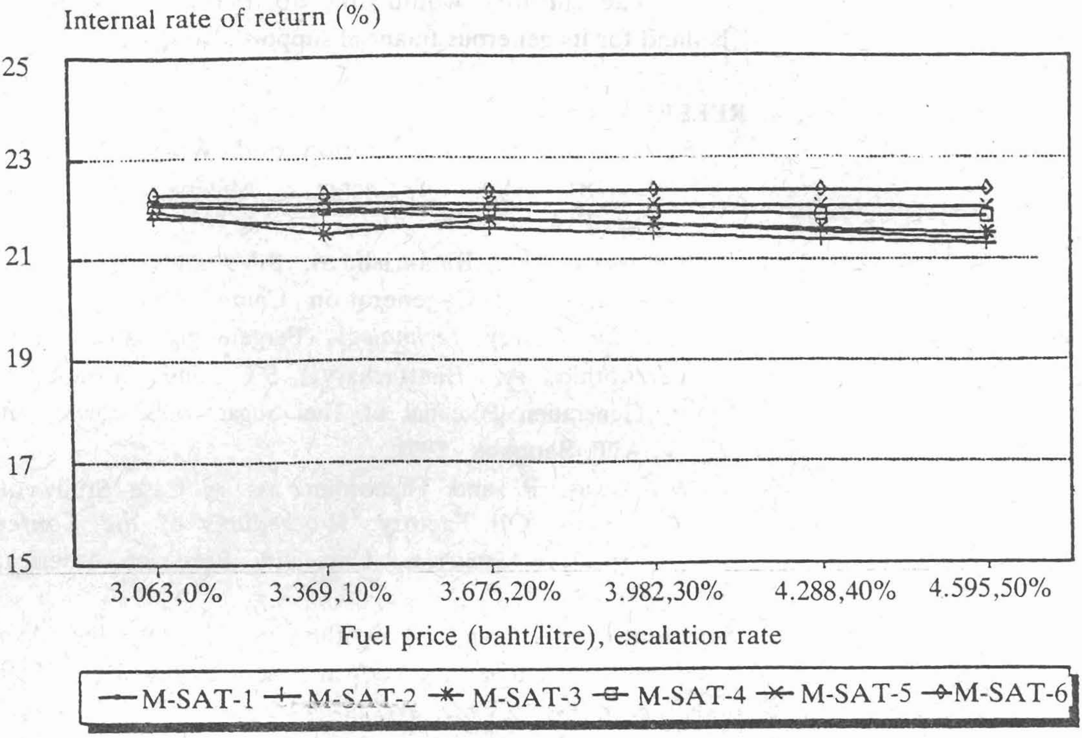


Fig. 8 Effects of operating hours on investment



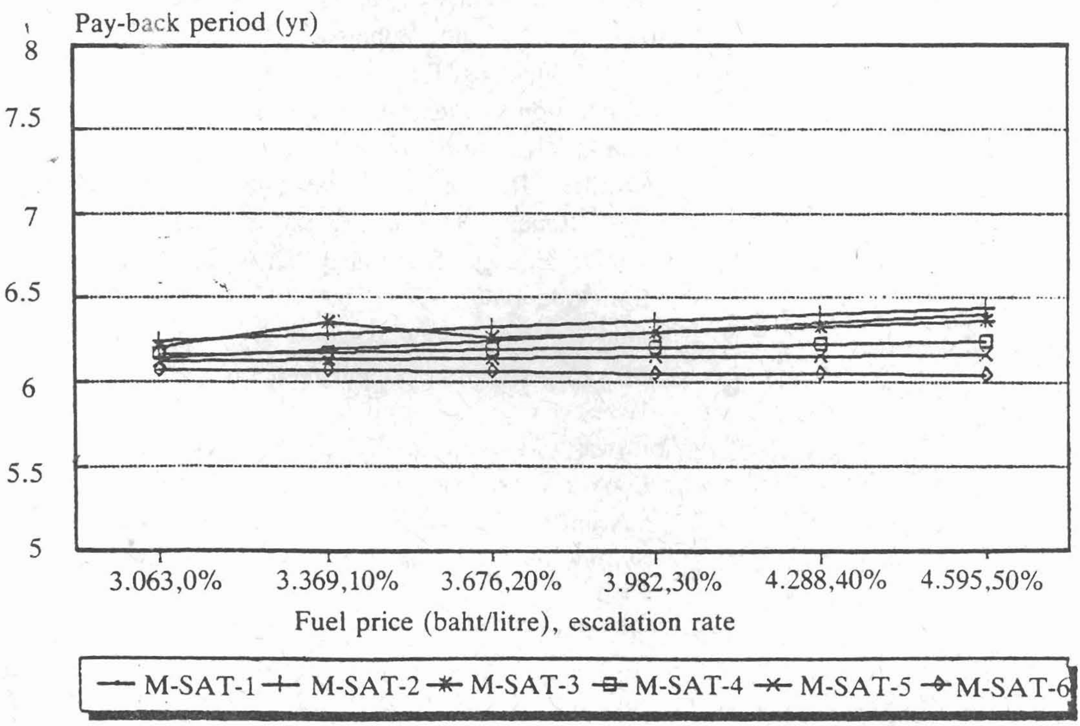


Fig. 9 Effects of fuel price on investment

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