GA-A16100
SUMMARY
UC-77

1170-MW(t) HTGR-PS/C PLANT APPLICATION-STUDY REPORT: ALUMINA-PLANT APPLICATION

by
R. RAO, A. T. McMAIN, JR., and J. D. STANLEY

Prepared under
Contract DE-AT03-76SF70046
for the San Francisco Operations Office
Department of Energy

DATE PUBLISHED: MAY 1981

GENERAL ATOMIC COMPANY

DISCLAIMER

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
NTIS Price Codes: Printed Copy A02; Microfiche A01

GA-A16100
SUMMARY
UC-77

GA-A--16100 Summ.

DE82 007219

1170-MW(t) HTGR-PS/C PLANT APPLICATION STUDY REPORT: ALUMINA PLANT APPLICATION

by
R. RAO, A. T. McMAIN, JR., and J. D. STANLEY

Prepared under
Contract DE-AT03-76SF70046
for the San Francisco Operations Office
Department of Energy

GENERAL ATOMIC PROJECT 6600
DATE PUBLISHED: MAY 1981

GENERAL ATOMIC COMPANY

INTRODUCTION

Aluminum refining uses two major energy-intensive processes:

1. Aluminum oxide or alumina is obtained from bauxite via the Bayer chemical process. This process uses a significant amount of steam to react with bauxite and for mechanical drive. It also requires electric power.

2. Alumina is reduced to aluminum by electrolysis. This process requires large amounts of electric power.

Figure 1 shows a schematic process flow diagram from ore reduction to aluminum production. Most existing commercial aluminum plants use energy from natural gas power plants. Hydroelectric power supplies a very small fraction of the total aluminum industry electric power requirements.

The HTGR-PS/C was developed by General Atomic (GA) specifically for industries which require both steam and electric energy. The GA 1170-MW(t) HTGR-PS/C design is particularly well suited to industrial applications and is expected to have excellent cost benefits over other energy sources. Because the HTGR produces high-temperature, high-pressure steam at conditions identical to those from fossil-fired boilers, a fairly direct substitution can be made for existing large oil or gas-fired industrial boilers. This gives maximum flexibility in establishing cogeneration heat cycles to produce steam at process conditions.

The 1170-MW(t) high-temperature gas-cooled reactor - process steam/cogeneration (HTGR-PS/C) is considered to be well suited for application to both existing and new commercial aluminum plants. Presently, the aluminum industry must switch to sources of energy such as coal or nuclear to

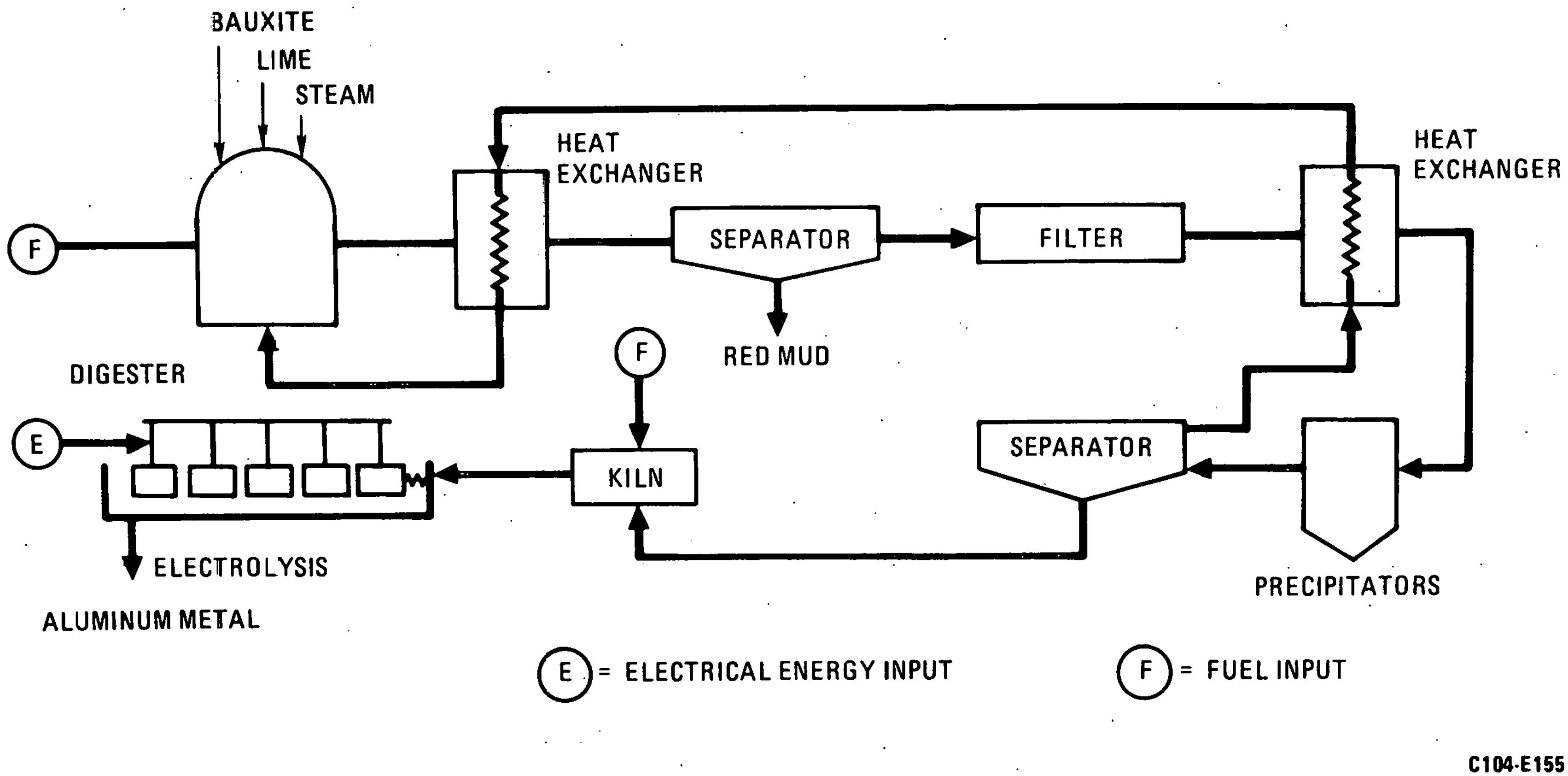


Fig. 1. Process flow diagram for aluminum mill application

conserve gas and oil fuels. For the near term, the aluminum industry is most likely to choose coal; however, interest in utilizing a nuclear cogenerating unit is expected, because such a plant is not only cost effective, but it also eliminates many of the cumbersome environmental control issues associated with coal plants.

This report considers the HTGR-PS/C application to producing alumina from bauxite. For the size alumina plant considered, the 1170-MW(t) HTGR-PS/C supplies 100% of the process steam and electrical power requirements and produces surplus electrical power and/or process steam, which can be used for other process users or electrical power production. Presently, the bauxite ore is reduced to alumina in plants geographically separated from the electrolysis plant. The electrolysis plants are located near economical electric power sources. However, with the integration of an 1170-MW(t) HTGR-PS/C unit in a commercial alumina plant, the excess electric power available [~233 MW(e)] could be used for alumina electrolysis.

APPLICATION REQUIREMENTS

Table 1 shows the steam and electrical energy requirements for a typical commercial alumina plant processing 726,680 tonnes (800,000 tons) per year of alumina (Al_2O_3). As indicated, an 1170-MW(t) HTGR-PS/C could satisfy 100% of the plant thermal and electric energy requirements. The given breakdown of steam pressure and temperature at various process stages is tentative, pending the availability of a detailed process flow diagram. Possibly, the process and the steam drive system could be modified to better use the higher steam pressure and temperature available from the HTGR-PS/C plant.

PLANT DESIGN

An 1170-MW(t) HTGR-PS/C has excess capacity for the process steam and electrical power requirements of the 725,680 tonne (800,000 ton) per year alumina plant considered in this study. The excess capacity can produce

TABLE 1
ENERGY REQUIREMENTS FOR A 726,000 TONNE (800,000 TON) PER YEAR COMMERCIAL ALUMINA PLANT

Utility Energy Requirements (a)	MW	Energy Requirements Provided by HTGR-PS/C	MW
1. Steam for alumina process at plant entry at P = 4.96 MPa (721 psia) T = 321°C (610°F) (min) (superheated) W = 107 kg/s (850,000 lb/hr) Oil and gas used in boilers.	317	Steam at HTGR-PS/C plant exit at P = 5.45 MPa (790 psia)[b] T = 381°C (718°F)[c] W = 107 kg/s (850,000 lb/hr)	317
2. Electric power for alumina process. Power produced by natural gas power plant.	94[d]	Electric power	94[e]
3. Electric power for electrolysis of alumina. Power produced by natural gas power plant	400 to 500[f]	Electric power for electrolysis of alumina	223[g]

[a] P = pressure, T = temperature, W = flow.

[b] Allows for pressure losses in steam transmission.

[c] Process flow diagram will specify superheat requirements: 381°C (718°F) is offered by steam cycle diagram (see Section 3.1).

[d] Planned to purchase from grid when present natural gas power plant is turned off.

[e] Provided by HTGR-PS/C; the 1170-MW(t) plant cogenerates more power; see Section 3.1 for more details.

[f] Estimate only.

[g] Electric power available from 1170-MW(t) HTGR-PS/C plant; see Section 3.1 for details. Remaining power from grid.

additional process steam for sale to other users, additional electric power for sale to a utility or for use by the alumina electrolysis plant, or any desired combination of excess steam and electric power. The local market for other process steam uses, plant economics, proximity of the electrolysis plant, etc., would determine the cycle selected. Two limiting heat cycles have been studied: (1) maximum process steam (Fig. 2) and (2) maximum cogenerated electric power (Fig. 3).

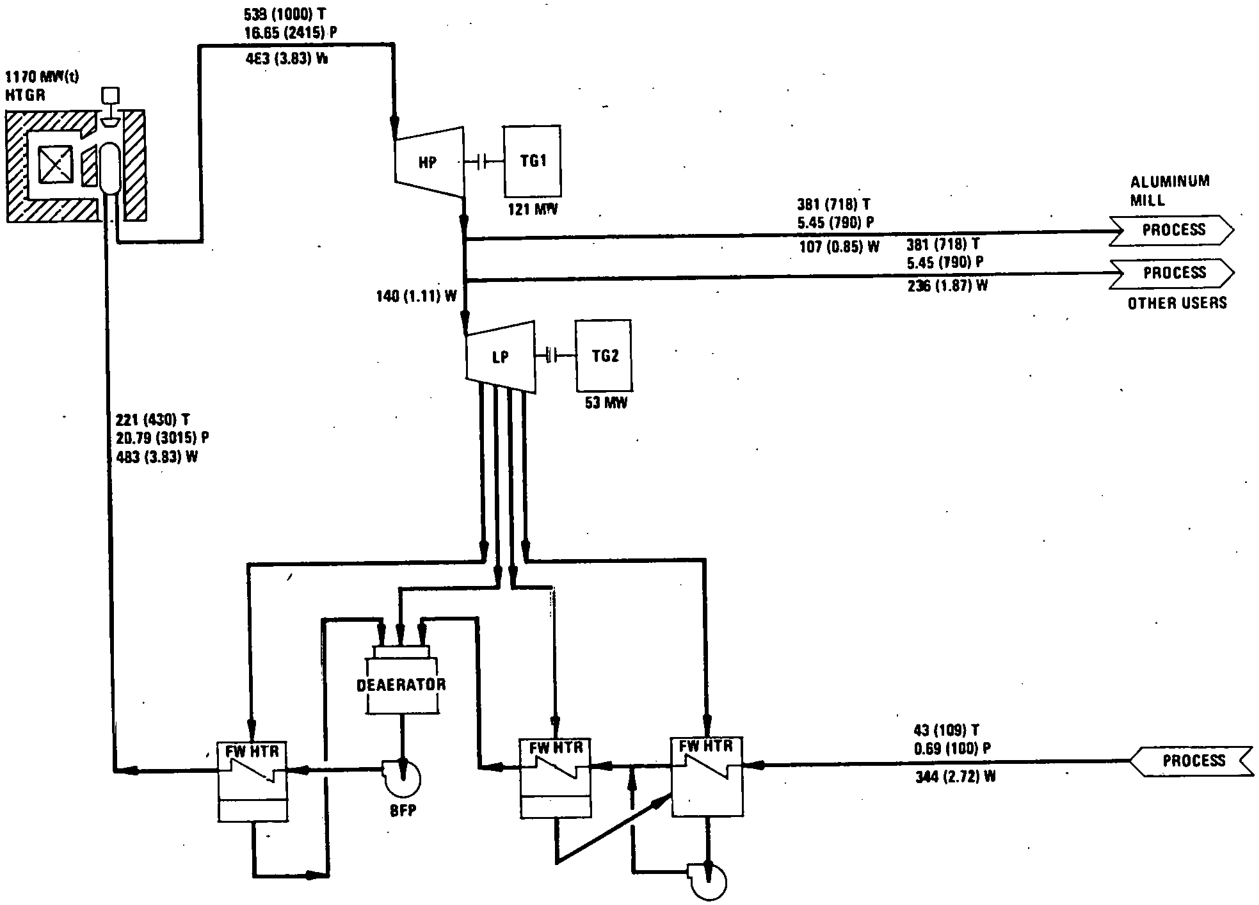
The plant entry should have nominal steam conditions of ~4.96 MPa/321°C (720 psia/610°F); some variation is acceptable. The cycles studied supply steam at 5.45 MPa/381°C (790 psia/718°F), providing a margin for transmission losses. The alumina plant can provide additional steam conditioning by throttling and/or desuperheating as required.

ECONOMIC ANALYSIS

The revenue requirement method was selected to evaluate alternative projects. This technique is appropriate for evaluating long-lived coal and nuclear cogeneration power plant projects. It determines the revenue needed by the firm as compensation for all fixed and variable expenditures. Hence, the revenue requirements of the firm equal the consumer cost for the process steam cogenerated.

Table 2 compares estimated energy costs for the 1170-MW(t) HTGR-PS/C plant versus a comparable coal-fired PS/C plant for an alumina plant. It shows a clear advantage for the HTGR over a coal-fired plant.

This analysis is based on economic assumptions used to evaluate utility cogeneration projects in progress for the Department of Energy (DOE) by GA in coordination with Gas Cooled Reactor Associates (GCRA). Table 3 gives the principal assumptions of the economic analysis, a key one being the 18% fixed charge rate for capital use/recovery. Such a rate may be higher if industrial ownership ground rules are applied. Therefore, the economics



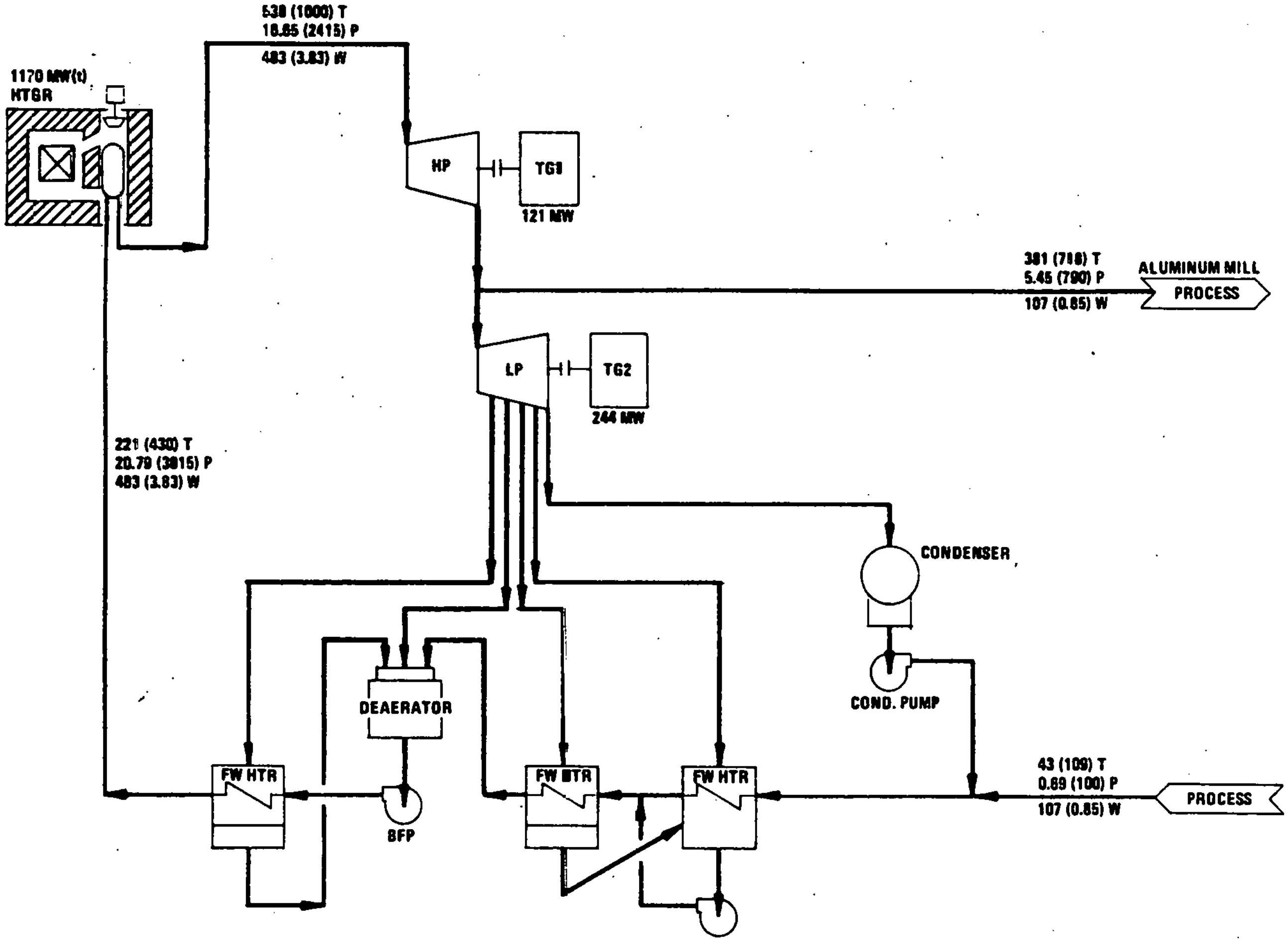
ALLOCATION OF REACTOR POWER OUTPUT	MW	%
PROCESS USES		
ELECTRIC POWER	94.0	8.0
STEAM POWER TO PROCESS	316.9	27.1
SUBTOTAL	410.9	35.1
OTHER USES		
STEAM POWER	696.7	59.6
ELECTRIC POWER	44.6	3.8
LOSSES	17.8	1.5
TOTAL REACTOR POWER OUTPUT	1170	100

LEGEND

W = FLOW KG/S (10^6 LB/HR)
P = PRESSURE MPa (PSIA)
T = TEMPERATURE °C (°F)

C011 - E012

Fig. 2. Cycle diagram for an 1170-MW(t) HTGR-PS/C plant for 726,000 tonne (800,000 ton) per year aluminum mill application (maximum process steam)



ALLOCATION OF REACTOR POWER OUTPUT	MW	%
PROCESS USES		
ELECTRIC POWER	94.0	8.0
STEAM POWER TO PROCESS	316.9	27.1
SUBTOTAL	410.9	35.1
OTHER USES		
ELECTRIC POWER	232.6	19.9
LOSSES		
CONDENSER	480.6	41.1
OTHER	45.9	3.9
TOTAL REACTOR POWER OUTPUT	1170	100

LEGEND

W = FLOW KG/S (10^6 LB/HR)
P = PRESSURE MPa (PSIA)
T = TEMPERATURE °C (°F)

C011 - E013

Fig. 3. Cycle diagram for an 1170-MW(t) HTGR-PS/C plant for 726,000 tonne (800,000 ton) per year aluminum mill application (maximum cogenerated electrical power)

TABLE 2
ECONOMIC ANALYSIS OF HTGR-PS/C PLANT VERSUS COAL-FIRED PS/C PLANT FOR ALUMINA PLANT APPLICATION

	HTGR-PS/C Case 1	Coal-PS/C Case 1	HTGR-PS/C Case 2	Coal-PS/C Case 2
Heat input to cycle (MW)	1170.0	1230.2	1170.0	1230.2
Heat output in process steam (MW)	1013.5	1013.5	317.0	317.0
Net electrical power output (MW)	138.6	144.7	326.6	336.0
Capital Costs ($ x 10^6)				
Base capital cost (1/80 $)	573	378	658	442
Escalation through construction	572	427	657	499
Interest during construction	359	160	412	188
Total capital cost (1/95 $)	1504	965	1727	1129
Annual Costs ($ x 10^6/year)[a]				
Fixed charges	271	174	311	203
Fuel costs	81	299	81	299
O&M costs	63	69	63	69
Credit for electric power	(145)	(150)	(340)	(348)
Total annual costs	270	392	115	223
Process Steam Cost [mills/kW(t)-hr ($/MMBtu)]	45.28 (12.75)	65.59 (18.47)	61.8 (17.41)	119.3 (33.59)
Ratio of energy cost to cost with HTGR-PS/C	--	1.4	--	1.9

[a] 1/95 $ levelized over a 30-year period.

TABLE 3
ECONOMIC ANALYSIS ASSUMPTIONS

Commercial operation of all plants:	1/95
Capacity factor:	70%
Levelizing period:	30 years
Electric power credit:	22 mills/kW-hr (80 $)
Discount rate:	10%/year
Fixed charge rate:	18%/year
Interest during construction:	10%/year (simple interest)
Coal cost escalation:	8%/year
Fuel oil escalation:	9%/year
All other escalation:	6%/year
Construction period:	6 years for all plants (2 years for No. 6 oil-fired plants)
U_3O_8 (yellowcake) cost:	$121/kg ($55/lb) in 1990, rising to $264/kg ($120/lb) in 2030
Separative work unit (SWU) cost:	$100/kg-SWU (80 $)
Tails assay:	0.2%
Coal cost:	4.64 mills/kW-hr ($1.36/MMBtu) (80 $)
No. 2 oil cost:	18.2 mills/kW-hr ($5.33/MMBtu) (80 $)
No. 6 oil cost:	13.5 mills/kW-hr ($3.95/MMBtu) (80 $)
HTGR-PS/C fuel cycle cost (includes recycle):	11.23 mills/kW-hr ($3.29/MMBtu) (1/95 $ levelized over 30 years)

should be determined using the economic ground rules appropriate for the specific application. Industrial user input is being developed regarding possible alternative economic ground rules.

Ultimately, the economic analysis method will be determined by the nuclear cogeneration plant ownership:

1. Industrial ownership with connection to the utility grid for backup electric power and sale of excess power (per recent Federal Energy Regulatory Commission rulings regarding a more favorable arrangement for industry).

2. Utility ownership with both steam and cogenerated electric power sold to nearby industry.

3. Consortia ownership and sale of energy to industry and local utilities.

The analysis compares the process steam cost of the HTGR-PS/C versus a coal-fired cogenerating plant. It credits the electric power produced by the HTGR and coal-fired cogenerating plants and indicates a clear advantage for the HTGR over the coal alternative.