INTERNATIONAL SYMPOSIUM
on
ENERGY, ENVIRONMENT AND ECONOMICS

THE UNIVERSITY OF MELBOURNE
Victoria, Australia
20-24th November 1995

TRANSACTIONS

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EDITOR: E.J. Colville

ENERGY
ENVIRONMENT
ECONOMICS

THE UNIVERSITY OF MELBOURNE

Paper 8C2

The Use Of A Parallel Passage Plastic Film Rotary Heat Exchanger For An Industrial Heat Reclaim Application

W.M.J. Ellul

Ecopower Consultants Pty. Ltd.

ABSTRACT

A novel rotary air heater or sensible heat regenerator has been installed, commissioned and tested, in a Melbourne industrial paper drying machine with the purpose of recovering waste heat from the drier exhaust to preheat fresh air to the drier and substantially reduce the natural gas usage of the drier. The system was designed to use a novel rotational speed automatic control to maintain flue exhaust temperature exiting the heat exchanger at a high enough level to avoid harmful condensation of drier products in the gas stream. The system operation and test results are described and economic savings on natural gas cost reduction estimated for the operation of the drier with waste heat recovery. An economic analysis indicates a simple payback of 1.7 years on the capital cost of the installation.

KEYWORDS

Waste Heat Recovery Rotary Sensible Heat Exchanger Regenerator Drying Preheat Fresh Air Exhaust Temperature Control Condensation Simple Payback Economic

INTRODUCTION

Ecopower Consultants recently designed and installed a waste heat recovery system including a novel rotary air to air heat exchanger (heat wheel) at Jac Australia Pty Ltd adhesive label manufacturing plant at Tottenham Victoria. The system recovers waste heat from a water based self adhesive coating drier which significantly reduces the natural gas required to operate the plant. The project was one of several energy cost savings recommendations by Ecopower after conducting a full Energy Audit of the factory.

Ecopower Consultants is accredited by the I. E. Aust. to conduct energy auditing under a Commonwealth Government EEAP program which funds 50% of the cost of most audits.

The heat wheel was manufactured by Rotary Heat Exchangers Pty Ltd Melbourne, is a world first and utilises a high temperature resistant Kapton plastic film which forms the matrix for heat transfer and will operate in this application with exhaust temperatures up to 200 C.

The heat wheel operates at very high efficiencies of over 90%. A novel method of avoiding the harmful affects of condensation of condensable gases in the exhaust gas exit due to the high efficiency cooling was avoided by controlling the rotational speed of the wheel.

The rotary heat wheel is often termed a sensible heat regenerator and uses for this type of heat exchanger ranges from heat recovery in air conditioning systems and fruit drying, where temperatures are relatively low, Van Leersum (1978), as well as in combustion air pre-heating in modern electricity power stations where temperatures up to 400 C are used with metal matrix construction, Ellul et al (1985).

ROTARY HEAT WHEEL CONSTRUCTION

The heat wheel is constructed by spirally winding the plastic Kapton film, which is about 1 mm thick and 150 mm wide, around a central aluminium wheel hub. Channel section Aluminium spokes extend from the bub and contain 1 mm thick spacers which separate the plastic film to form a wheel matrix of narrow parallel passages for gas flow and heat transfer. This optimises the high heat transfer and low pressure drop characteristics of the unit forming a very efficient low pressure drop compact design.

Heat is indirectly transferred from the hot exhaust gas flow to the fresh air flowing in a counterflow direction by the parallel passage plastic wheel matrix as the wheel rotates between the two flows. The heat wheel is located inside an insulated plenum chamber which separates the exhaust from the heated fresh air to the drier. This is shown in Figure 1 which is a schematic of the heat recovery system and in the photographs of the roof mounted heat recovery system.

Clearance and rubbing seals are used to minimise any leakage of exhaust gas into the fresh air stream and carryover of exhaust into the fresh air stream by the rotating matrix is kept to a minimum by the low rotational speed of the wheel. A small variable speed AC electric motor is used to drive the heat wheel and a small fresh air fan is used to blow fresh air into the fresh air side and to assist the larger drier exhaust fan which provides most of the driving force for exhaust gas and fresh air flow in the system.

ADHESIVE COATING DRIER

The drier is indirectly heated by heat transfer oil which is heated by a natural gas fired hot oil heater. A centrifugal exhaust fan provides a large fresh air flow through the drier and results in a continuous high temperature exhaust flow out of the drier which, prior to the installation of the heat recovery system, was exhausted directly to atmosphere through a flue on the roof of the factory.

The fresh air at ambient conditions was blown directly into the drier where it was heated and exhausted to atmosphere at temperatures ranging from 80C to 200C depending on the actual drying process being used during production. The exhaust air contains drying products which could not be recycled back to the drier. Therefore an air to gas heat exchanger can be used to recover heat from the hot exhaust and result in a substantial reduction in natural gas consumption.

As the drier is operated typically around the clock, considerable savings can be achieved.

SYSTEM OPERATION AND CONTROL

As shown in Figure 1, the drier hot exhaust gas, location 4, passes through the rotary heat wheel where it is cooled by the heat exchanger matrix, location 3, prior to venting to atmosphere through the flue stack. Fresh air, location 1, is drawn in past the heat wheel where it is heated by the rotating matrix and forms the heated fresh air, location 2, which enters the drier to replace the vented exhaust gas.

In order to avoid condensation problems in the exhaust stream, the system was designed to automatically control a preset flue exhaust or exit temperature by controlling the rotational speed of the heat wheel by controlling the variable speed drive.

The heat wheel rotates between the range 2 RPM and 20 RPM. A slower rotating wheel transfers less heat and consequently results in a higher flue stack temperature. As the wheel increases in speed it transfers more heat resulting in a lower flue exit temperature and a greater risk of condensation.

Flue exit temperature needs to be maintained above vapour dew point temperature to avoid the harmful corrosive affects of condensation in the heat recovery system and flue stack. The dew point temperature limits will also depend on the particular vapours in the stream which vary depending on the particular drying production run.

PERFORMANCE TESTS

Performance tests were conducted on the waste heat recovery system by Ecopower Consultants.

The aims of the tests are:

- To determine the heat exchange performance of the system under varying conditions.
- To determine whether condensation of flue products and contamination of the wheel matrix will occur and if so to determine operational strategy to avoid condensation and contamination.
- To estimate the annual energy cost savings and payback period of the installation to Jac Australia.

Tests were conducted on three separate days over a two week period at drier exhaust temperatures 87 C, 125 C and 142 C. Results for the 142 C tests are shown in Figures 2 & 3.

ANALYSIS OF RESULTS

Figure 2 shows the variation with wheel rotational speed of heat transfer efficiency Eh for the hot (exhaust gas) stream and Ec for the cold (fresh air) stream,. Figure 3 shows the variation with wheel rotational speed of heated fresh air, temperature 2 and exhaust gas, temperature 3, exiting the heat exchanger.

The results clearly indicate that (as was expected) due to a much higher exhaust gas flow than fresh air flow, there is an imbalance of efficiencies indicated by Ec for the fresh air side being much larger than Eh for the exhaust gas side. Ec efficiencies of close to 100% are easily obtained because of the high efficiency of the heat wheel as well as the effect of the flow imbalance favouring Ec. Note that the drier is designed to allow fresh air to enter through other locations which cannot be easily directed through the heat recovery system and accounts for the unbalanced flows.

The test results indicate that high efficiency in heat transfer is quickly obtained at relatively low rotational speeds and that the flue gas exhaust temperature can be controlled by controlling the wheel speed.

Inspection of the wheel on shutdown indicated that the matrix is remaining remarkably clean and dry with no contamination on the matrix, but evidence of condensation of white fluid was evident at the base of the flue section. The results indicate that this is more likely to occur when the set point temperature is set low and is the result of condensation occurring along the exposed flue section. Increasing the set point temperature and insulating the flue are measures that have been adopted to avoid condensation as the exhaust is cooled while travelling in the flue pipe. Periodic inspections during down times were also recommended.

ECONOMIC EVALUATION

Fresh air flow was measured by pitot static measurements across the 600 mm dia fresh air duct. This indicated that fresh air flow was 5,875 kg/h.

The design fresh air requirement for the drier is given as 8,025 kg/h (2.2 kg/s) and exhaust flow as 10,975 kg/h by the drier manufacturer. This gives a heat exchanger efficiency imbalance of 60% which as expected, approximately equates to the imbalance in Eh and Ec seen in the results.

Note that due to a deterioration of the original plenum box access door seals due to the high temperature a proportion of air was being sucked into the fresh air chamber prior to entering the heat wheel and would account for the discrepancy in fresh air flow measurement. For the purpose of the economic analysis the design air flow value is used. This problem was later rectified by improving the access door sealing arrangement.

Waste Heat Recovery

Waste heat recovery was calculated using the fresh air flow and temperature change between ambient temperature and heated fresh air temperature 2 as given in the following equation.

Heat recovery = $m_{fa} \times Cp \times \Delta t$ [GJ/h]

Where m_{fa} and Cp are respectively the fresh air mass flow rate and specific heat. For the three exhaust gas temperature conditions of the tests the following results were obtained:

Drier Exhaust Temp	Heat Recovery GJ/h
87 C	0.6
125 C	0.9
142 C	1.0

These results indicate that as expected, the higher the temperature of operation the larger the heat recovery rates and consequently the higher the natural gas cost savings.

Estimated Average Savings and Payback Period

Assuming a 6,500 hr annual operation which corresponds to five day 24 hr operation and some weekend operation, an average heat recovery rate of 0.9 GJ/h and a $4/GJ natural gas cost, energy cost savings become:

6,500 x 4.0 x 0.9 = **$23,400 per annum**

This represents a **1.7 years** payback for a capital installation cost of $39,000.

Due to the relatively high exhaust gas temperatures used by the drier, the relatively small seasonal variations in ambient is not expected to significantly affect these savings.

ACKNOWLEDGMENTS

The assistance given by Colin Corlass-Brown, Engineering Manager Jac Australia Pty Ltd and his staff is gratefully acknowledged.

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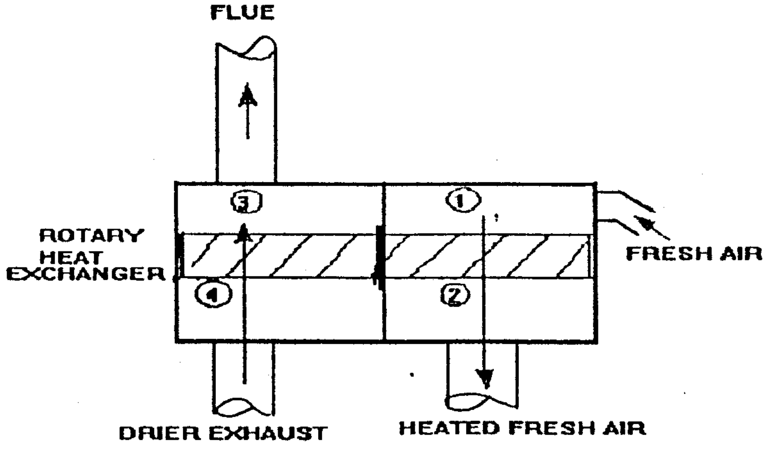
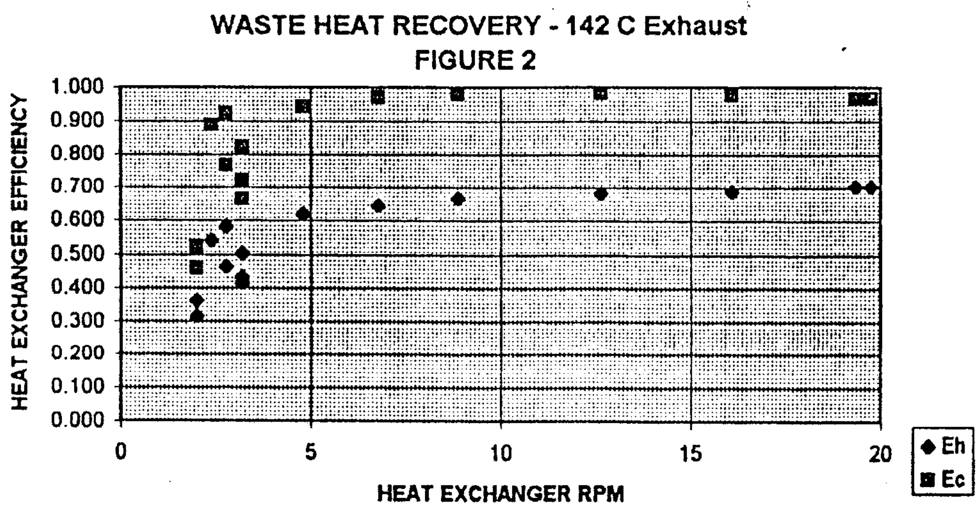
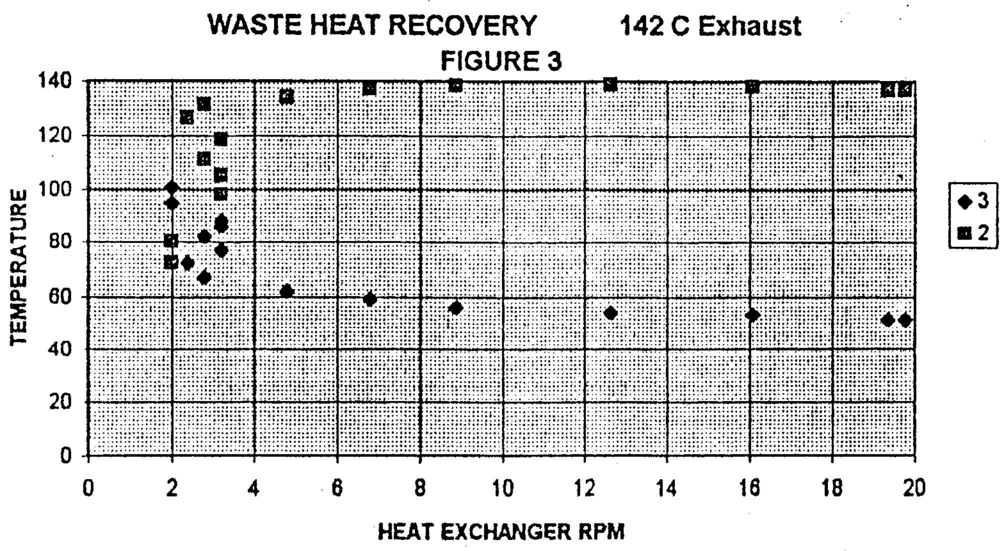
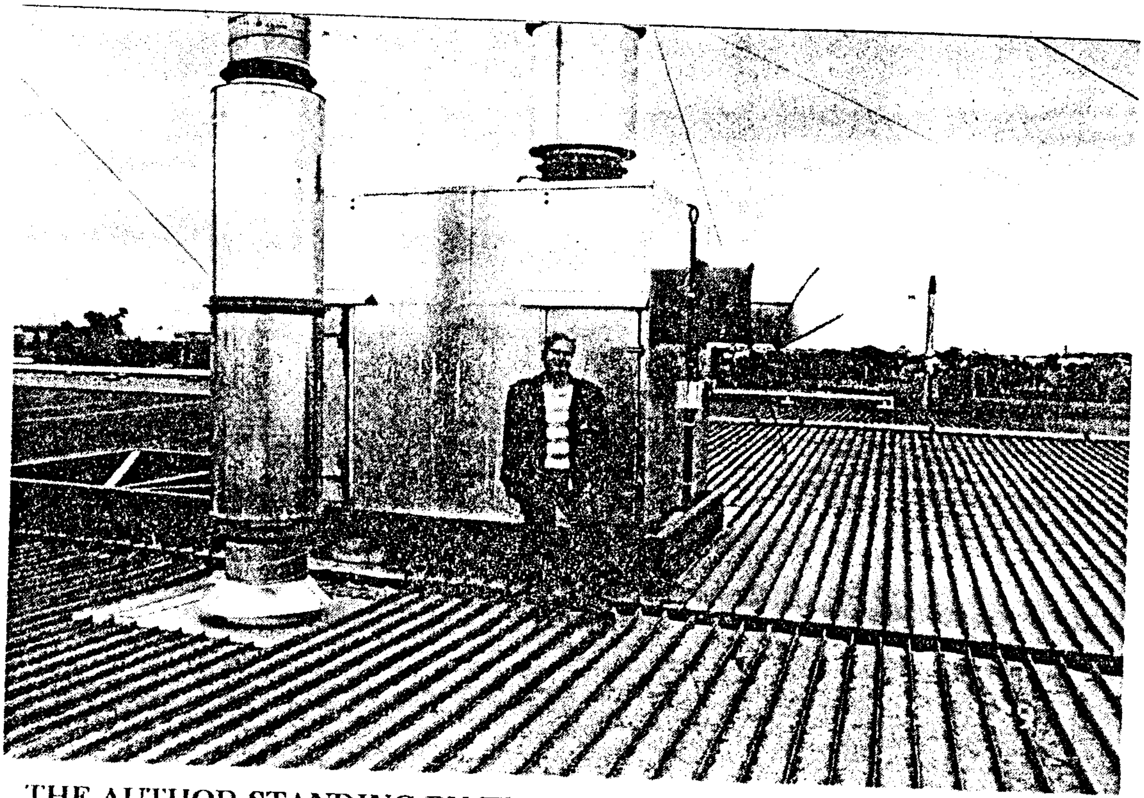


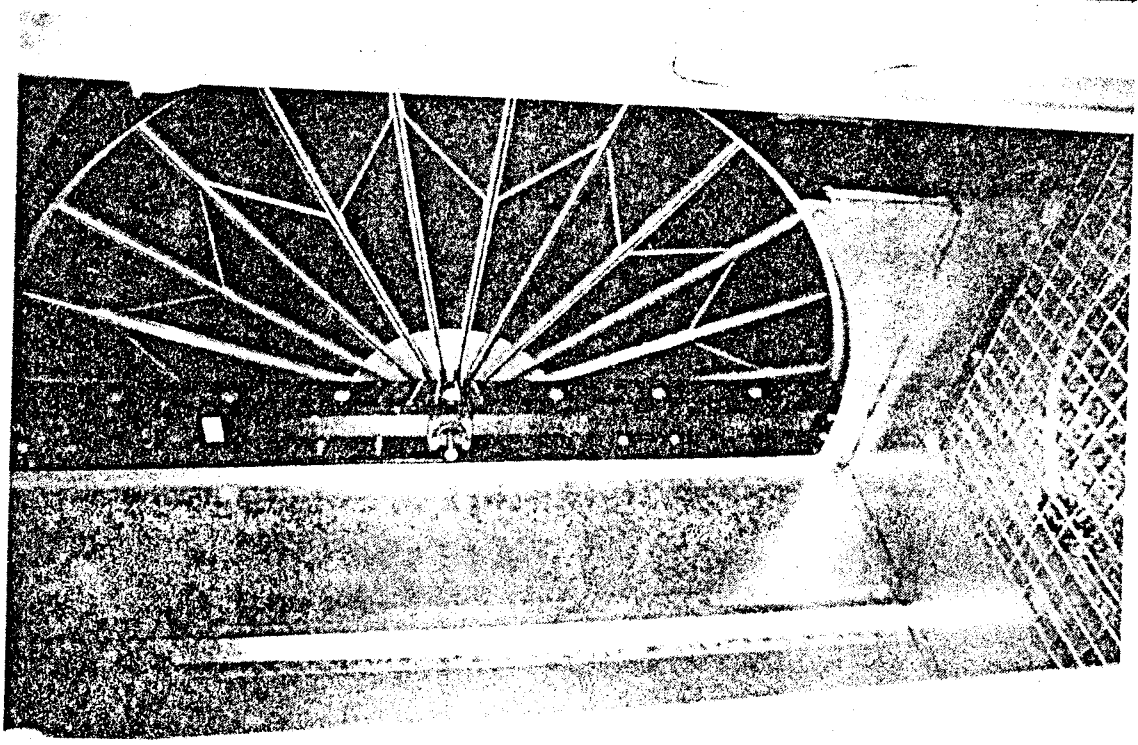
FIG 1. WASTE HEAT RECOVERY SYSTEM



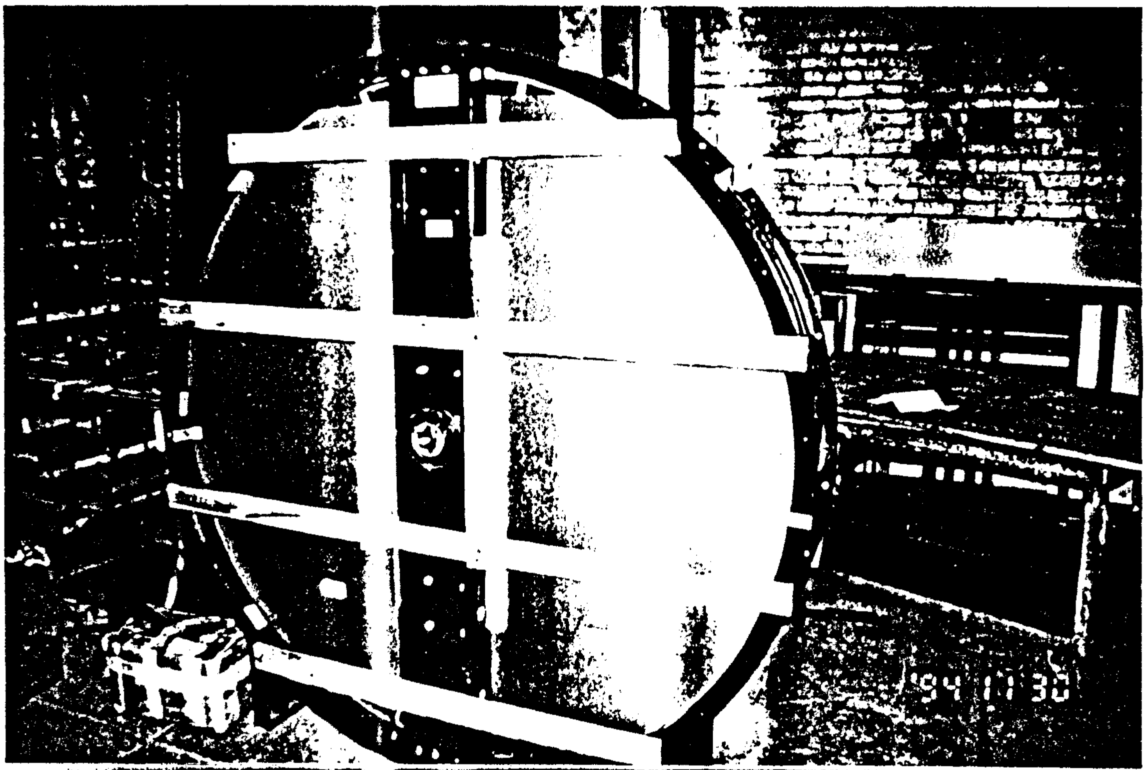


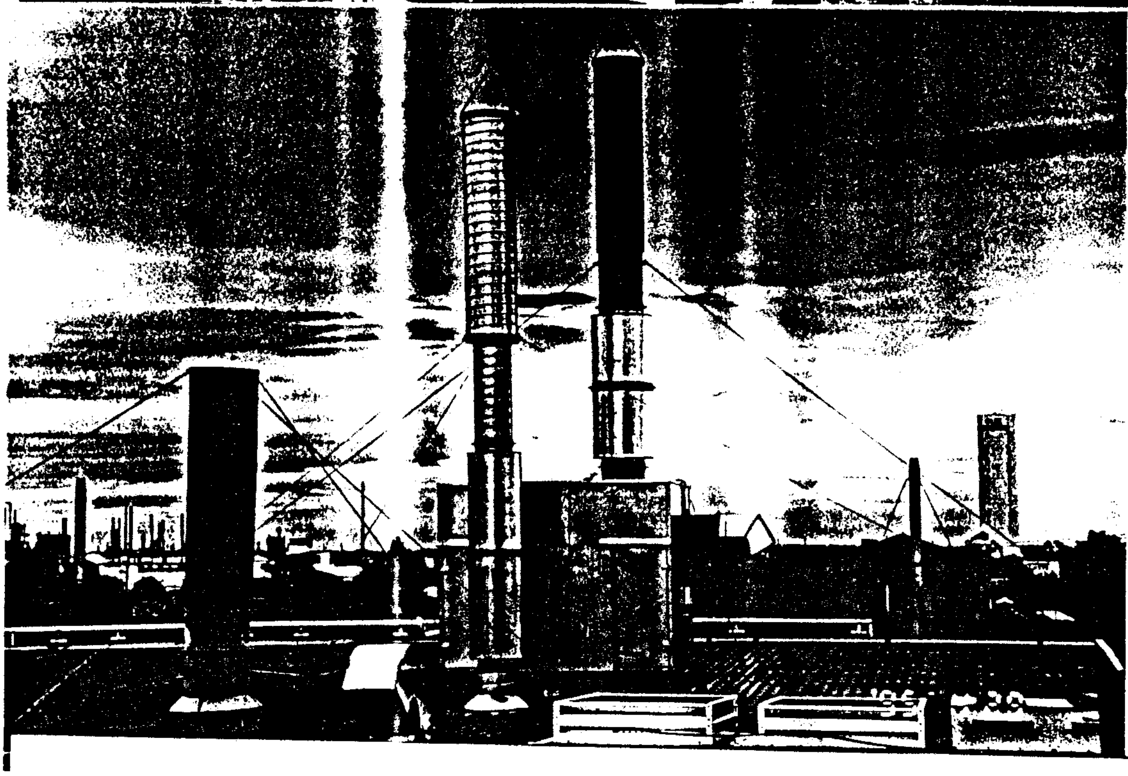


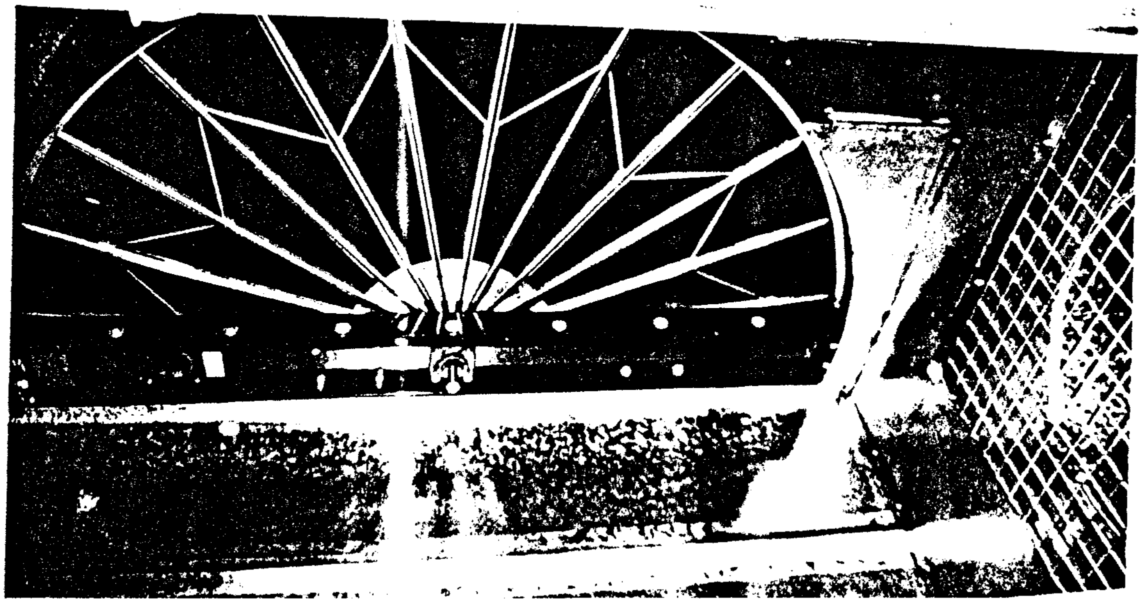
THE AUTHOR STANDING BY THE ROOF MOUNTED HEAT RECOVERY SYSTEM AT JAC AUSTRALIA PTY LTD

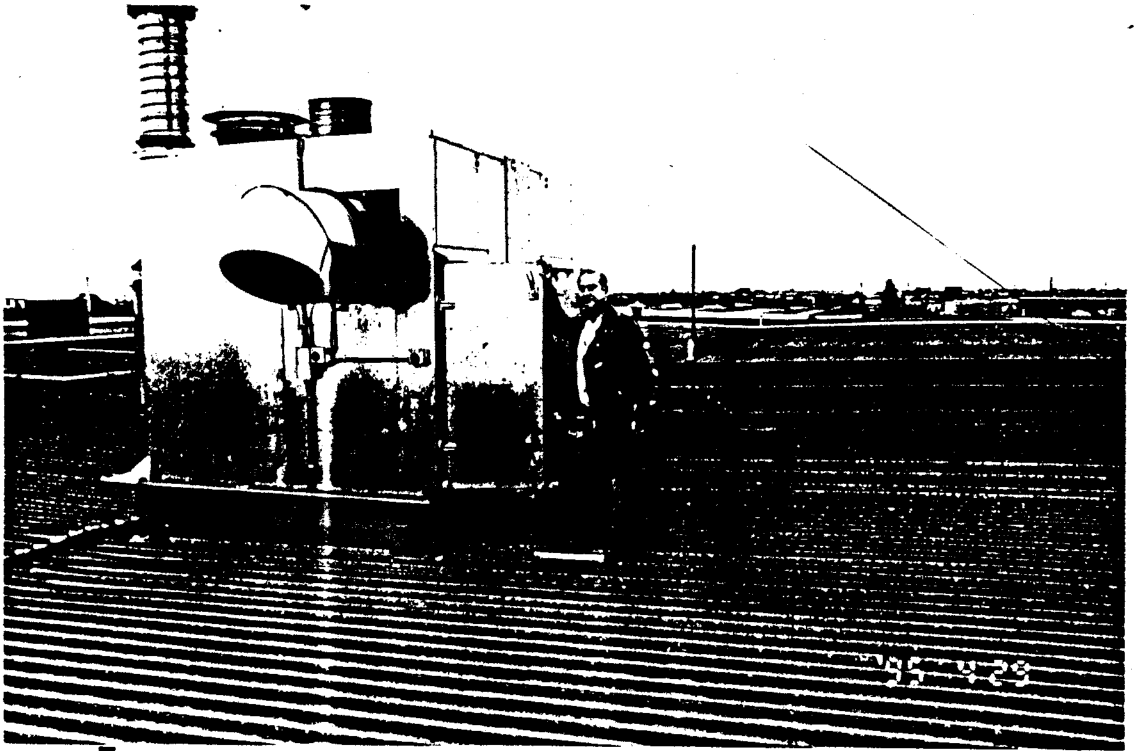


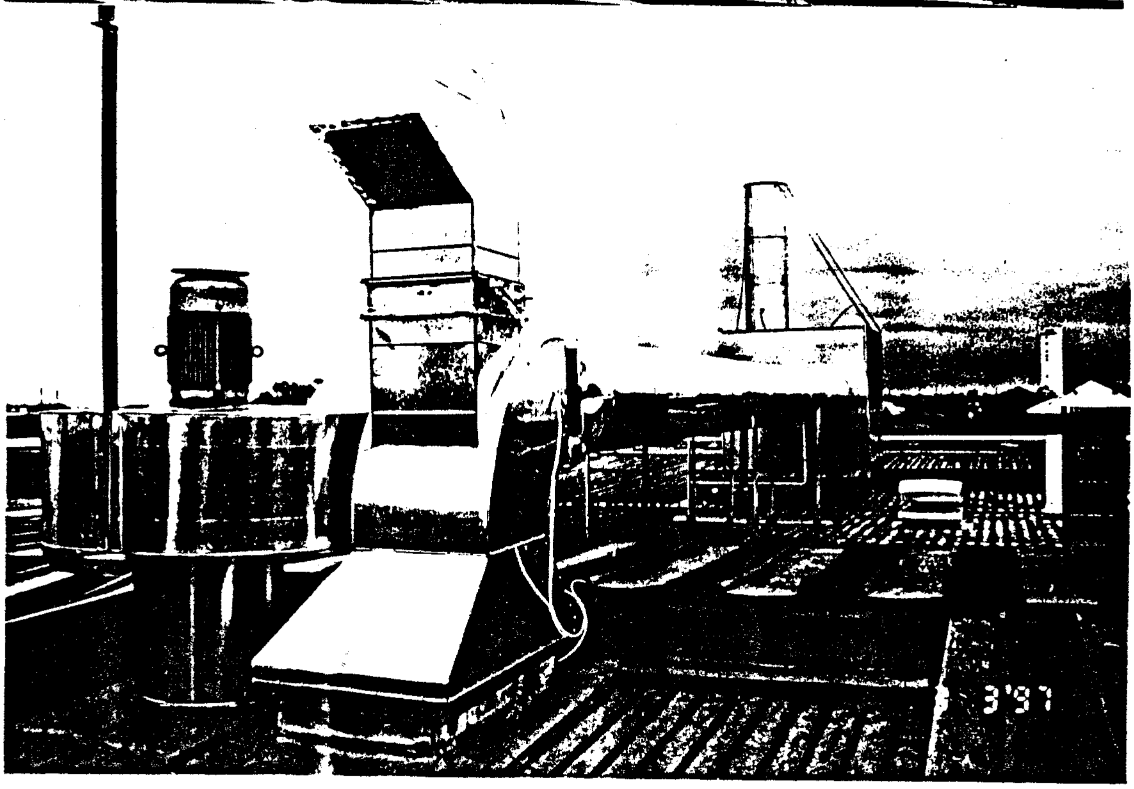
THE ROTARY HEAT WHEEL INSIDE THE PLENUM CHAMBER WHICH SEPARATES THE EXHAUST FROM THE HEATED FRESH AIR







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