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STS PROJECT BULLETIN (C 010494)

ELECTRICITY PRODUCTION FROM FURNACE OFF-GASES

ABSTRACT

A power station producing electricity from furnace waste gases has recently been completed at SAMANCOR METALLOYS in Gauteng, South Africa. A feasibility study conducted in 1991 first identified the potential for utilising the off gases from three electric arc furnaces which were being flared to atmosphere.

The gas, with main combustible constituents of CO and H2, is fed from the furnaces via wet scrubbers to a custom designed water tube boiler. The resulting high pressure steam is then passed through a fully condensing steam turbine attached to a 50 MW generator. The steam is condensed in an air cooled condenser rather than a water cooled system in order to conserve water.

INTRODUCTION

This paper describes a project for generating electricity utilising the furnace off gases from electric arc furnaces at SAMANCOR METALLOYS. One of the largest manganese alloy plants in the world located at Meyerton in Gauteng South Africa.

The furnaces, which are used to produce ferromanganese and silicomanganese consist of three 46 MW closed electric arc units. The electricity consumption comprises 40% of the cost of production. Any savings in electricity therefore would impact positively on profit and competitiveness.

Coal is used as a reductant in the furnaces and the off gas produced, the main elements of which are:

CO	73.2%
CO_2	6.4%
CH_4	1.2%
H_2	11.6%
N_2	3.1%

For design purposes, the calorific value of this gas is taken as 10.9 MJ/nm^3 at a production rate of $17nm^3/s$.

After going through the wet scrubbers, the off gas was being flared to atmosphere. Investigations revealed that up to 185 MW (th) would be flared at peak production times with four furnaces in operation, which if converted to electrical energy would represent a significant percentage of maximum demand.

A feasibility study was initiated to explore options of utilising the gas. Pre-heating the ore feed to the furnaces was one option which appeared attractive; but would involve a major, costly retrofit and was thus excluded. Thoughts then turned to electricity generation and three options were considered:

- Using the gas directly in a gas turbine.
- Firing the gas in boiler and using the resulting steam to power a turbine-alternator set.
- A combined cycle system.

The gas turbine and combined cycle systems were excluded on economic grounds and the option of steam generation for expansion through a turbine was decided upon.

Based on projected benefits and cost effectiveness, the project was given the go ahead and a detailed design initiated.

THE DESIGN

An overview of the design

The design calls for the off gas to be piped from the furnaces, after passing through the wet scrubbers, to the power station site. The gas is then directly fired in a custom designed water tube boiler and requires no further cleanup before being vented through the stack.

The steam produced in the boiler is then expanded through a steam turbine coupled to a generator. After passing through the turbine, the steam is condensed and returned to a deaerator for feed into the boiler. The electricity generated is fed into the works high tension main via a step up transformer.

A water demineralising plant will provide the make up water to the deaerator and the feed water is pre heated in a low pressure heater prior to entering the deaerator.

A requirement of the power station is to be able to operate over a wide range of gas supply rates, as this is dependent on production rates in the furnaces. The control range of the boiler needs to be from 18% to 110% of M.C.R. as well as needing load changing capabilities up to 25% of M.C.R. per minute.
The boiler also has to operate without a back-up fuel as the only alternative fuel is (high cost) LPG which is for main burner light-up only. The boiler and turbo-alternator controls on one of three parameters, namely:

- Frequency control (50Hz).
- Load set point control.
- Gas availability control.

Frequency control is needed to maintain the generated electricity at 50Hz with a steady gas supply and fluctuating electrical load. Load set point control controls the boiler and turbine-alternator so as to maintain a certain steady electrical output. Gas availability control varies the electrical output according to the gas availability at the time. It is this, third condition that forms the essence of the control philosophy.

Communication between the individual components of the power station and with the central control room is vital to effect this control philosophy, and so a sophisticated digital control system has been installed.

A process flow diagram of the steam and condensate system is shown in figure 1.

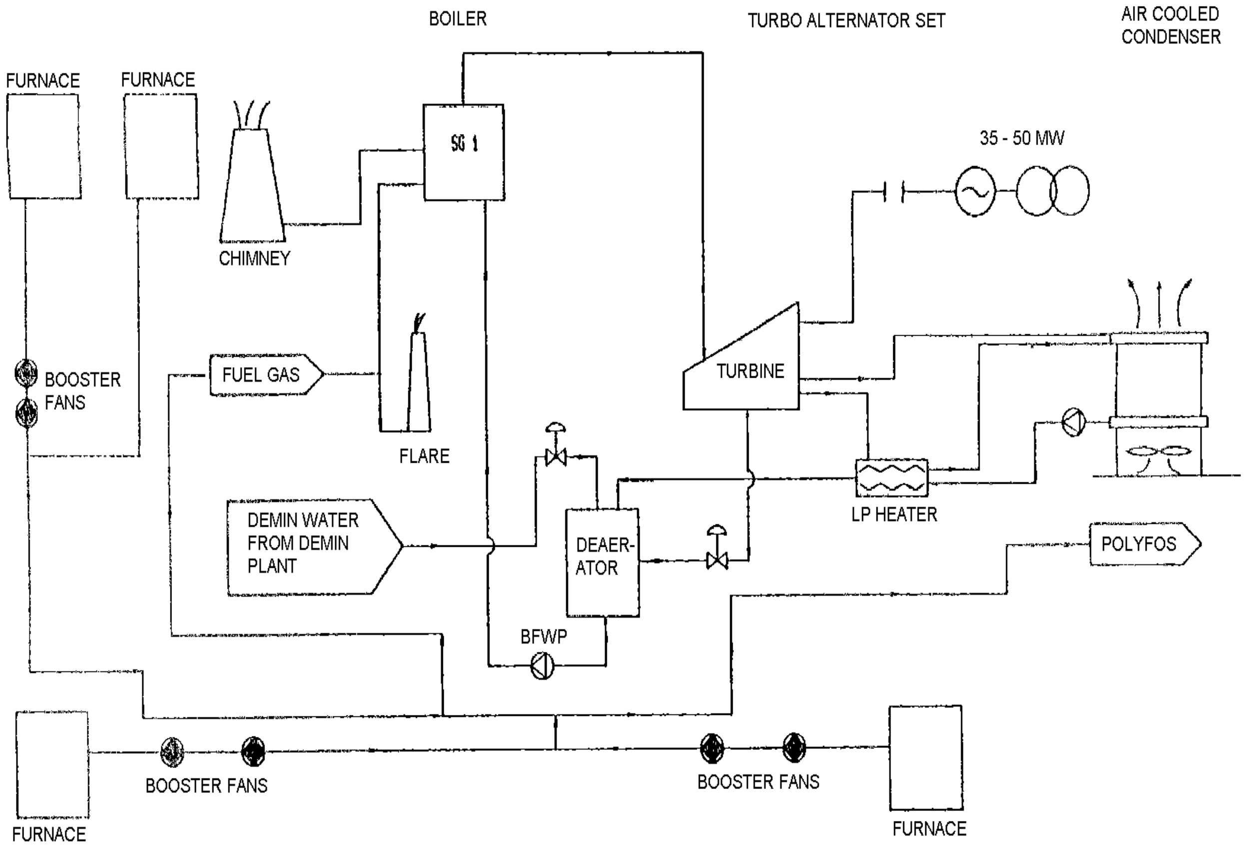

FIGURE 1 - STEAM & CONDENSATE SYSTEM

The Boiler

Tenders were invited from eleven boiler manufacturers both South African and international. The specifications of the boiler were:

▪	Peak Load	180 t/h
▪	M.C.R.	165 t/h
▪	Steam pressure Steam Header Outlet	6 700 kPa (a)
▪	Steam temperature Steam Header Outlet	520 ºC
▪	Steam temperature control range	110% - 40% M.C.R.
▪	Boiler control range	110% - 18% M.C.R.
▪	Feed water temperature	120 ºC

A particular feature of the boiler is the high turndown ratio required and the wide control range, down to 18% of M.C.R., necessary due to the fluctuating nature of the gas supply and the inlet requirements of the steam turbine.

The boiler design selected is single drum water tube boiler which fulfilled all of the design requirements in addition to being a respected manufacturer with a good track record in units of similar design. In order to provide the control range necessary, the boiler design included:

- Six variable firing burners.
- Three superheating units.
- Two stages of de superheating with spray conditioning for steam temperature control.

For added efficiency the boiler includes an economiser and gas recirculation is incorporated to assist in meeting the steam temperature at reduced loads. A process flow diagram of the selected design is shown in figure 2.

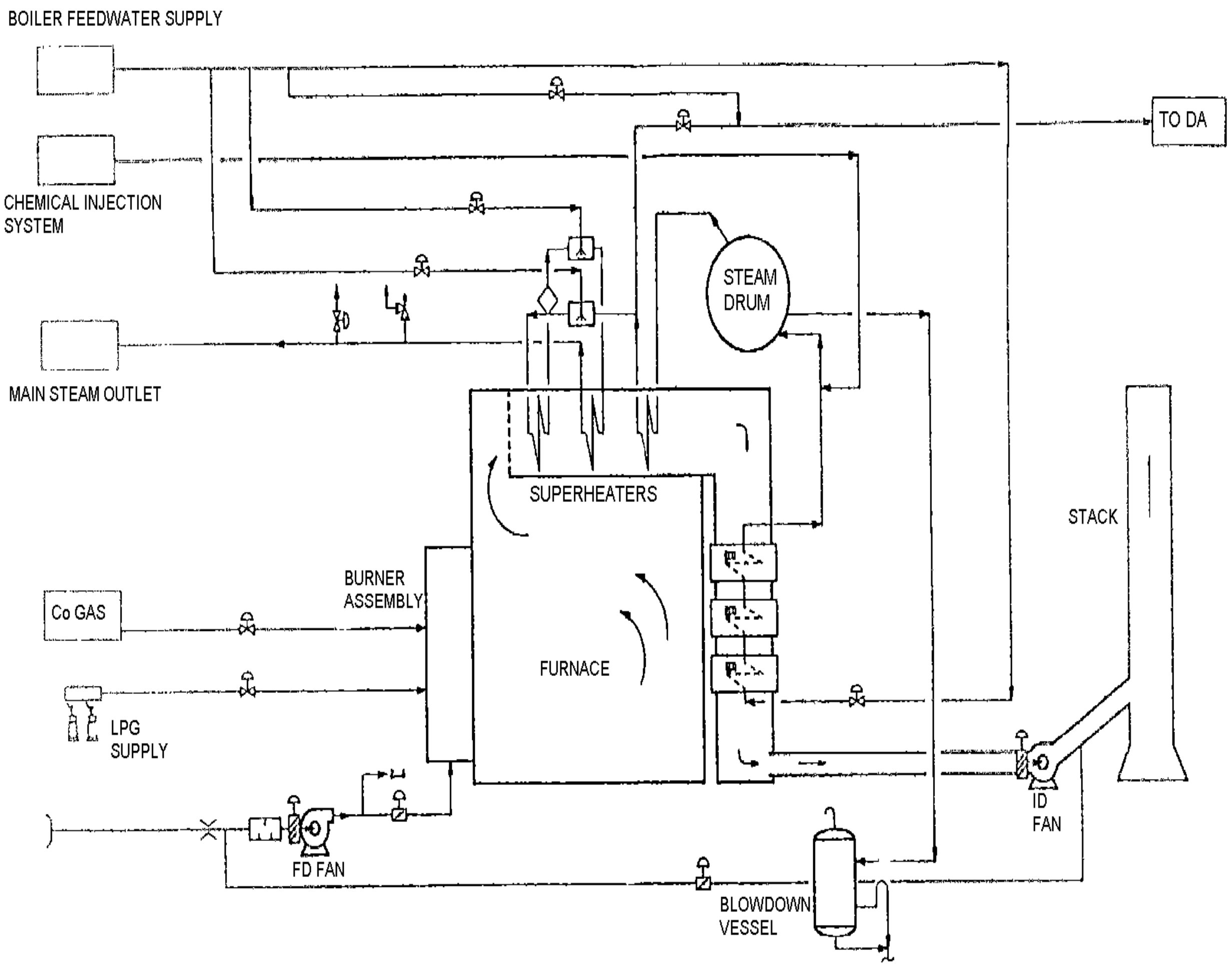

FIGURE 2 - PROCESS FLOW DIAGRAM OF THE BOILER

The Turbo-Alternator package

The Turbo-Alternator package includes the supply of an L.P. heater, a mechanical draught air cooled condenser, steam-jet air ejectors and a steam evaporative system for auxiliaries cooling. The high cost and scarcity of water at site motivated the selection of the air cooled condenser as an alternative to a conventional evaporative water cooled system.

As with the boiler design, the turbo-alternator operates over the wide range of conditions determined by the gas availability and to meet this large operating range efficiently, the turbine is equipped with six sequentially operated governor valves mounted in a steam chest cast integrally with the H.P. casing. The governor valves are actuated by an electro-hydraulic servo mechanism.

A process flow diagram of the most significant components of the turbine package are shown in figure 3.

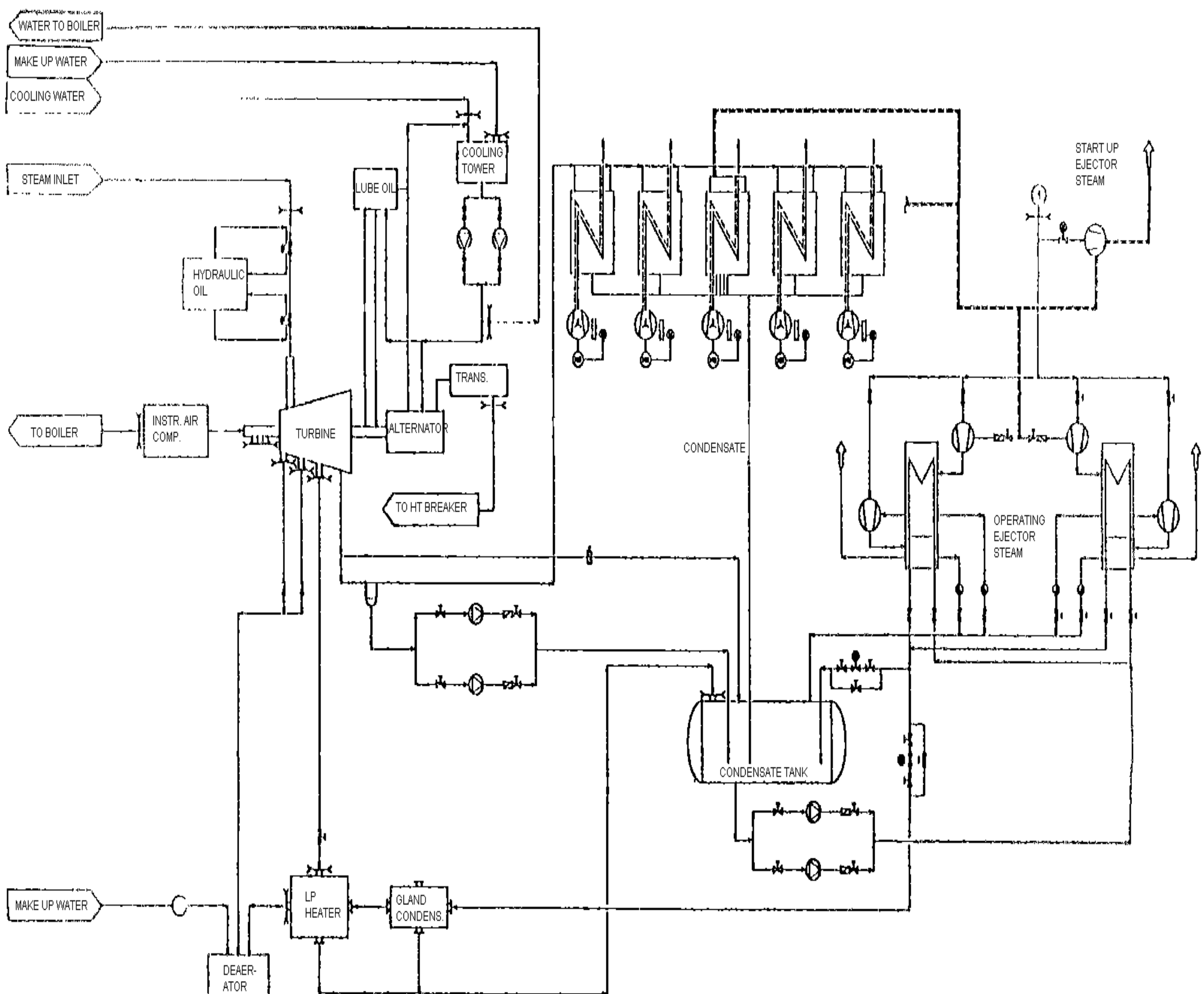

FIGURE 3 - P.F.D. OF TURBINE, LP HEATER AND CONDENSER

The Construction

The selection of the power station site was made so as to minimise the gas supply system pressure loss thus eliminating the need for additional booster fans with related capital and operating expense. A geophysical survey of the area was undertaken since large areas of the works have a dolomite sub structure and sinkholes have occurred in the past.

It is beyond the scope of this paper to go into details of the construction which proceeded in the usual manner for a project of this size. Time from board approval to useful production of power was approximately three years.

Commissioning and Performance

The commissioning period of the project included the following tests:

- Boiler efficiency tests.
- Boiler performance tests.
- Turbine performance tests.
- Deaerator performance tests.

Boiler Efficiency Tests

The boiler efficiency was determined during a performance test carried out by the boiler manufacturer as per the conditions of contract. Due to gas availability at the time of the test, the boiler tests were carried out at 80% M.C.R. The average boiler efficiency was found to be 93.3% based on L.H.V. The average temperature of the flue gas was 149 ºC and the CO content was less than 25ppm.

The boiler efficiency was within the limits specified in the contract and therefore deemed acceptable.

Boiler Performance Tests

The performance of the boiler was tested by performing three steam temperature control tests.

The first test called for the main steam temperature to be maintained within 8 ºC of the set-point temperature of 520 ºC for loads between 40% and 110% of M.C.R.

The second test called for the steam temperature to be maintained at least 100ºC above saturation loads between 18% and 40% of M.C.R.

The final test called for temperature control within 15ºC during load ramping conditions of 25 % of M.C.R per minute.

All three of these tests were completed satisfactorily according to contractual obligations.

Turbine Performance Tests

The turbine performance tests were carried out at 30MW, 28MW and 20MW. Tests at higher loads were not carried out due to limitations in maximum steam flow. During these tests, measurements were taken to determine:

- Corrected Gross Heat Consumption ($CGHC_{corr}$)
- Corrected Net Heat Consumption (NHC_{corr})
- Corrected Generator Output (PG_{corr})
- Corrected Net Output (P_{net})
- Auxiliary Power Consumption (P_{aux})

It was necessary for these tests to satisfy the performance specifications laid out in the contract. The results of the tests are shown in Table 1.

These results are in accordance with the contractual specifications of the turbine-generator and were therefore accepted by the client. It is anticipated, based on these test results, that the planned future fourth furnace will bring the output up to a maximum rating of 50MW.

TABLE 1 - SUMMARY OF TEST RESULTS

PERFORMANCE			**LOAD**		
Test			**1**	**2**	**3**
Load		**MW**	**28**	**30**	**20**
Corrected Gross Heat Consumption	GHC_{corr}	kJ/kWh	9891.7	10053.2	10551.7
Corrected Net Heat Consumption	NHC_{corr}	kJ/kWh	10235.5	10377.1	11070.9
Corrected Generator Output	PG_{corr}	kW	29165	30915	20327
Corrected Net Output	P_{net}	kW	28222	29971	19390
Auxiliary Power Consumption	P_{aux}	kW	942.2	944.5	937.3

Deaerator Performance Tests

The deaerator design specified that the dissolved oxygen content in the deaerated water would not exceed 0.007 ppm. For the performance test, the dissolved oxygen content was measured at 5 minute intervals over a period of four and a half hours.

Only steam was used for deaeration during the test and the readings taken showed dissolved oxygen contents of less than 0.007 ppm thus satisfying the conditions of contract.

CONCLUSIONS

This project, the first of its kind in Africa, can be described as a success. Environmentally harmful and economically wasteful furnace off-gasses have been converted into useful electricity, with the peak power generation currently of 35 MW significantly reducing the production costs of the client.

In addition to this, the technical challenges of producing electricity from such a widely fluctuating fuel source have been overcome by the engineering skill and innovative design of all the major role players of the project. Due to the networking and co-operation between the members of this multi national team, local engineering skills have been enhanced.

ACKNOWLEDGEMENTS

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REFERENCES

Wellbeloved D B & Hall W D, *The Utilisation of Waste Gas at Metalloys*. paper presented at the "Enerconomy 92" seminar.

http://home.pacific.net.au/~steamtech/complete.htm