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ENERGY EFFICIENCY AUDIT REPORT
TITOGRAD ALUMINUM PLANT
TITOGRAD, MONTENEGRO, YUGOSLAVIA

MARCH 1992

PREPARED BY: RCG/HAGLER, BAILLY, INC.
Arlington, VA

and

TEKON Tehno-Konsalting
Belgrade, Yugoslavia

U.S. EMERGENCY ENERGY PROGRAM FOR EASTERN AND CENTRAL EUROPE

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
BUREAU FOR EUROPE
WASHINGTON, D.C. 20253

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OFFICE OF DEVELOPMENT RESOURCES
ENERGY & INFRASTRUCTURE DIVISION
WASHINGTON, D.C. 20253

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QUALITY ASSURANCE

The contents of this report include recommendations based on data provided by the client plant, measurements made on site, calculations, and engineering judgment. The conclusions reached were based on a limited engagement of only about one week's duration in the plant, and not an exhaustive engineering analysis. RCG/Hagler, Bailly, Inc. certifies that this report conforms to the level of best commercial practice for industrial energy audits of similar level of effort, as conducted in the United States. This report has been prepared under the guidance of a registered Professional Engineer, licensed to practice in the United States.

PRELIMINARY ENERGY AUDIT
KOMBINAT ALUMINUJUMA TITOGRAD (KAT)
ALUMINA DIVISION

CONTENTS

DESCRIPTION	PAGE
I. EXECUTIVE SUMMARY	1
II. INTRODUCTION	3
III. ENERGY CONSUMPTION ANALYSIS	6
IV. RECOMMENDATIONS FOR ENERGY EFFICIENCY IMPROVEMENT	7
A. GENERAL AND ENERGY MANAGEMENT	8
B. LOW-COST SHORT-TERM IMPROVEMENTS	17
C. CAPITAL IMPROVEMENTS	32
V. ADDITIONAL RECOMMENDATIONS - OUTSIDE SCOPE OF ALUMINA PLANT	35
APPENDICES	43
1. MONTHLY ENERGY DATA	
2. DAILY ENERGY DATA	
3. BOILER COMBUSTION EFFICIENCY	
4 ALUMINA CALCINER COMBUSTION EFFICIENCY	

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PRELIMINARY ENERGY AUDIT
KOMBINAT ALUMINIJUMA TITOGRAD (KAT) - ALUMINA
TITOGRAD, MONTENEGRO, YUGOSLAVIA

BY
RCG/HAGLER, BAILLY, INC. AND TEKON (TEHNO-KONSALTING)

I. EXECUTIVE SUMMARY

A team of engineers from RCG/Hagler, Bailly, Inc. and TEKON, carried out site activities at Kombinat Aluminijuma Titograd (KAT) Alumina plant from April 1-5, 1991 to work together with KAT staff to identify and implement improvements to energy efficiency.

Based on consumption in 1990 and energy prices prevailing at the time of the visit, total energy costs for 1991 at KAT Alumina are estimated as $15.7[1] million, as follows:

mazout (heavy fuel oil): 97.500 tons per year, $12.7 million
purchased electric power 6.8 MW peak demand, $0.8 million
purchased electric energy 55,000 MWh/yr, $2.2 million.

RCG/Hagler, Bailly estimates the potential for energy efficiency improvement at KAT Alumina as 10-15% without process changes. During the survey, the RCG/Hagler, Bailly team identified short-term, low-cost energy efficiency projects, which, if implemented, will achieve an energy cost savings of $924,000 per year, or 5.9% of expected 1991 energy costs, at a total cost of $137,000 (a financial payback of 2 months):

RCG/Hagler, Bailly recommends the following procurement budget for KAT Alumina, subject to final approval by USAID:

A.3, B.4 & D.1: Infrared thermal imager ($17,000)
B.1: Calciner continuous O2 and CO instruments ($17,000)
B.2: Boiler continuous O2 and CO instruments ($12,000)

KAT Alumina agreed to pay for installation and other costs necessary to implement the projects and make full use of the equipment supplied by USAID.

[1] Energy costs are quoted in US dollars in this report because of the severe devaluations of the Yugoslav Dinar in early 1991. Yugoslavia is adjusting energy prices so that they remain relatively constant in US dollars.

KOMBINAT ALUMINIJUMA TITOGRAD (KAT)
ALUMINA DIVISION

Summary of energy efficiency projects

	Oil ton/yr	Electric MW	Electric MWh/yr	Cost MUS$/yr
BASE CASE	97,508	11.0	55,000	$15.700

RECOMMENDATIONS AND ESTIMATED SAVINGS:

	Oil ton/yr	Electric MW	Electric MWh/yr	Cost MUS$/yr
A. General & Energy Management				
A.1 Derate boiler #1	133			0.017
A.2 Close boiler ports	380			0.048
A.3 Efficiency teams	3,521	0.2	2,750	0.589
B. Short-term, Low-cost Efficiency Improvements				
B.1 Calciner combustion	488			0.063
B.2 Boiler combustion	571			0.074
B.3 Boiler #1 air heater	88		50	0.013
B.4 Calciner heat loss	812			0.105
B.5 Boiler #3 clean tubes	115			0.015
TOTAL SHORT-TERM SAVINGS	6,108	0.2	2,800	0.924
Percent of base case	6%	2%	5%	5.9%

II. INTRODUCTION

2.1 Plant Description and Energy Consumption

The Republic of Montenegro is one of the world's best natural sites for a vertically-integrated aluminum company such as Kombinat Aluminijuma Titograd (KAT), because of the abundance of hydroelectric power potential and the availability of high-grade bauxite ore.

The KAT plant is a full aluminum production facility, consisting of process plants for alumina, carbon anode, aluminum smelting, casting, rolling, and finished product lines for various products, including extrusions, sheet, plate, and foil. A power station provides steam and electricity for the alumina plant. Annual production is about 135,000 tonnes aluminum. In addition to supplying markets in Yugoslavia, KAT exports products with a value of over $100 million per year.

In 1990, KAT Alumina Division produced 268,517 tonnes of calcined alumina (raw material for aluminum smelting) and used 97,508 metric tons of residual fuel oil (mazout). Of this fuel, 70,428 tonnes were consumed in the powerhouse, which generated an average of 123 tonnes per hour of 55 bar steam for the process and 3.5 MW of cogenerated electricity, through backpressure turbines. An additional 6.8 MW (55,000 Mwh/yr) of electricity is purchased from the grid to serve the alumina plant demand of 10-11 MW. Bauxite to feed the alumina plant is mined in Montenegro near Niksic. Caustic soda and heavy fuel oil are not locally produced, and so must be imported to the region.

The April 1991 official price of mazout delivered to KAT by Jugopetrol was Dn 4,300 per tonne ($307), but KAT also imports fuel on the spot market when necessary. Imported fuel cost $130/tonne in April, whereas the higher, Government-controlled local price still reflected the Gulf conflict oil prices.

The greatest part of energy cost at KAT, as in any aluminum operation, goes for electric energy in smelting. The smelting operation at KAT has a peak demand of nearly 300 MW, and an annual consumption of about 2 million MWh per year, which represents about one-half the electricity consumption of the entire Republic of Montenegro. The total cost of this electric power is $120 million per annum, of which 1/3 is for demand and 2/3 is for energy charges. Electricity tariffs are now about $11 per kW per month (demand) and average $0.04 per kWh (energy), according to a time-

of-day tariff.

2.1 Energy Audit Activities

A team of senior engineers from RCG/Hagler, Bailly, Inc. and TEKON, carried out site activities at KAT Alumina from April 1-5, 1991 to work together with KAT staff to identify improvements to energy efficiency. The project manager for the effort was Mr. Savovic Svetozar, Dipl. Ing., Director of Alumina Division at KAT, assisted by Dr. Miodrag Kaludjerovic, Director of Investment, and Dr. Mrkic Milo, Director of the KAT Aluminum Institute. The RCG/Hagler, Bailly team consisted of:

David Keith, RCG/Hagler, Bailly, Project Director
Dr. Larry Banta, consultant to RCG/Hagler, Bailly, on leave from Mechanical Engineering Dept., University of West Virginia
Lazarevic Dusan, TEKON, Project Manager

At the request of the management of KAT Alumina, the audit team focused their efforts in the short time available on combustion systems in the power station and alumina kiln.

During the first day of the audit, the team traveled to Titograd, conducted a seminar on energy management, exhibited RCG/Hagler, Bailly's portable energy efficiency monitoring instruments, and held discussions with plant management to plan the audit. Based on agreement with KAT the first day, the primary focus of the audit became a controlled experiment, attempting to achieve immediate energy savings through improvements in combustion efficiency. For this purpose, RCG/Hagler, Bailly's digital combustion analyzer (which measures O_2, CO, CO_2, unburned hydrocarbon combustibles (HC)) was used, together with a laptop personal computer, using software developed by RCG/Hagler, Bailly which calculates combustion efficiency from these measurements, on the basis of the chemical equations of combustion (molal basis). Based on these measurements, the staff of the KAT boiler house and calcining kiln made adjustments to operating parameters in a stepwise approach until optimum combustion efficiency was achieved.

Two full days were spent tuning 3 of the plant's 4 boilers and another full day was spent tuning the calcining kiln. This exercise resulted in small percentage improvements in efficiency, which, if maintained, will yield significant annual cost savings.

By the end of the week, KAT had implemented new management directives for setting boiler draft, kiln secondary air, and

limiting the load on boiler #1, in order that the savings achieved will be maintained to the extent possible using KAT's available instrumentation.

The RCG/Hagler, Bailly team presented its recommendations to Mr. Savovic, Dr. Kaludjerovic, and Dr. Mirkic at the final review meeting April 5, 1991, before leaving KAT. RCG/Hagler, Bailly recommended, and KAT agreed, that fixed O2 and CO meters and a portable kit should be procured under the USAID emergency energy program, so that KAT will be fully able to maintain the savings. The RCG/Hagler, Bailly team observed that the standard of management and engineering expertise already in place at KAT is quite high. Technical staff is very knowledgeable about energy conservation in general, especially in relation to their process. The RCG/Hagler, Bailly team expects that this staff, with a few additional instruments, tools, and equipment, will be fully capable of making significant improvements to energy efficiency.

The RCG/Hagler, Bailly team would like to express their sincere appreciation for the extraordinary assistance and warm hospitality offered by the staff of KAT. It is only because of their openness and cooperation that this effort was possible. The RCG/Hagler, Bailly team is glad to have had the opportunity to become friends with the staff of KAT, and hopes to return their hospitality at some time in the future, whenever KAT staff visit the United States.

III. ENERGY CONSUMPTION ANALYSIS

A graphical presentation prepared by RCG/Hagler, Bailly of basic data received from KAT Alumina on energy consumption, production, specific energy consumption, and other key parameters is attached as Appendix 1.

These graphs are provided for use by KAT in identifying variations in energy efficiency. The analysis is a tool to point the way for more detailed investigations. These detailed investigations are beyond the scope of the current study, but several points are evident from the analysis. The main points arising from the analysis which were used to develop specific recommendations are as follows:

Electric energy consumption is not well correlated to production.

Peak electrical demand is growing, up 6% in 1990 over 1989, with 5% higher demand in January-March 1991, as compared to the same months in 1990.

Boiler efficiency has decreased over the past few years, by about 4%.

Specific energy consumption of the calciner is very consistent.

For aluminum hydrate production, specific steam and electric consumption seem to have increased slightly over the past three years.

Conversion ratio of caustic soda to aluminum hydrate has deteriorated significantly over the past three years.

Conversion ratio of bauxite to aluminum hydrate has deteriorated significantly over the past three years.

IV. RECOMMENDATIONS FOR ENERGY EFFICIENCY IMPROVEMENT

RCG/Hagler, Bailly's recommendations for energy management and efficiency improvement have been grouped in three categories:

A. General and Energy Management - These projects are opportunities which are recommended for immediate action, and require little or no expenditure. These projects affect management systems and techniques, rather than process equipment. These projects are the primary focus of the USAID Emergency Energy Program for Yugoslavia.

B. Low-cost, Short-term Improvements - These projects are low-cost improvements to process plant and equipment which are recommended for implementation in the short-term (in 1991). Because of the low cost and quick payback (less than one year), these projects could be implemented from the company's annual maintenance budget. Some of these projects may be of interest to the USAID Emergency Energy Program for Yugoslavia.

C. Capital Improvements - These projects are longer term projects, requiring investment of more than $100,000. Such projects would require careful study, beyond the scope of this preliminary energy audit. These projects are also beyond the scope of funding under the USAID Emergency Energy Program for Yugoslavia.

A. GENERAL AND ENERGY MANAGEMENT

POWER PLANT
KAT Action A.1 -
Derate boiler #1 to 45 tons per hour of steam.

Existing Conditions:

During the course of the audit, the RCG/Hagler, Bailly team identified that the forced draft fan for boiler #1 was unable to supply sufficient air for complete combustion.

Various measurements were made and the highest load which was achievable with complete combustion was 45 tons steam per hour. RCG/Hagler, Bailly suspects that the air preheater is leaking (see action B.3).

In the as-found condition, the boiler was supplying 48 tons per hour, with all dampers of the forced draft system fully open. The following measurements compare the as-found conditions of boiler #1 with the damper fully open at 48 tons per hour steam flow and the conditions with the damper fully open at 45 tons per hour steam flow. Detailed calculations of combustion efficiency are provided in Appendix 3.

	Measurements				Calculation	Estimate	
	O2 %	CO ppm	HC %	Temp C	Combstn effy on LHV,%	Mazout tonne/yr	Cost K$/yr
Boiler #1							
48 ton/hr	4.0	1200	0.08	160[2]	92.2	17,607	2,289
44.5 ton/hr	4.4	35	0.00	160	92.9	17,474	2,272
savings						133	17

Recommendation:

Derate the boiler, in other words, not operate boiler #1 at loads above 45 tons per hour. If the preheater is leaking, the leak will continue to grow, and the boiler will have to be further derated if CO or significant smoke is visible. (Note: Mr. Savovic, the Director of the KAT Alumina plant ordered that this recommendation

[2] Assumed temperature after air preheater, but not including dilution from leaks (see Action B.3). Assumption is based on measured temperature at other KAT boilers.

be implemented immediately.)

Expected results:

RCG/Hagler, Bailly estimates that KAT can continue to operate boiler #1 at an efficiency equal to the condition as left at the end of the audit week, if the boiler is derated. This would correspond to an improvement in boiler efficiency from 92.2% to 92.9% on lower heating value (LHV). The expected savings amount to 133 tonnes mazout per year, or $17,000 per year, a savings of 0.75% of the annual fuel used in boiler #1.

A. GENERAL AND ENERGY MANAGEMENT

POWER PLANT
KAT Action A.2 -
Close boiler access ports

Existing Conditions:

During the audit, the RCG/Hagler, Bailly team observed that the boiler access ports were open during operation. The size of these ports is large, approximately 0.5m x 0.5m each. Two or three are located on the sides of each boiler, looking into the furnace. Most of the time, the furnace draft is such that air is being drawn into these ports. Once in a while, a puff of combustion gases will shoot out the port. This represents a safety hazard, since the ports are on the walkway path, so someone could get burned.

The air drawn in through these ports represents excess combustion air, and therefore an energy loss up the stack. This is indicated by the fact that the boilers could not be tuned below about 5% oxygen without CO. RCG/Hagler, Bailly expects that for burners of the type used at KAT, a lower level of excess air should be achievable (for example, the alumina calciner was tuned to 3.2% oxygen without CO).

Recommended actions:

Close the ports and adjust combustion conditions accordingly.

Expected results:

RCG/Hagler, Bailly expects that the boiler should be able to operate at 3% excess oxygen in the stack, if all ports are closed. From a base value of 5%, this represents an improvement in combustion efficiency of 0.5%, as estimated by computer-aided methods, for a savings of $48,000 per year for four boilers (detailed calculation of a boiler with CLOSED PORTS is included in Appendix 3):

	Assumptions O2 %	CO ppm	HC %	Temp C	Calculation Combstn effy. on LHV,%	Estimate Mazout tonne/yr	Cost K$/yr
Typical KAT boiler (one of four boilers)							
before	5.0	0	0.00	160	92.6	17,607	2,289
after	3.0	0	0.00	160	93.1	17,512	2,277
savings						95	12

A. GENERAL AND ENERGY MANAGEMENT

ENERGY & UTILITIES
KAT Action A.3 -
Put energy efficiency teams in action to reduce energy losses

Existing conditions:

Energy requirements at KAT are growing year-by-year for a given level of production. This is indicative of a deteriorating situation which could benefit from increased maintenance.

During the audit, the RCG/Hagler, Bailly team observed steam leaks with substantial energy cost in the power plant and the alumina plant. There also appears to be an opportunity to return additional steam condensate from the plant to the boilerhouse.

Recommended action:

RCG/Hagler, Bailly recommends that KAT form "Energy Efficiency Teams" for steam, electric motors, and compressed air. Personnel for this team should be drawn from KAT staff, and this exercise should become a continuous part of plant operations and maintenance.

The Steam Efficiency Team would be responsible for the identification and repair of leaks in steam systems, and to inspect and repair thermal insulation. The Electric Motor Efficiency Team would be responsible to survey electric motor load and efficiency, check and clean motors, replace underloaded motors, rewind or replace motors with excessive reactance, and develop a plan for introduction of high efficiency motors. The Compressed Air Efficiency Team would be responsible to evaluate efficiency of compressed air systems, and to seek out and repair leaks in compressed air lines.

The Steam Efficiency Team should have the following tasks:

- Develop an inventory of the uses of steam in the plant.
- Carry out a survey of the condition of steam pipe insulation in the plant, using thermocouples and other temperature indicators.

- Check the operation of all steam traps in the plant on a monthly basis, using the "glove test" or other simple methods. Repair or replace leaking traps as found.

- Carry out a survey of steam leaks on a monthly basis. For each leak found, calculate the cost of the leak (using Georgia Tech's Steam Leak chart on the following page) and estimate the cost to repair the leak. If the payback period is less than 1 year, recommend the repair of the leak. Develop a log to keep track of the growth of leaks from month-to-month. Develop a monthly plan for repairs.

The Electric Motor Efficiency Team should have the following specific tasks:

- Based on nameplate and available meters, make a complete inventory of all motors over 10 kW, which identifies the motor number, rating (kW), location, age, voltage, rpm, running amperes, expected annual energy consumption, description of use.

- Obtain curves of efficiency vs. percentage load and power factor vs. percentage load from KAT's major suppliers of motors families of motors now installed in the plant.

- Develop specifications for the procurement of new motors for the plant, for new applications. Obtain manufacturer's data on price, efficiency and power factor (cos phi) for alternative lines. In the U.S., manufacturers offer two types of electric motors - standard motors and high efficiency motors which reduce energy consumption by 3-10% for the same application. The increase in efficiency is greatest for smaller sizes (under 50 kW), since large motors are relatively efficient. The high efficiency motor costs about 50% more than the standard motor, but in applications with high duty factor (over 4,000 hours per year, like KAT), this incremental cost can be recovered in one year or less. RCG/Hagler, Bailly expects that the results of this analysis will result in the development of a new specification, for high efficiency motors.

- After carrying out the analysis and developing the new high efficiency specification for new motors, consider the possible replacement of existing motors with high efficiency motors on a phased basis. One way to

12A

Energy Tips

Energy management suggestions from the Industrial Energy Extension Service
a joint service of the Georgia Office of Energy Resources and Georgia Tech's Engineering Experiment Station.

ENERGY TIP NO 2

ELIMINATE STEAM LEAKS

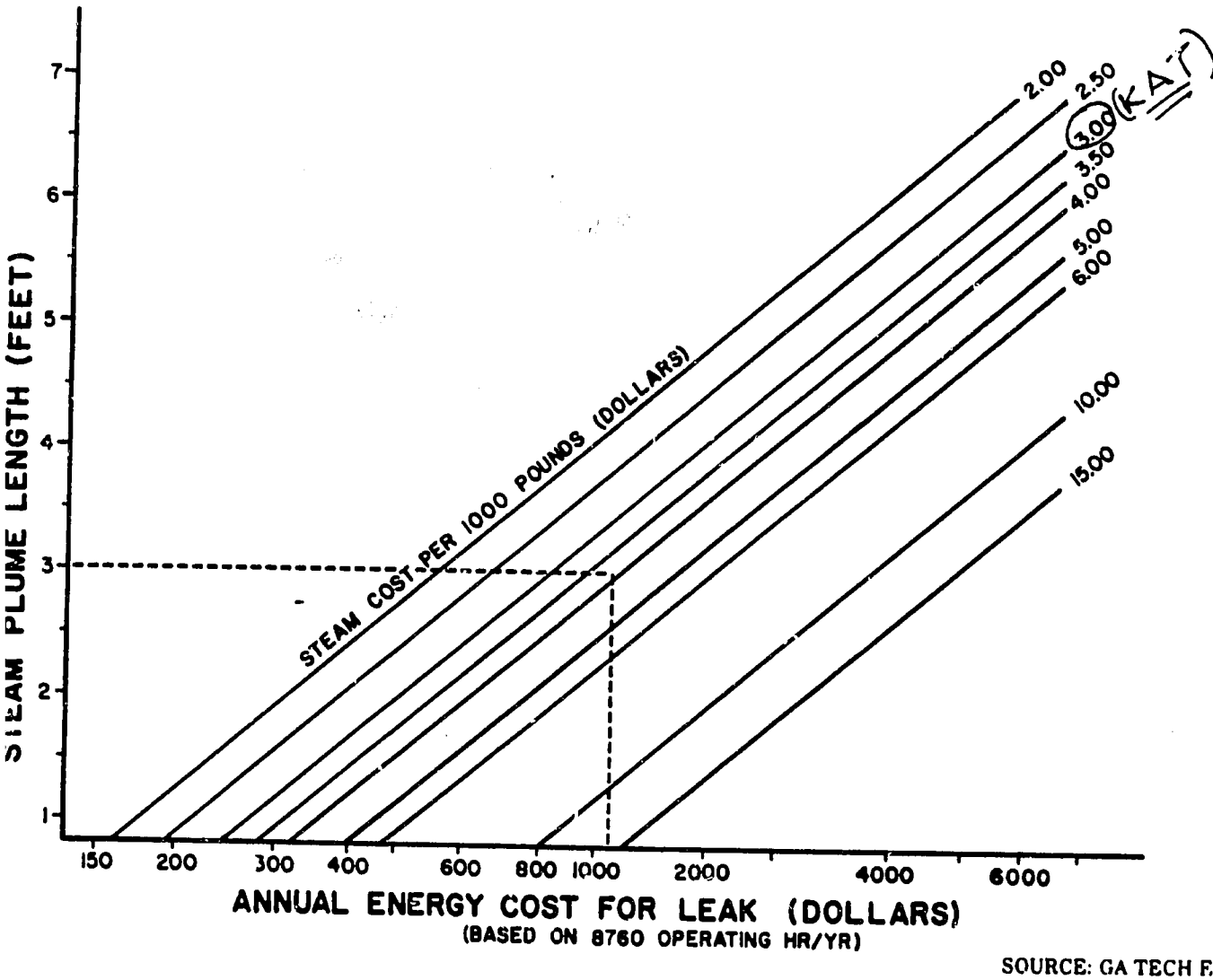
A conspicuous waste of energy are the numerous steam leaks at pipe joints, valves, unions, etc. Until the cost of energy skyrocketed, it was generally thought that small leaks should be tolerated and that fixing them was not worth the time or cost.

The graph below is a rough approximation of what a steam leak costs in terms of annual fuel expense. To use the graph, determine the leak's "Blow Length" by measuring the length of the steam plume or the approximate distance at which water condenses out of the stream onto your hand (usually beyond the visible plume). Enter the graph with the blow length and move across to the corresponding cost of steam line determined by using the "Steam Cost" chart, Energy Tip No. 1. Read the annual energy cost at the bottom of the graph.

EXAMPLE

A survey of a plant's steam distribution system reveals a steam leak at an equipment connection flange. The plume length of the leak is approximated at 3 ft. What is the energy cost of not fixing the leak?

Using the graph and a steam cost of $4.00/1000 lbs determined from Energy Tip No. 1, the annual cost is $1200.



SOURCE: GA TECH EES

implement this policy would be to buy a quantity of high efficiency motors which would be used to replace burned-out motors, instead of rewinding them. Often, rewound motors have lower efficiency than new motors, as the magnets can suffer reduced flux if they are overheated in the process. Efficiency loss can also result because rewinding is usually done to lower quality standards than new manufacturing, so increased friction can result from slight misalignment. Finally, if wire of smaller diameter or higher resistivity is used in the rewind job, resistive losses will increase. It is the RCG/Hagler, Bailly team's experience that a rewound motor has an efficiency 1-5% less than a new motor, and rewinding costs 50% or more of the cost of a new motor.

- Using portable volt-ammeter, power factor meter, carry out an electric motor load survey. The load (kW, kVAR, cos phi), voltage on each phase, and efficiency of all motors over about 10 kW should be checked using a systematic procedure.

- Using a strip-chart demand recorder, carry out power demand survey (kW, kVAR, metered demand kW, and kWh/shift) for load centers over 100 kW. Based on this data, develop a power demand balance for the plant, under various operating conditions.

- Based on the results of the power demand survey, work together with process personnel to investigate ways to reschedule operations to reduce peak demand and to shift consumption from peak to off-peak hours.

- If motors with excessive reactance are identified, they should be taken out of service for rewinding or replacement.

- Institute a monthly policy of motor maintenance. Check that bearings are getting proper lubrication. Electrical connections should be checked and tightened if necessary. The housing and ventilation air intake on all motors should be cleaned to improve cooling and efficiency. Compressed air should be used to blow out dust and dirt from internal parts of the motor (air should be dry and less than 4 bar pressure to avoid damaging insulation). The motor and its drive system drive should be checked for proper alignment, proper belt tension, and proper lubrication. Insulation should be tested with a

megohmeter, and a log should be kept of these readings so that comparisons can be made from month-to-month. Check for excessive vibration.

- As underloaded motors are identified by the survey, they should be changed for motors appropriately sized for the job. The inventory (developed above) should serve as the basis for moving motors from one location to another within the plant to match sizes to loads. If properly sized motors are available from spares or stocks, replacements of a given kW rating should prioritized on the basis of the possible efficiency improvement (degree of underloading and operating hours per year).

- If phase-to-phase voltage imbalance is found (over 2%), then adjustments should be made to correct the problem. For every 2% variation in phase-to-phase voltage, a motor loses about 1% in efficiency. For the 0.4 kV system, the phase voltages should be equal within ±5 volts, otherwise efficiency is reduced. Voltage imbalance can be caused by loose or corroded connections at bus bars, starter terminals, fuses, or the motor itself. If the problem is caused by single-phase loads which are attached one of the phases, these loads should be more equally distributed among the phases, or else the transformer should be retapped.

The Compressed Air Efficiency Team should have the following tasks:

- Based on design data, make an inventory of all uses of compressed air

- On a monthly basis, carry out an analysis of air compressor efficiency and record in logbook. If less than design, investigate the causes.

- Carry out a survey of the plant every month to identify compressed air leaks, and record them in a log book. Measure the flow of leaks using a velometer and prepare a report, with the monthly cost of each leak clearly indicated. Develop a plan for leak repair, based on priority.

Expected results:

The RCG/Hagler, Bailly team estimates that the potential savings of

an improved maintenance program based on these procedures is 2% of peak electrical demand, 5% of Alumina plant's electric energy consumption and 5% of steam energy consumption. The savings are estimated as follows:

Electrical:
2% x 11 MW x $11,000/MW/mo x 12 mo/yr = $29,000/yr
5% x 55 million kWh/yr x $0.04/kWh = $110,000/yr

Thermal (mazout for steam):
5% x 70,428 tons/yr x $130/ton = $450,000/yr

The maintenance program will increase motor life, thereby reducing replacement and rewinding costs over the long run. The maintenance and monitoring program will also reduce the frequency of shutdowns in production operations because of motor failures, thereby having a productivity benefit. These benefits are not estimated in this report.

Equipment required:
(1) Digital strobe tachometer
(1) Digital multimeter/megohmeter with current clamp and Power factor meter
(1) Velometer
(1) Digital thermocouple indicator and probes
(1) Infrared thermal imager (USAID)
total estimated cost $25,000

RCG/Hagler, Bailly estimates that KAT should budget $200,000 per year for additional incidental equipment and repairs (additional maintenance), such as steam traps, insulation, motors, and the like.

Financial analysis:

Based on a cost of $25,000 and a net savings of $489,000 per year, the project payback period is less than one month.

Schedule:

Task 1 - RCG/Hagler, Bailly prepares specification for IR thermal imager and submits for approval by USAID.
Milestone: June 21, 1991

Task 2 - USAID provides final approval for procurement.
Milestone: June 31, 1991

Task 3 - RCG/Hagler, Bailly issues purchase order for equipment.
Milestone: July 2, 1991

Task 4 - Equipment delivered to KAT.
Milestone: September 13, 1991

Task 5 - Equipment installed in plant, and KAT completes development of operating procedure for use of equipment.
Milestone: September 27, 1991

Task 6 - Equipment fully operational and in use, monitoring begins by KAT.
Milestone: October 11, 1991

B. LOW-COST, SHORT-TERM IMPROVEMENTS

ALUMINA CALCINER
KAT Action B.1 -
Improve combustion efficiency - install fixed instrumentation to measure CO and O_2 content of the alumina calciner stack gases. Revise operating procedures.

Existing Conditions:

The control of the calciner is presently done based on historical data using the feed rate of the hydrate as the independent variable and the combustion parameters as the controlled variables. The operator consults an operator's log page corresponding to the hydrate feedrate. The pages list operating parameter settings which are considered optimal for each feedrate. He then sets the fuel oil pressure to the two burners, the primary air damper, the secondary air damper and the induced draft fan damper according to the guidelines prescribed by the log sheet. Feedback occurs in the form of several temperature measurements, measurement of pressure in the calciner and in the primary air duct, measurement of CO_2 in the exhaust gases and periodic measurement of the angle of repose of the product. Angle of repose correlates to the degree of calcination of the product. The calciner presently consumes about 27,080 metric tons per year of residual oil.

On 4 April, 1991 the RCG/Hagler, Bailly team made a series of measurements of the calciner exhaust gases using our portable combustion analyzer. Parameters measured were fuel input, CO, O_2, HC (combustibles), stack temperature, hydrate feedrate and several pressures and damper settings. At the time of the first measurement, the following conditions existed:

CO	over 2500 ppm (off scale of instrument)
CO_2	15.3 %
HC	0.6 %
O_2	1.5 %
T	230 Deg C
Input	56 ton/hr of hydrate feed
Oil	3,800 liter/hr

A computer analysis (see Appendix 4) later showed that these conditions indicate a combustion efficiency of 87.2%, based on lower heating value (LHV). The high concentration of CO and the presence of significant amounts of soot (HC) in the stack indicated

that insufficient air was being supplied to the burners for complete combustion of the fuel. With the equipment currently in place, this condition could not be detected by the operators, since only CO_2 is measured at the calciner outlet, and since the electrostatic precipitator which cleans the stack gases removes the soot and smoke from the stack gas.

Some experiments were then undertaken to determine if the combustion efficiency could be raised by adjusting the air-fuel ratio to the burners to lower the amount of combustible material in the stack. This was to be done by opening the primary air damper. The damper was opened in several small steps until it was 100% open. This action reduced the HC content of the stack gas from 0.60% to 0.00% and the CO from over 2500 ppm to 40 ppm (parts per million). The secondary air damper was then opened slightly to provide still more air. At the final settings, the following operating conditions were observed:

CO	40 ppm
CO_2	14.0 %
HC	0.00 %
O_2	3.2 %
T	255 Deg C
Input	56 ton/hr
Oil	3,800 liter/hr

Computer combustion efficiency analysis by RCG/Hagler, Bailly showed that the new combustion efficiency had been raised to 88.8%. This increase in combustion efficiency illustrates the potential for significant energy conservation in this piece of equipment:

KAT ALUMINA - CALCINER COMBUSTION EFFICIENCY

	Measurements				Calculation	Estimates	
	O2 %	CO ppm	HC %	Temp C	Combstn on LHV,%	Mazout tonne/yr	Cost K$/yr
Calcining kiln							
before	1.5	3500	0.60	230	87.2	27,080	3,520
after	3.2	40	0.00	255	88.8	26,592	3,457
savings						488	63

Recommended Actions:

RCG/Hagler, Bailly will recommend to USAID that equipment for monitoring O_2 and CO content of the stack gases be provided to KAT under the USAID Yugoslavia Emergency Energy Assistance Program.

KAT would be expected to pay for installation of the equipment, training of calciner operators in its use, and revision of the calciner operating procedures. We recommend several modifications to the calciner control procedure:

1. Fuel input to the calciner should be regulated to give properly calcined product without unnecessary overheating. The proper burning rate will depend on not only the feed rate of the hydrate, but on the hydrate moisture content, the ambient weather conditions which affect skin losses, the amount of heat lost up the stack, the temperature and flow rates of the primary and secondary combustion air and the quality and temperature of the fuel. The quality of the product out of the calciner is the most important parameter, and should in some way be linked to the firing rate. We recommend that studies be performed which correlate some continuously measurable variable with product quality. Possibilities might be product temperature at the outlet, electrical conductivity, product density, product color, or even angle of repose, provided that some way can be found to measure the parameter on a very frequent if not continuous basis. Burner firing rates should be adjusted to maintain proper product quality, rather than setting them according to hydrate feed rate.

2. Control combustion air to the burners based on the O_2 and CO content of the stack gases rather than on the hydrate feedrate. Primary and secondary air should be regulated to give the minimum amount of excess air to the burner which is required for complete combustion of the fuel. The burners should fire smoothly and steadily without the persistent pulsing evident while we were there. The pulsing indicates inadequate mixing of the combustion air and fuel in the flame envelope, or perhaps inadequate atomization of the fuel. The combustion air delivery system should be investigated. It is possible that insufficient primary air is being delivered and the pulsing results from combustion of partially burned gases mixing with the secondary air further down the kiln. As an experiment, KAT might try leaving the primary air damper completely open and gradually cutting back the fuel flow to one or both burners to see if the pulsing stops. The flame geometry and air flow patterns in the firing end of the kiln are complex, and we did not have sufficient time during our visit to fully understand this aspect of the kiln operation.

3. Set the induced draft fan damper to maintain a slight negative pressure in the kiln in order to prevent loss of product and

destruction of the seals by hot gases. The important parameters here are the pressure drops across the dust removal equipment, especially the cyclones. Manufacturer's literature should be consulted to determine the recommended pressure drops for efficient particulate removal. Stack gas flowrates must be adequate to carry away the products of combustion and the water released from the hydrate. Flowrates must also be kept high enough to prevent condensation of water, NOx and SOx in the dust removal equipment and in the stack. Heat transfer from the hot air to the product in the calciner is also somewhat affected by the air velocity, so precise determination of the proper flowrate is rather complex. However, the most energy-efficient operation will be achieved by minimizing the amount of air blown up the stack. Reducing exhaust gas flowrates will reduce the amount of thermal energy loss as well as the amount of fan power required to move the air. We recommend that KAT engineers perform some experiments to determine the effects of changes on induced draft damper settings on product quality, dust removal efficiency and gas temperatures in the stack. From these experiments, new operating procedures can be devised to guide operators in running the calciner for maximum efficiency.

Expected Results

The experiment described above demonstrated that significant energy savings are possible in the operation of the alumina calciner. By completely burning the fuel entering the calciner, the combustion efficiency was raised by 1.6% for the conditions in effect at the time. It must be noted that much experimentation needs to be carried out by KAT engineers to find optimal operating conditions for other feedrates, weather conditions, etc. The experiment begun by RCG/Hagler, Bailly associates would need to taken one step further even for the feedrate already tested--namely, oil flow to the burners would need to be cut back to allow for the fact that more energy is now being extracted from each liter of fuel. The increase in combustion efficiency means that the same amount of hydrate should be adequately calcined using roughly 2% less fuel. At the current consumption rate of 27,080 tons per year of oil and a price of $130 per ton of mazout, the potential savings are approximately $63,000 per year.

It is possible that efficiency improvements at other feedrates could be greater than or less than those for this particular rate, and so the calculation above is only approximate. However, the potential savings are clearly significant. The cost of implementing this recommendation would be approximately $17,000,

calculated as follows:

Instrumentation (USAID)	
Oxygen and CO Analyzer	$8,000
(Ametek Thermox WDG-HPIIC, or equivalent)	
Calibration gas and spare cells	$2,000
Instrument Cable	$1,400
200 meters 6pr Shielded twisted pair @ $7/m	
Installation and Calibration	$500
20 man-hours @ $25/hr	
Experimentation for Operating Curves	$5,000
200 man-hours @ $25/hr	
Total	$16,900

Financial analysis:

The simple payback on the project is less than 4 months. An economic analysis would give a similar result, since border prices ($130/ton) are taken as the basis for the financial analysis rather than local fuel oil prices (which are now higher, but are expected to change once adjustments are made to reflect the world oil market conditions).

Schedule:

Task 1 - RCG/Hagler, Bailly prepares specification for combustion sensors and submits for approval by USAID.
Milestone: June 21, 1991

Task 2 - USAID provides final approval for procurement.
Milestone: June 31, 1991

Task 3 - RCG/Hagler, Bailly issues purchase order for equipment.
Milestone: July 2, 1991

Task 4 - Equipment delivered to KAT.
Milestone: September 13, 1991

Task 5 - Equipment installed in plant, and KAT completes development of operating procedure for use of equipment.
Milestone: September 27, 1991

Task 6 - Equipment fully operational and in use, monitoring

begins by KAT.

Milestone: October 11, 1991

B. LOW-COST, SHORT-TERM IMPROVEMENTS

BOILERHOUSE
KAT Action B.2 -
Improve combustion efficiency - install fixed instrumentation to measure CO and O_2 content of the boiler stack gases. Revise operating procedures.

Existing Conditions:

The control of the air to fuel ratio in the boilers is presently done based on operators' experience for a given load. The operator sets the fuel oil pressure to the burners and the damper on the forced draft fan according to his experience. Visible smoke from the stack is used as an indicator. As a check, a manual reading of oxygen content is made in the stack of each boiler once each day using a portable oxygen analyzer (made by Teledyne Instruments) and kept in a diary.

Annual fuel consumption in the boilers is estimated as 70,428 metric tons of mazout (based on 1990 data).

On 2-4 April, 1991 the RCG/Hagler, Bailly team made a series of measurements of the calciner exhaust gases using our portable combustion analyzer. Parameters measured were fuel input, CO, O_2, HC (combustibles), stack temperature, combustion air pressure (draft) and other pressures and damper settings. Compute_ analysis, performed later, was used to calculate combustion efficiency based on lower heating value (LHV).

In the initial readings taken, a high concentration of CO and the presence of significant amounts of soot (HC) in the stack of boiler #1 indicated that insufficient air was being supplied to the burners for complete combustion of the fuel.

In boiler #3 and boiler #4, combustion air in excess of optimum was found, indicating avoidable heat loss up the stack.

Boiler #2 was found to be tuned to a satisfactory condition.

Some experiments were then undertaken to determine if the combustion efficiency could be raised by adjusting the air-fuel ratio to the burners in boilers 1, 3, and 4. This was to be done by opening the primary air damper.

KAT POWER PLANT - BOILER COMBUSTION EFFICIENCY

	Measurements O2 %	CO ppm	HC %	Temp C	Calculation Combstn effy on LHV,%	Estimates Mazout tonne/yr	Cost K$/yr
Boiler #1							
before	4.0	1200	0.08	160	92.2	17,607	2,289
after	4.4	35	0.00	160	92.9	17,474	2,272
savings						133	17
Boiler #2							
before	8.2	6	0.00	160	91.1	17,607	2,289
after	5.2	32	0.00	160	92.6	17,321	2,252
savings						286	37
Boiler #3 (not changed)							
as found	4.8	3	0.00	180	91.8	17,607	2,289
Boiler #4							
before	7.3	12	0.00	160	91.7	17,607	2,289
after	5.5	24	0.00	160	92.5	17,455	2,269
savings						152	20
TOTAL SAVINGS (4 BOILERS)						571	74

Computer-aided combustion efficiency analysis by RCG/Hagler, Bailly, performed after the audit visit, showed that combustion efficiency had been raised to over 92% after the tune-up. This increase in combustion efficiency illustrates the potential for significant energy conservation in the boilers.

Recommended Actions:

RCG/Hagler, Bailly will recommend to USAID that equipment for monitoring O_2 and CO content of the stack gases be provided to KAT under the USAID Yugoslavia Emergency Energy Assistance Program. Unfortunately, because of limitations of funding available, this system can be procured for only ONE BOILER under the USAID program.

KAT would be expected to pay for installation of the equipment, training of boiler operators in its use, and revision of the boiler operating procedures to control combustion air to the burners based on the O_2 and CO content of the stack gases. Primary and secondary air should be regulated to give the minimum amount of excess air to the burner which is required for complete combustion of the fuel.

If the use of the equipment succeeds in saving energy, KAT should

be able to pay for the other three boilers to be retrofitted, using the energy savings as a source of funding.

Expected Results

The experiment described above demonstrated that significant energy savings are possible in the operation of the boilers.

At the current consumption rate of 70,428 tons per year of oil, the potential savings of 571 tons represent 0.8% of total consumption. The annual savings are approximately:

0.8% x 70,428 tons/year x US $130/ton = US $74,000 per year

The cost of implementing this recommendation would be approximately $12,000 for each boiler, calculated as follows:

Instrumentation (USAID)	
Oxygen and CO Analyzer	$8,000
(Ametek Thermox WDG-HPIIC, or equivalent)	
Calibration gas and spare cells	$2,000
Instrument Cable	$ 400
60 meters 6pr Shielded twisted pair @ $7/m	
Installation and Calibration	$500
20 man-hours @ $25/hr	
Experimentation for Operating Curves	$1,000
40 man-hours @ $25/hr	
Total	$11,900

Financial analysis:

Based on a total installed cost of $48,000 (for all four boilers) and a savings of $74,000 per year, the payback period is less than 8 months. An economic analysis would give a similar result, since border prices ($130/ton) are taken as the basis for the financial analysis rather than local fuel oil prices (which are now higher, but are expected to change once adjustments are made to reflect the world oil market conditions).

Schedule:

Task 1 - RCG/Hagler, Bailly prepares specification for combustion sensors and submits for approval by USAID.
Milestone: June 21, 1991

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Milestone: September 27, 1991

Task 6 - Equipment fully operational and in use, monitoring gins by KAT.
Milestone: October 11, 1991

B. LOW-COST, SHORT-TERM IMPROVEMENTS

BOILERHOUSE
KAT Action B.3 -
Repair leaking air preheater on Boiler #1

Existing Conditions:

The RCG/Hagler, Bailly team observed that boiler #1 was unable to supply sufficient air for complete combustion and must be derated (see Action A.1). A further observation is that the stack temperature for boiler #1 was only 130C, as compared to 160C in the other boilers. These conditions indicate that the air preheater for boiler #1 is probably leaking - part of the combustion air provided by the forced draft fan is diluting the exhaust gas stream, thereby reducing its temperature.

Recommended Actions:

The RCG/Hagler, Bailly team did not confirm the leak by an oxygen test. We recommend that this test be carried out by KAT (using their existing Teledyne oxygen meter). The oxygen content of the flue gas stream should be measured in two places - before and after the air preheater. If there is any appreciable increase in oxygen content, the leak would be confirmed.

if the leak is confirmed, the air preheater should be repaired whenever the boiler is next taken out of service for an extended overhaul. In the meantime, Action A.1 should be maintained - the boiler should be derated.

Expected Results:

Repairing the leak will enable boiler #1 to operate at full capacity. In some instances, this may enable the power plant to operate with only two boilers instead of three, which would save fuel energy associated with fixed losses. There will also be electrical savings, as the forced combustion air now going up the stack will be used for its intended purpose.

These savings are estimated as follows:

Mazout: 0.5% of annual fuel use of one boiler
0.005 x 17,605 ton/yr = 88 ton/yr
88 ton/yr x $130/ton = $11,000/yr

Electrical: 10 kW, 5000 hours per year
10 kW x 5000 hr/yr = 50,000 kWh/yr
50,000 kWh/yr x $0.04/kWh = $2,000/yr

Total = $13,000/yr

The cost of repairing the air preheater depends on the number of tubes which need replacement. We estimate the cost as $20,000 or less.

Financial analysis

If the cost is $20,000, the payback period would be 1.5 years.

B. LOW-COST, SHORT-TERM IMPROVEMENTS

ALUMINA CALCINER
KAT Action B.4 -
Reduce heat loss - use portable infrared thermal imaging device to monitor refractory condition.

Existing Conditions:

Substantial heat is radiated from the shell of the calciner, which is a rotary kiln about 80 meters in length. Heat loss is reduced by the refractory lining inside the kiln. Thermocouples are installed in two locations to monitor the temperature inside the kiln. Regular measurements and logs of refractory conditions are not made because KAT does not have the necessary equipment.

Recommended action:

RCG/Hagler, Bailly team recommends that KAT adopt a new procedure for monitoring refractory wear, based on temperature readings from an infrared thermal imaging device (to be procured under Action A.3). This device can locate hot spots and damaged sections of refractory so that repairs can be made during scheduled maintenance shutdowns.

The device should be used in conjunction with a logbook drawn up for this purpose. The log should allow the operator of the thermal imager to enter readings along the length of the kiln and also across the diameter at each location.

The thermal imager should be specified to give a monochromatic image of the surface of the kiln or other equipment. The temperature readout should be capable of 0-1000C.

Expected results:

RCG/Hagler, Bailly estimates that the use of the thermal imager, together with revised maintenance procedures to optimize refractory replacement, can reduce annual fuel consumption in the calciner by 3%. At the current consumption rate of oil, the energy savings are estimated as follows:

3% x 27,080 tons/yr x US$130/ton = $105,000 per year

The cost of the IR thermal imager, with temperature readout, is

estimated as $17,000.

RCG/Hagler, Bailly estimates an additional maintenance budget of $30,000 per year, to allow for shutdowns and refractory, will be required.

Financial analysis:

Based on a cost of $17,000 and a net savings of $75,000 per year, the payback period is less than 3 months.

B. LOW-COST, SHORT-TERM IMPROVEMENTS

BOILERHOUSE
KAT Action B.5 -
Clean tubes to reduce stack temperature on Boiler #3

Existing Conditions:

The RCG/Hagler, Bailly team observed that boiler #3 had a stack temperature of 180C, whereas the other boilers were 160C.

Usually a high stack temperature indicates fireside deposits of soot, which reduce heat transfer efficiency.

Recommended Actions:

The RCG/Hagler, Bailly team recommends that the cause of the higher temperature be checked, and confirmed by a thermocouple test. If deposits are indicated, then the tubes should be cleaned whenever possible. It may be beneficial to advance maintenance schedules to achieve the savings sooner.

Stack temperature should be used as a diagnostic for boiler maintenance. The logs should be monitored, and the readings used to make decisions regarding maintenance.

Expected Results:

Reducing the stack temperature from 180C to 160C will increase combustion efficiency at boiler #3 slightly, an annual savings of about $15,000. Detailed calculations are provided in Appendix 3.

KAT POWER PLANT - BOILER COMBUSTION EFFICIENCY

	Measurements				Calculation	Estimates	
	O2 %	CO ppm	HC %	Temp C	Combstn effy on LHV,%	Mazout tonne/yr	Cost K$/yr
Boiler #3							
before	4.8	3	0.00	180	91.8	17,607	2,289
after	4.8	3	0.00	160	92.4	17,492	2,274
savings						115	15

The cost cleaning the boiler depends on problem that is found. We estimate the cost as $10,000 or less, for a payback period of less than one year.

C. CAPITAL INVESTMENT

ALUMINA CALCINER
KAT Action C.1 -
Investigate the possibility of preheating primary combustion air for calciner.

Existing Conditions:

The air used in the combustion process is drawn at ambient temperature by a forced draft fan and injected into the burner housing. Secondary air is also pulled through the planetary cooler and enters the housing through the product exit port in counterflow to the alumina. At the time of our visit, the secondary air was entering the calciner at about 240 degrees C. Neither the absolute flowrates nor the ratio of primary to secondary air flow is known. The burner is constructed as a long tube which extends well into the rotating part of the kiln, so that the last few meters of the kiln form a cooling section for the alumina before it drops into the planetary cooler. The alumina leaves the kiln and enters the cooler at approximately 620 degrees C. Since calcination takes place at 1200 degrees C, considerable cooling of the product occurs inside the kiln. Some of the heat is passed to the secondary air stream, and the rest is dissipated through the shell of the kiln to the atmosphere.

Recommended Actions:

Two opportunities may exist for waste heat recovery in the calciner. The most likely option is to use some of the heat presently dissipated through the calciner skin to preheat combustion air. The accompanying sketch shows a metal shroud constructed around the cooling section of the calciner. Primary combustion air would be drawn through the space between the shroud and the hot calciner skin, preheating the air and increasing the cooling of the product in the kiln.

The second opportunity is not certain but will be offered as a suggestion for KAT engineers to evaluate. The idea is to increase the heat transfer from the product to the secondary air stream if possible. This would be done by adding lifting flights to the cooling section of the calciner and to the first section of the cooler, if they do not already exist. A sketch of the arrangement is shown in Figure 2. The lifting flights scoop up the alumina and drop it through the secondary air stream, thus increasing the surface contact between the alumina and the secondary air. Better

heat transfer from the alumina to the air would result.

As noted in the preceding discussion of the calciner (see action B.1), the RCG/Hagler, Bailly team did not have sufficient time to fully investigate the entire operation of the calciner, especially the air flow patterns in the firing end, which are complex. It is possible that such lifting flights are already installed. If not, KAT engineers may wish to evaluate this project as a further opportunity in addition to preheating the primary air. It could obviously only be implemented during a shutdown of the calciner, perhaps during refractory replacement operations.

Expected Results:

Precise calculations cannot be offered here in the absence of detailed data on air flow rates, kiln skin temperatures and precise dimensions of equipment, but some order of magnitude estimates can be made. From observations during our visit, it appeared that considerably more primary air is being used than secondary air, so for conservatism, let us estimate that 50% of the air entering the kiln is primary air. If the oil consumption of the calciner is 24,000 tons per year (after the combustion efficiency improvement, action B.1) and the combustion takes place at an air/fuel ratio of 15:1 (7% excess air), then 165,000 tons of air per year are supplied by the primary air system. The shroud should allow combustion air preheating by at least 50 degrees C. With proper baffling, perhaps higher temperatures could be achieved, but shroud construction would be more difficult and expensive. Even a 50 degree preheat is worth a significant investment:

165,000 tons/yr x (950 KJ/ton- C) x 50 C = 7,840 GJ/yr

7,840 GJ/yr x 1 ton/42 GJ x US$130/ton = $24,300/yr

We anticipate larger savings are possible, since the estimate was deliberately conservative. The figures given below are only gross approximations, but should be reasonable. The figures include replacement of the current ductwork with larger ducting. There is some evidence that the present ductwork is too small anyway, since we had difficulty in obtaining sufficient primary combustion air. In addition, the heated air will be less dense, so we suggest replacing both the ductwork and the fan. The ductwork would obviously have to be rerouted, and the fan should be moved up to the calciner level or above it. We also suggest installing a motorized damper which the operator can control from inside the control room in response to burner changes.

Materials:		
Mild steel plate		$3,000
New ductwork		$2,000
New fan and motor		$12,000
New Damper and Control		$3,500
Labor:		
Engineering:	80 hrs @ $25	$2,000
Fabrication:	200 hrs @ $15	$3,000
Installation:	100 hrs @ $15	$1,500
	Total	$27,000

The cost to implement this measure would thus be about equal to the projected savings for one year.

V. ADDITIONAL RECOMMENDATIONS - OUTSIDE ALUMINA PLANT

D.1 Recommendation for aluminum smelting[3]
Study deterioration of efficiency in smelting

Existing conditions

Over the years, the efficiency of aluminum production at the smelters has deteriorated. The specific electricity consumption is now about 15 kWh/kg, whereas formerly the plant was able to achieve 14 kWh/kg.

During a brief walk through visit to see the smelting operation, the RCG/Hagler, Bailly team leader observed that the operator did not clean the contacts when he replaced the anode. There may be some build-up of alumina dust, as the contacts are directly above the pot. The slightest build-up of dirt can rob the cell of efficiency, because of the very low voltage (5 V).

Recommendation

RCG/Hagler, Bailly's spot check is not enough to make an assessment of the problem and to develop a solution. Such a project is recommended. It seems logical that the Aluminum Institute at KAT should lead this effort, with outside assistance if required.

RCG/Hagler, Bailly recommends that KAT use the IR thermal imager, to be procured under Action A.3 through USAID assistance, to inspect the electrical connections on the smelting pots by looking for hot spots, indicative of loose connections.

Expected results

Given the high electrical cost paid by the plant, the potential savings by reducing electrical consumption to 14 kWh/kg is at least $5 million per year:

Annual electricity costs at 15 kWh/kg:
- Demand (300 MW) = US$40 million/yr
- Energy (2 million MWh) = US$78 million/yr
- Total = $118 million/yr

[3] The aluminum smelting plant was outside the scope of RCG/Hagler, Bailly's effort, which was limited to alumina and the power station.

Annual electricity costs at 14 kWh/kg:

Demand (300 MW) = US$40 million (conservative assumption)
Energy (1.87 million MWh) = US$73 million/yr
Total = $113 million/yr

V. ADDITIONAL RECOMMENDATIONS - OUTSIDE ALUMINA PLANT

D.2 Recommendation for anode plant[4]

Seal air leaks in the anode baking ovens to improve combustion efficiency and reduce product damage.

Existing Conditions:

On the last day of the in-plant exercise, a very brief visit was made to the anode plant by two members of the RCG/Hagler, Bailly team to troubleshoot a problem with the anode baking ovens. Operators are currently having problems obtaining complete combustion of the fuel oil used to bake the green anodes. The engineer we talked to also indicated that they were having problems with cracking of the firebrick in the ovens and damage to the anodes from oxygen contact with the hot carbon during high temperature curing.

In the anode baking ovens, green blocks are stacked three high in pits between the combustion chambers and covered with petro-coke. Heat transfer takes place by conduction and radiation from the combustion chambers through the firebrick and the petro-coke filler to the blocks.

Combustion air is forced into the firing chambers by a forced draft fan. The air travels down the firing chamber to the burners which are inserted into the chambers via ports in the top. An induced draft fan draws the products of combustion further down the tube and out through vents to the stack. The burners are moved to new firing ports in leapfrog fashion as curing progresses. Unused firing ports are covered by loose-fitting brick plugs.

RCG/Hagler, Bailly engineers performed an analysis of the stack gases which showed a composition of 20% oxygen and negligible carbon dioxide plus a smoke spot number of 6, indicating high CO. The stack temperature was only 120 degrees C in front of the induced draft fan only a few meters from the point of combustion. These conditions indicate that very large amounts of air are infiltrating the exhaust gas system between the point of combustion and the induced draft fan.

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[4] The anode plant was outside the scope of RCG/Hagler, Bailly's effort, which was limited to alumina and the power station.

Much of this air is drawn into the firing chambers through gaps around the burner port plugs. Additional air comes in around bad seals where the suction fan plenum attaches to the firing chambers.

On the forced draft side of the burners, the firing ports are often uncovered to bleed off air, so as to keep the static pressure at the burners approximately neutral. This practice results in inadequate combustion air delivery to the burners.

Recommendation

We recommend that greater care be taken in sealing the unused burner ports on the induced draft side of the burners so as to cut down air infiltration. One simple method would be to use aluminum foil or other suitable material as gaskets between the combustion chamber brickwork and the plugs. Another possibility is to obtain or make a better plug with a taper to fit more snugly into the burner ports. Similarly, leaks around the induced draft fan plenum must be sealed as well as possible. It was unclear to us whether or not any type of seal is placed over the anode stack to prevent air infiltration through the granular coke filler material. If there is presently no seal on the top of the baking pits, one should be devised for them also, to prevent air from being drawn down through the granular coke to cracks in the firebrick. Air taking this pathway would cause damage to the anodes and possibly to the firebrick pit walls via thermal shock. KAT engineers indicated that the best anodes tended to come from the center of the three-high stack, and the worst from the top. Air leakage plus incomplete baking could be contributors.

We also recommend that the procedure for balancing the forced draft side of the combustion process be altered. Rather than removing burner port covers to bleed air, control the pressure by manipulating the dampers on the forced draft fan plenum. There is a damper for each combustion chamber, which should allow adequate balancing of the draft. These dampers are currently not used in favor of the bleed off technique. The bleed technique wastes fan power by pumping air that is not used for the combustion process.

Finally, more air must be supplied to the burners in some fashion. The current practice attempts to minimize the creation of positive pressure in the combustion chamber so as to reduce exfiltration of air from the chamber into the baking pits where it damages the anodes. If the seals on the downstream side of the burners can be sufficiently improved, it should be possible to run the entire system at a slight negative pressure, as is common practice in boilers. The induced draft fan certainly has capacity beyond what

is needed for combustion air, as evidenced by its ability to process huge amounts of infiltration air. Sealing the infiltration leaks should allow suction of adequate combustion air through the system. Some experimentation will be necessary to determine what flow rates are adequate to provide complete combustion. We suggest that KAT attempt to monitor air velocity in each combustion chamber rather than just static pressure. One simple way to do this would be to place two pressure probes in each chamber separated by a few meters, and monitor the pressure drop along the length of the chamber. The pressure drop per unit length should correlate with air flow rates through the chambers.

Expected Results:

Since we have no quantitative data on this part of the plant at all, calculations of potential savings are difficult. Simple visual examination of the stack shows that large amounts of fuel are being exhausted unburned representing energy loss. The smoke spot test of 6 in a highly diluted stream leads us to believe that as much as 5-10% of the fuel may be going up the stack as CO and soot. Judging by the number of burners in operation, the anode plant must consume nearly as much fuel as the calciner, unless its operating hours are fewer. Let us assume an annual consumption of 10,000 tons of oil per year as a conservative and easily scalable estimate. At $130 per ton, each one percent increase in combustion efficiency can save US $13,000 per year in fuel costs.

We expect that far more than 1% improvement is possible. In addition to the fuel savings, significant fan power will be saved. Air flow through both fans will certainly decrease when the infiltration and is cut back. The gases will be much hotter, negating the decrease slightly, however excess fan capacity will probably be available. The damper positions should be monitored over the range of operating conditions. They will vary, depending on the placement of the burners and fans. If most of the dampers are always kept more than half closed, consideration should be given to reduction of the fan speed. Air flow is proportional to fan speed, but power consumption is proportional to the cube of fan speed. Therefore, rather than dissipate fan energy across a damper, fan speed should be reduced until most of the dampers are nearly open at the maximum required air flow rates. We suspect that both fans may exhibit considerably lower power requirements, in which case they should be refitted with smaller motors to improve motor efficiency and power factor. Once some experience is gained with the new operating conditions, it may be possible simply to exchange the existing fan motors for ones of lower RPM and power ratings.

The cost of implementing the basic recommendation is very little, consisting primarily of labor for experimentation and a small amount of materials for the gasketing.

V. ADDITIONAL RECOMMENDATIONS - OUTSIDE ALUMINA PLANT

D.3 Recommendation for Kombinat Aluminijuma Titograd[5] Determine business strategy to cope with high electricity tariffs

Existing conditions:

Although the KAT complex was built to exploit cheap hydroelectric power, the system now in place in Yugoslavia does not favor regional variations in electricity tariffs. Thus KAT is faced with a situation in which its average cost for electricity is much higher than that of competing plants in other countries.

Established hydroelectric systems in the U.S. are able to deliver electrical energy at a marginal cost of supply on the order of US$0.03 per kWh, or less. Exchange rates and electricity tariffs are constantly changing in Yugoslavia, but the following appears to be a typical industrial tariff, in US dollars at Dn 22 = $1.00 (as found in Croatia in May 1991):

Demand charge: US$11 per kW per month
Energy charge (average of high season and low season):
Active: US$0.065 per kWh on-peak, 0800-1400 & 1800-2200
US$0.026 per kWh mid-peak, 1400-1800
US$0.018 per kWh off-peak, 2200-0800

Under such a tariff, a plant with a load factor of 1.0 would pay an average of US$0.039 per kWh for its energy charge, and a total cost (including demand charge) of US$0.054 per kWh.

Recommendation:

This situation jeopardizes the future of the plant. If the plant is expected to enter into the world market economy before electricity tariffs are adjusted to reflect regional variations in the cost of electric supply, then the plant will be judged uncompetitive by world standards. However, this judgment would be unfair, as it results only from the decision to have a national system of energy prices.

[5] KAT's management policy was outside the scope of RCG/Hagler, Bailly's effort, which was limited to energy engineering activities at alumina and the power station.

RCG/Hagler, Bailly recommends that KAT undertake a systematic effort to understand the potential for regional electricity prices. This effort should include the following steps:

1. Study of electricity prices and their impact on the competitiveness of KAT in the markets in which it operates.

2. Study of electricity tariffs paid by KAT's main competitors.

3. Study of benefit of KAT to the economy of Yugoslavia, in general, and Montenegro in particular.

4. Study of long-run marginal cost of electricity supply in Montenegro.

5. Development of strategy for the future of KAT, under various scenarios of electricity tariffs, competitiveness, and market conditions.

6. Investigate feasibility of restructuring or privatization of KAT as a fully integrated aluminum company, including not only bauxite, alumina, powerplant, smelting, casting and rolling, but also a hydroelectric facility. This should be one of the existing hydro units, which was developed to serve the needs of KAT.

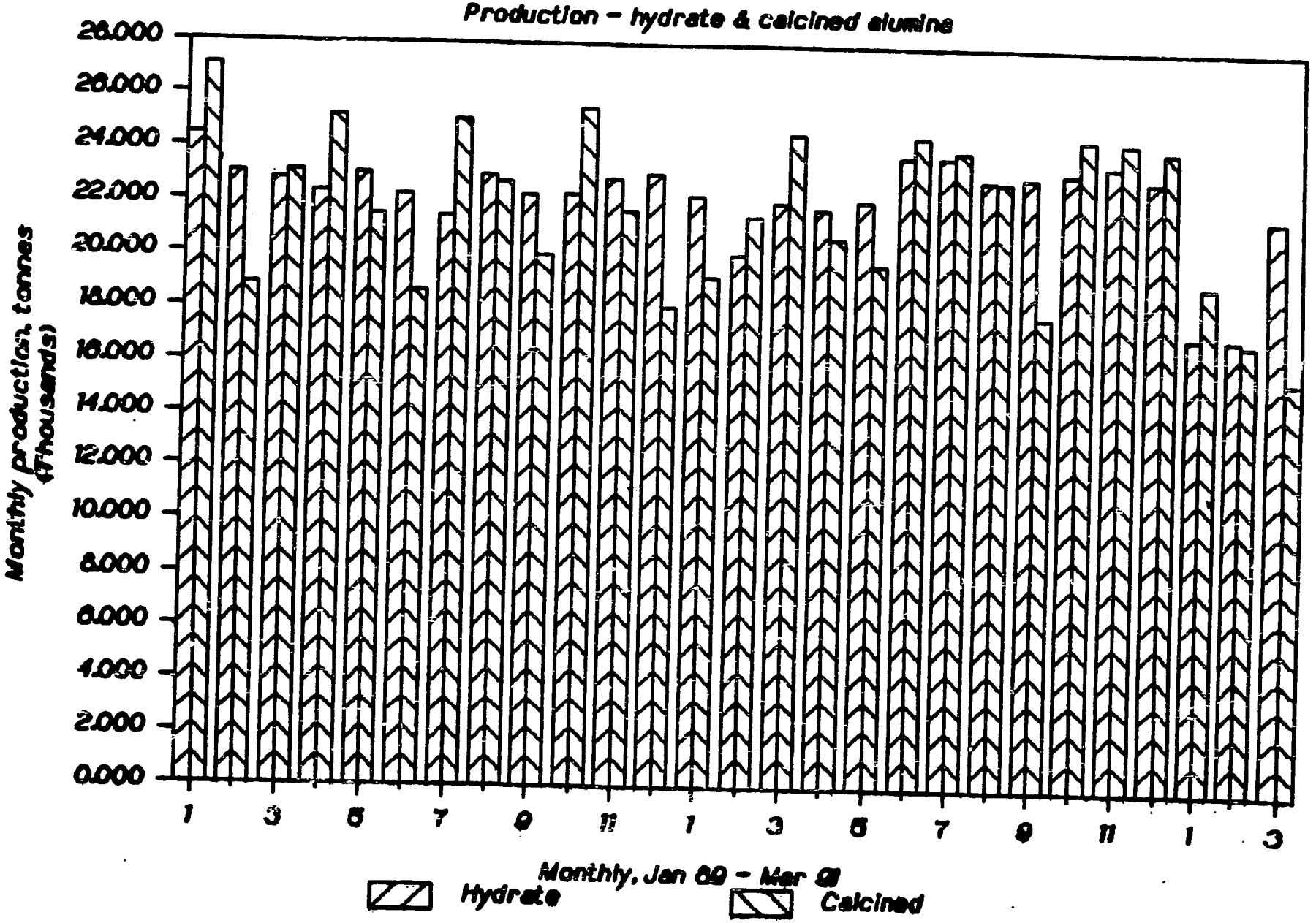
APPENDIX 1
GRAPHICAL PRESENTATION OF HISTORICAL ENERGY CONSUMPTION AND EFFICIENCY DATA

MONTHLY DATA

KOMBINAT ALUMINUJUMA TITOGRAD (KAT)
ALUMINA PLANT AND POWER PLANT

KAT - Alumina

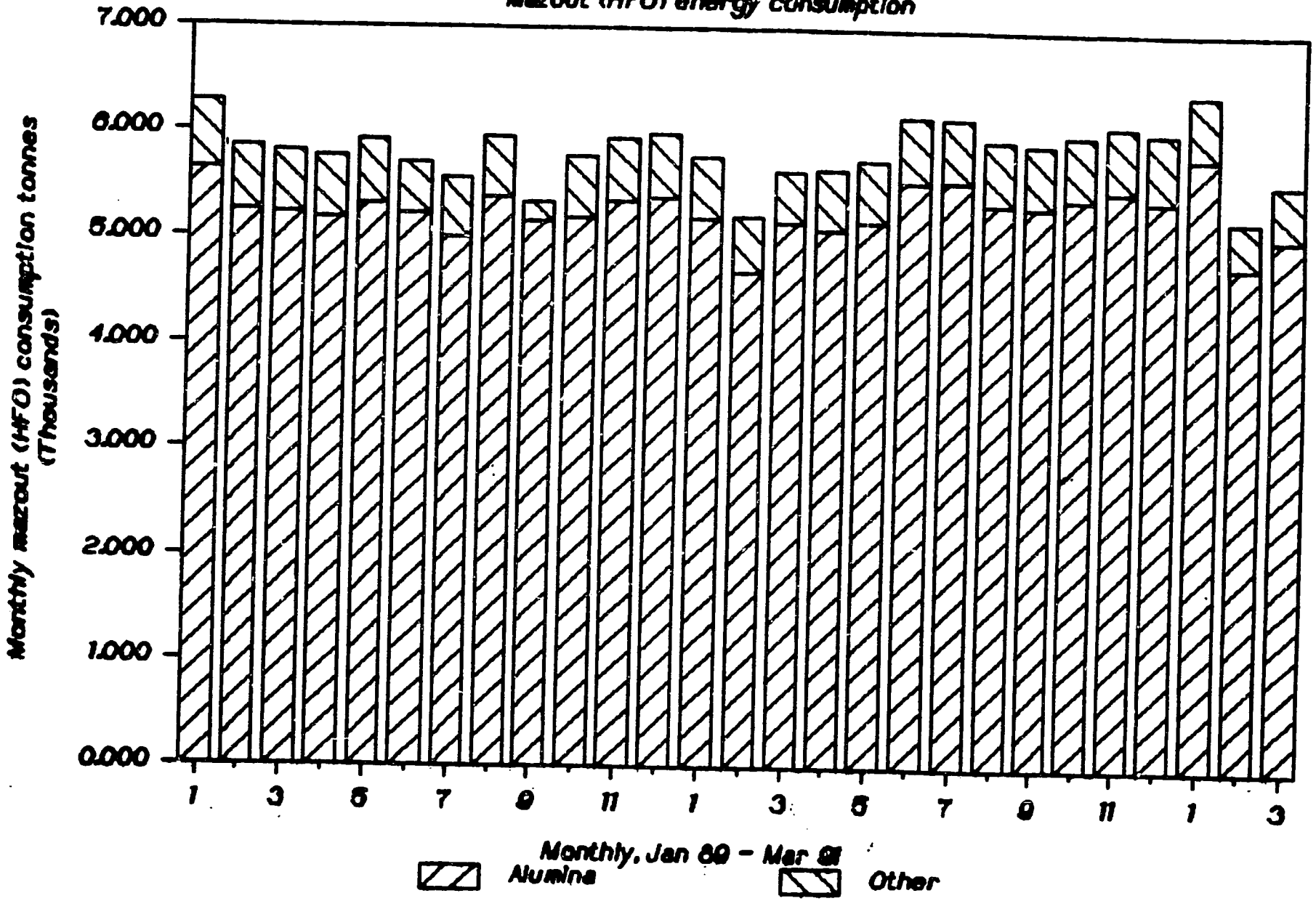
Production - hydrate & calcined alumina



-44-

KAT - Alumina

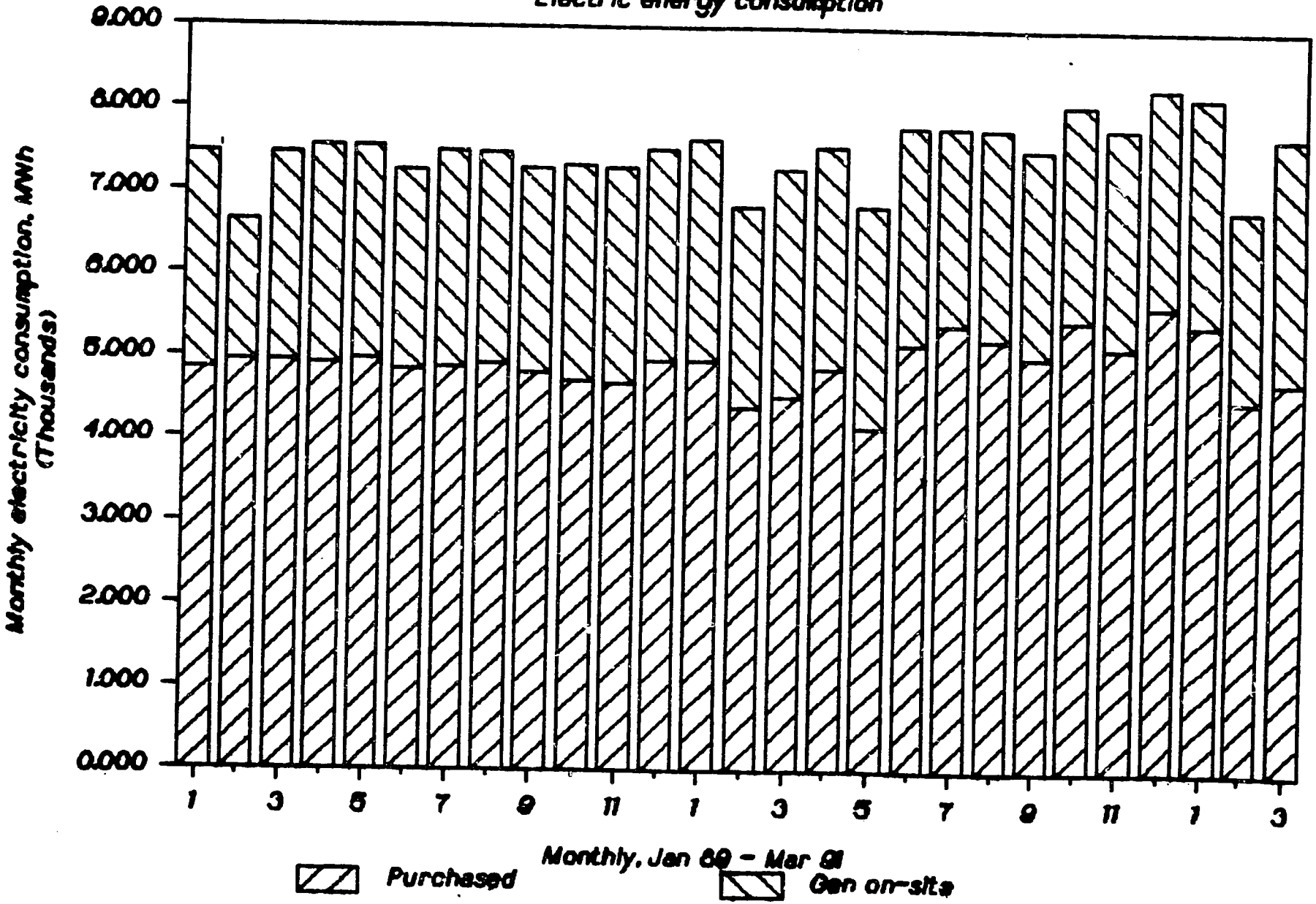
Mazout (HFO) energy consumption



45

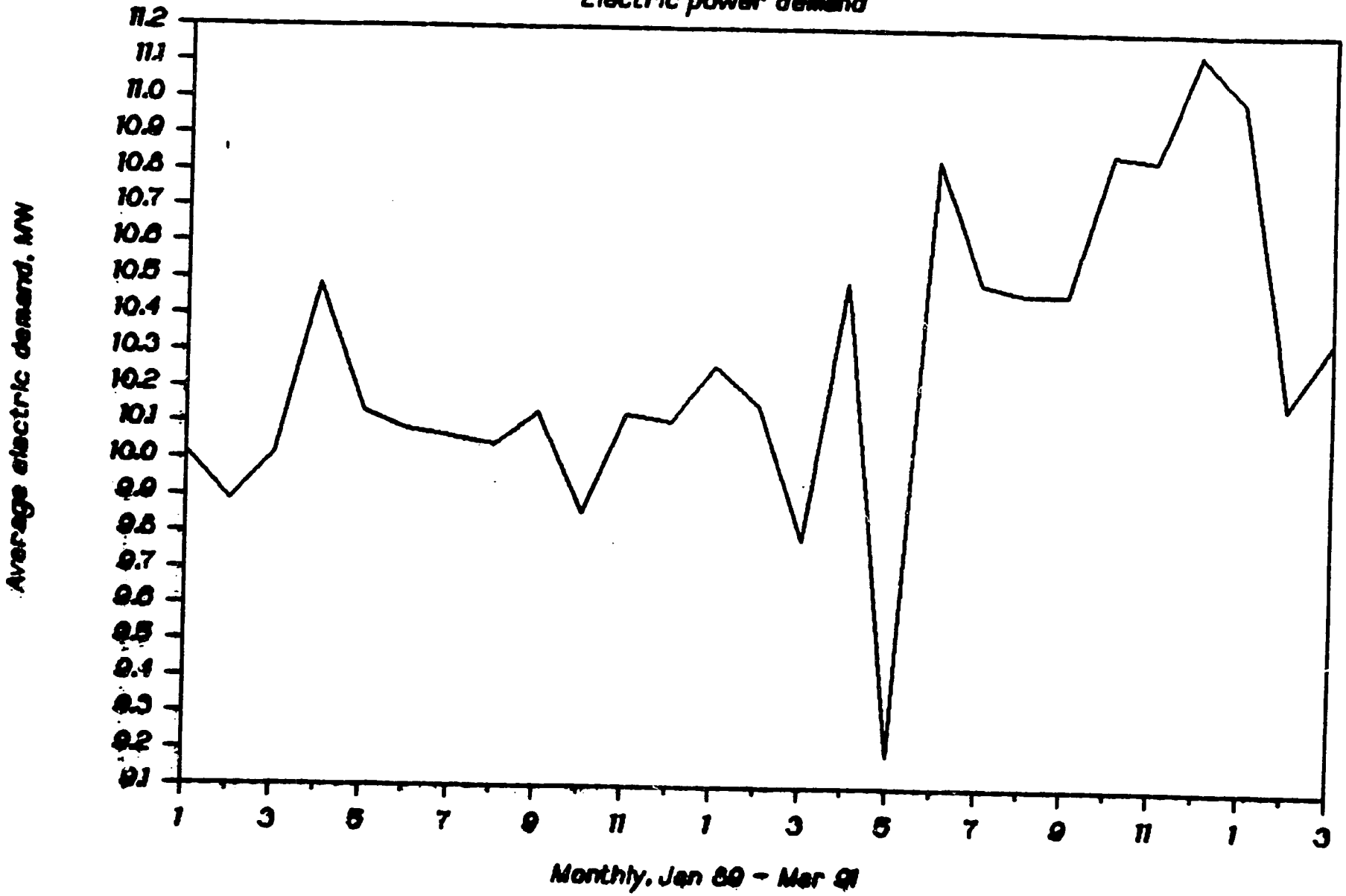
KAT - Alumina

Electric energy consumption



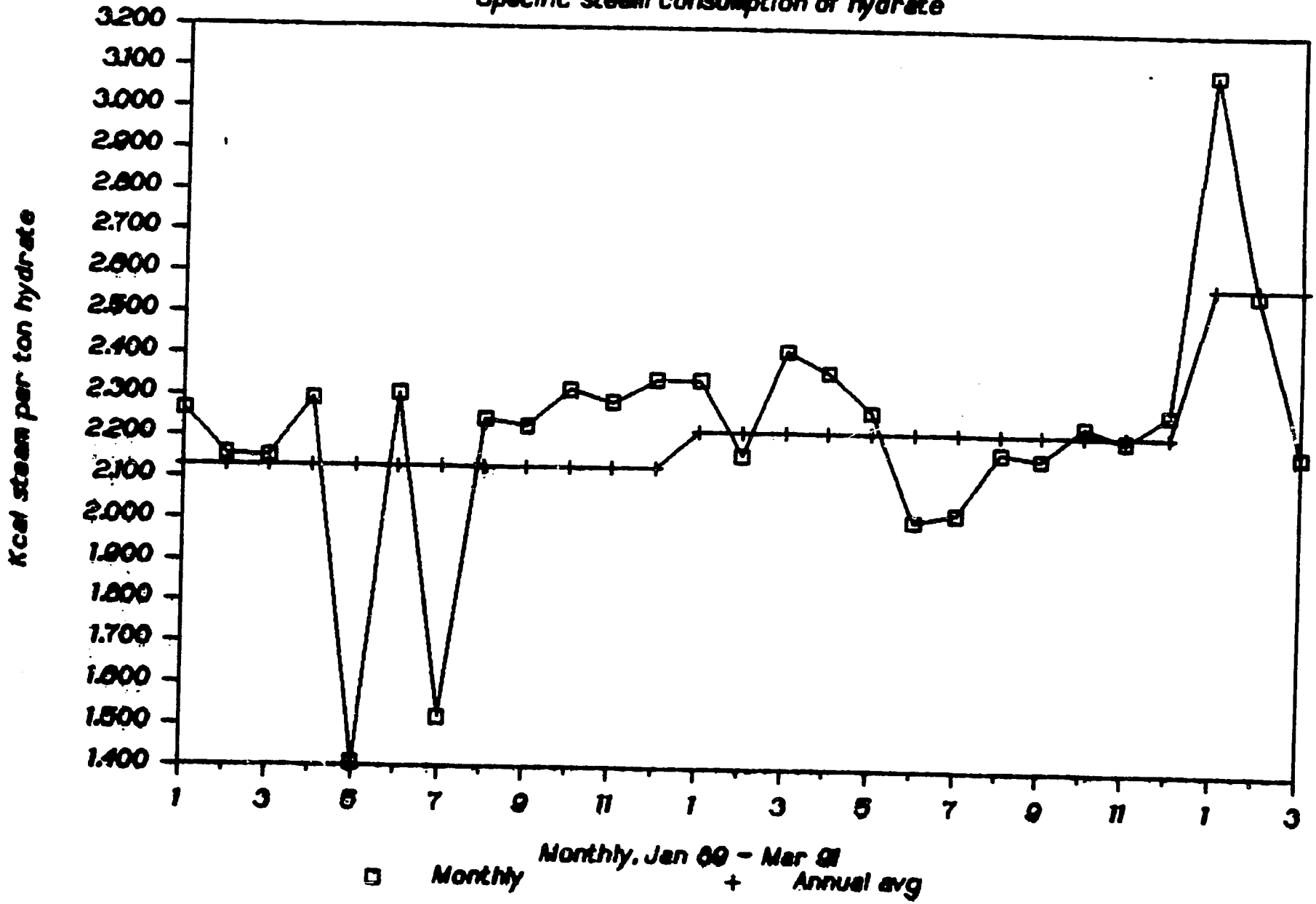
KAT - Alumina

Electric power demand

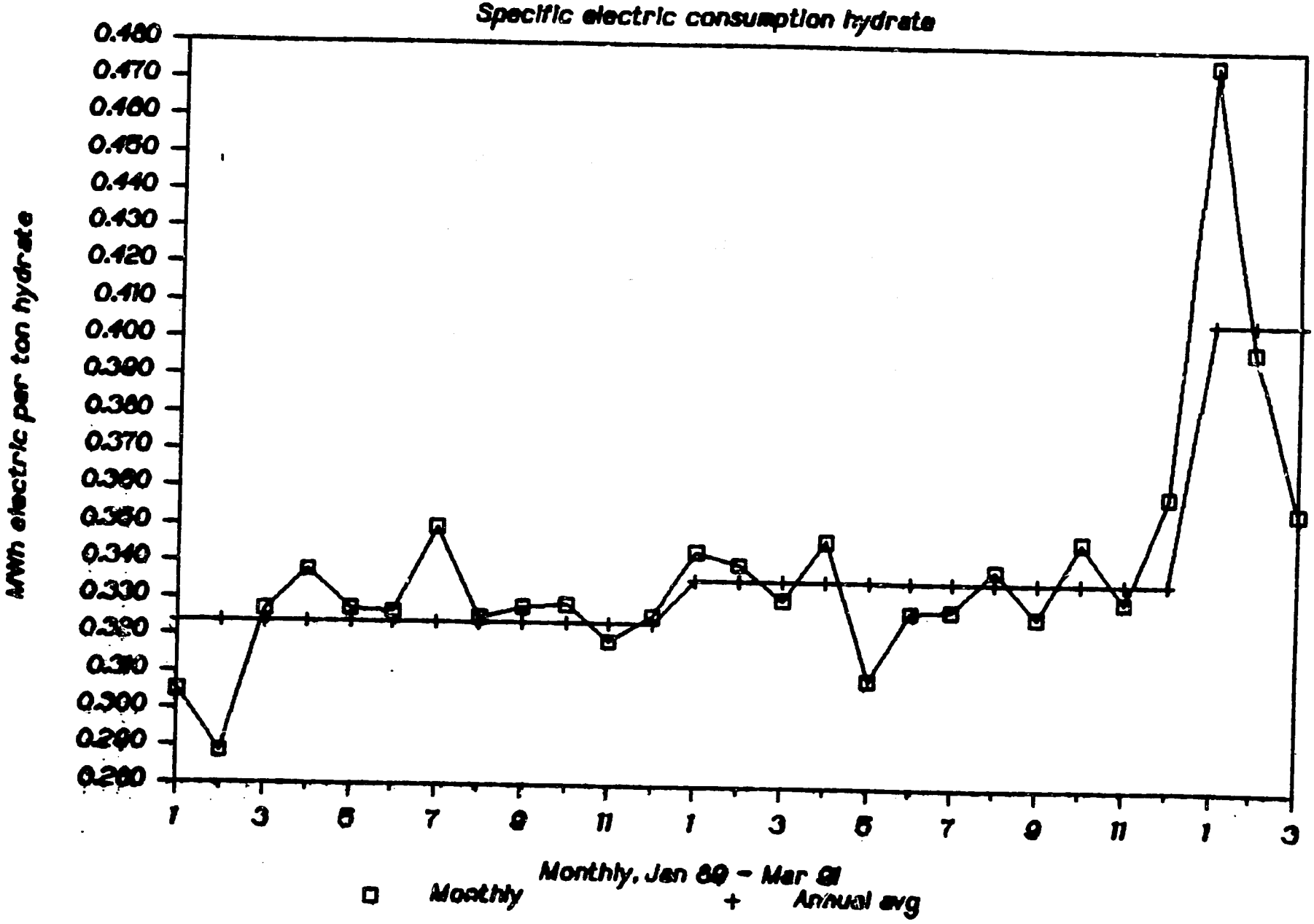


KAT - Alumina

Specific steam consumption of hydrate



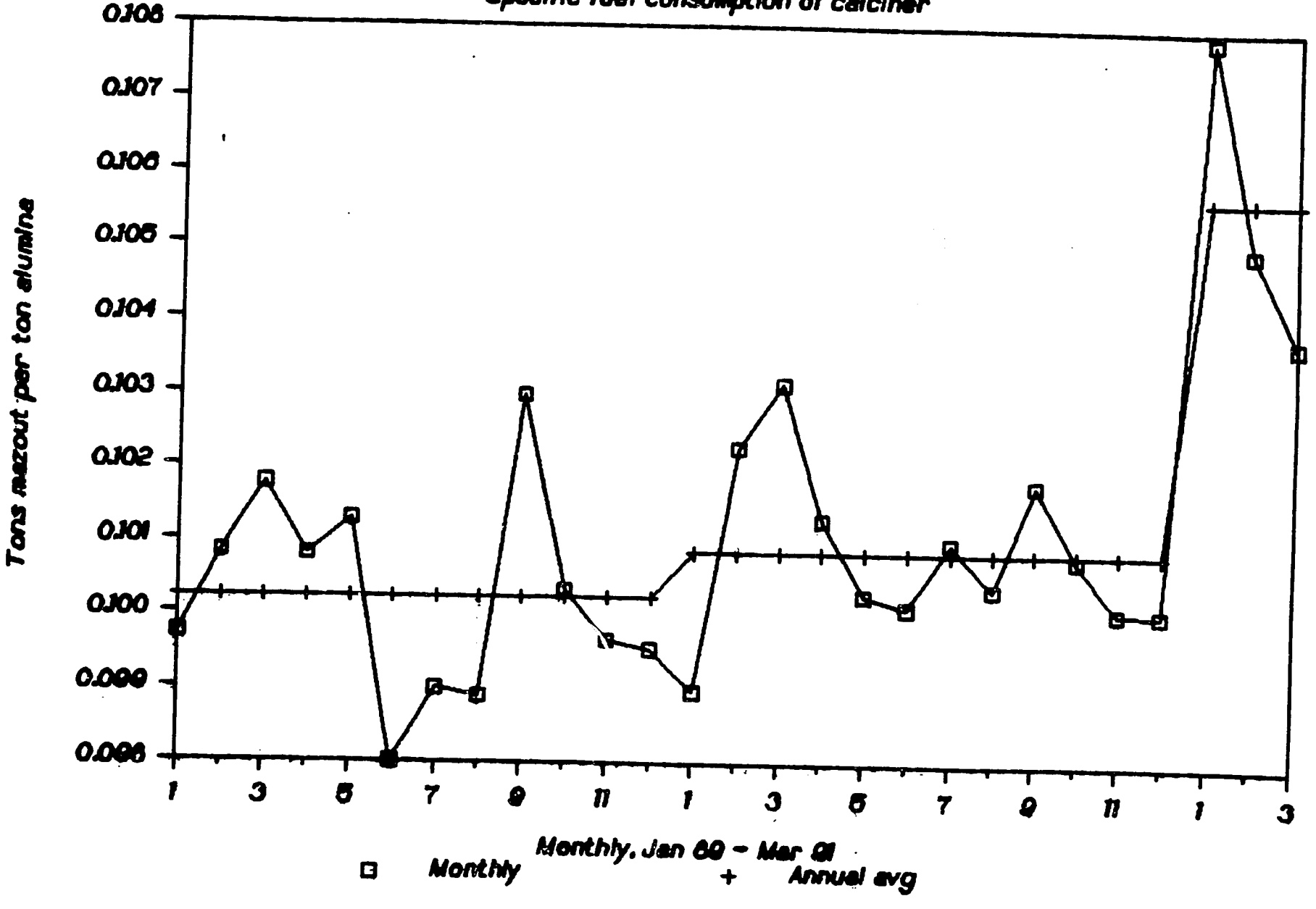
KAT - Alumina



49.

KAT - Alumina

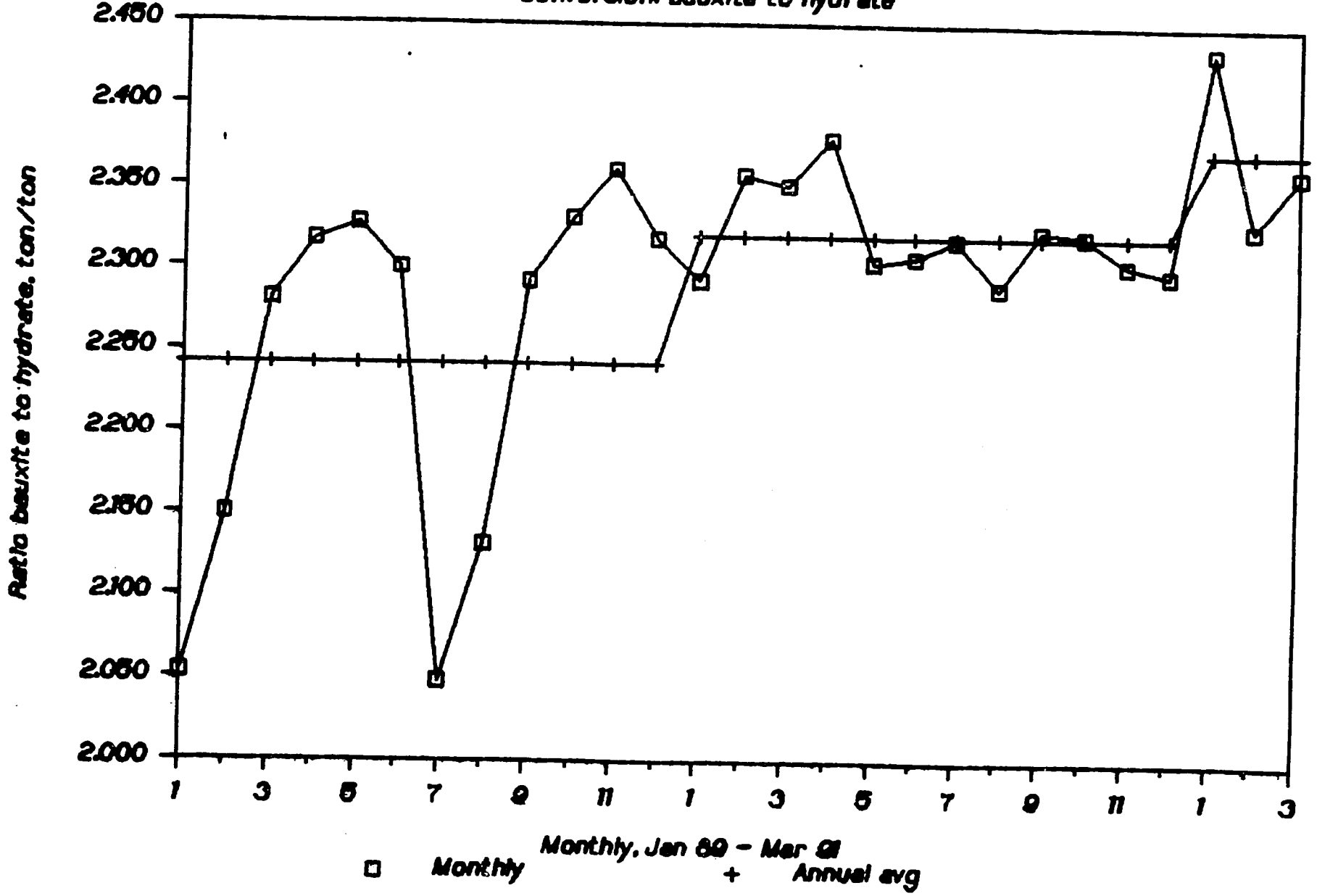
Specific fuel consumption of calciner



5.

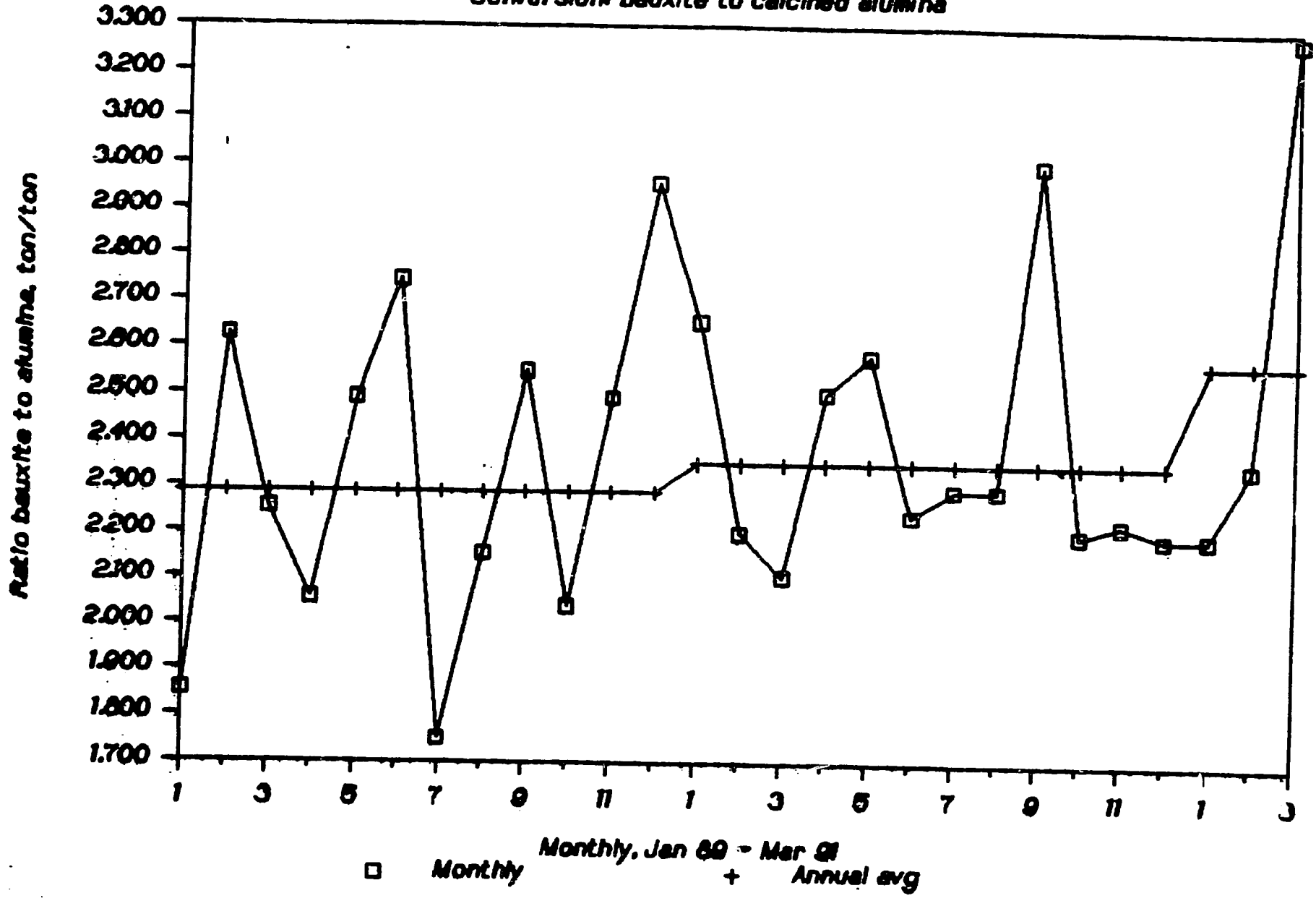
KAT - Alumina

Conversion: bauxite to hydrate



KAT - Alumina

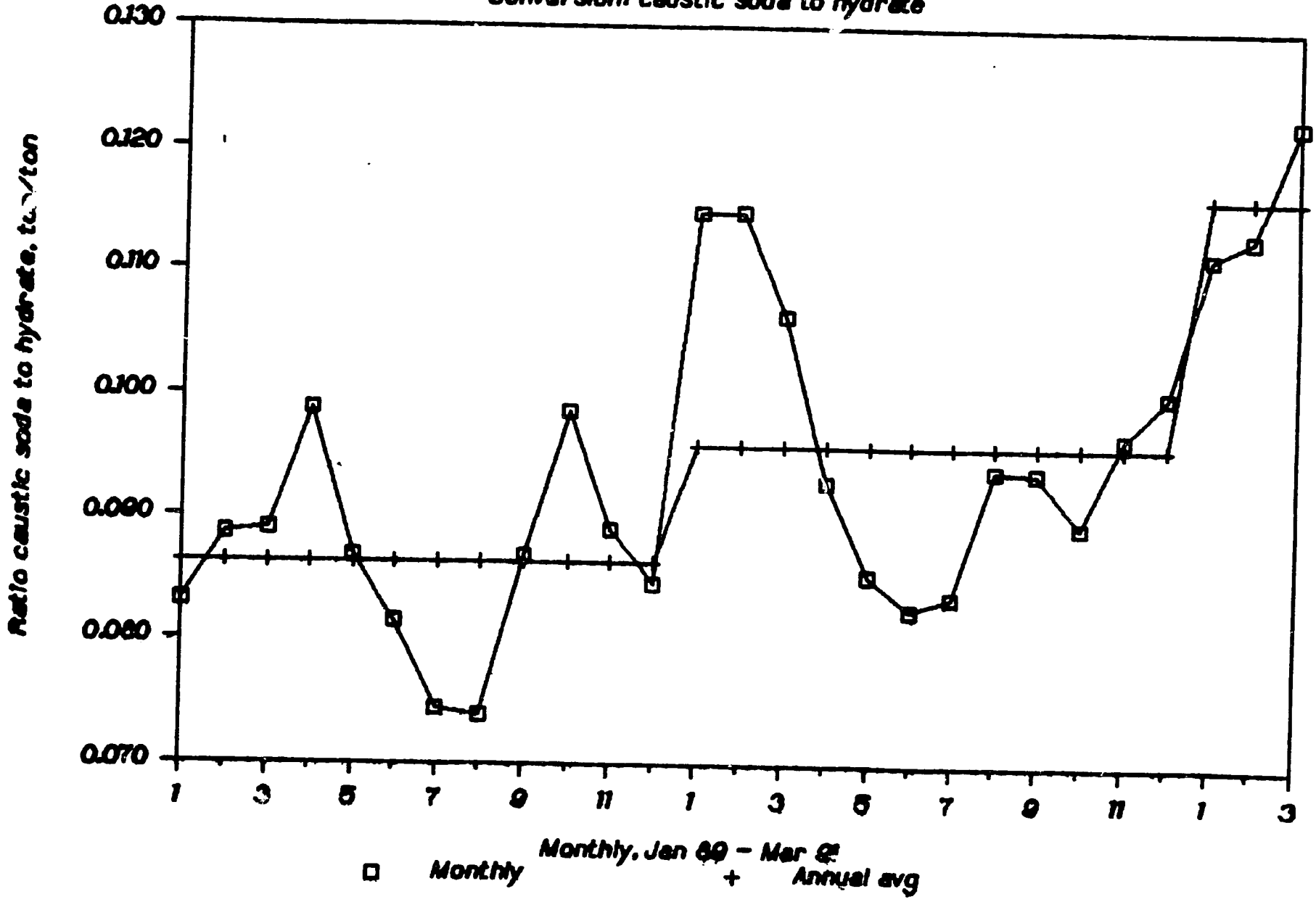
Conversion: bauxite to calcined alumina



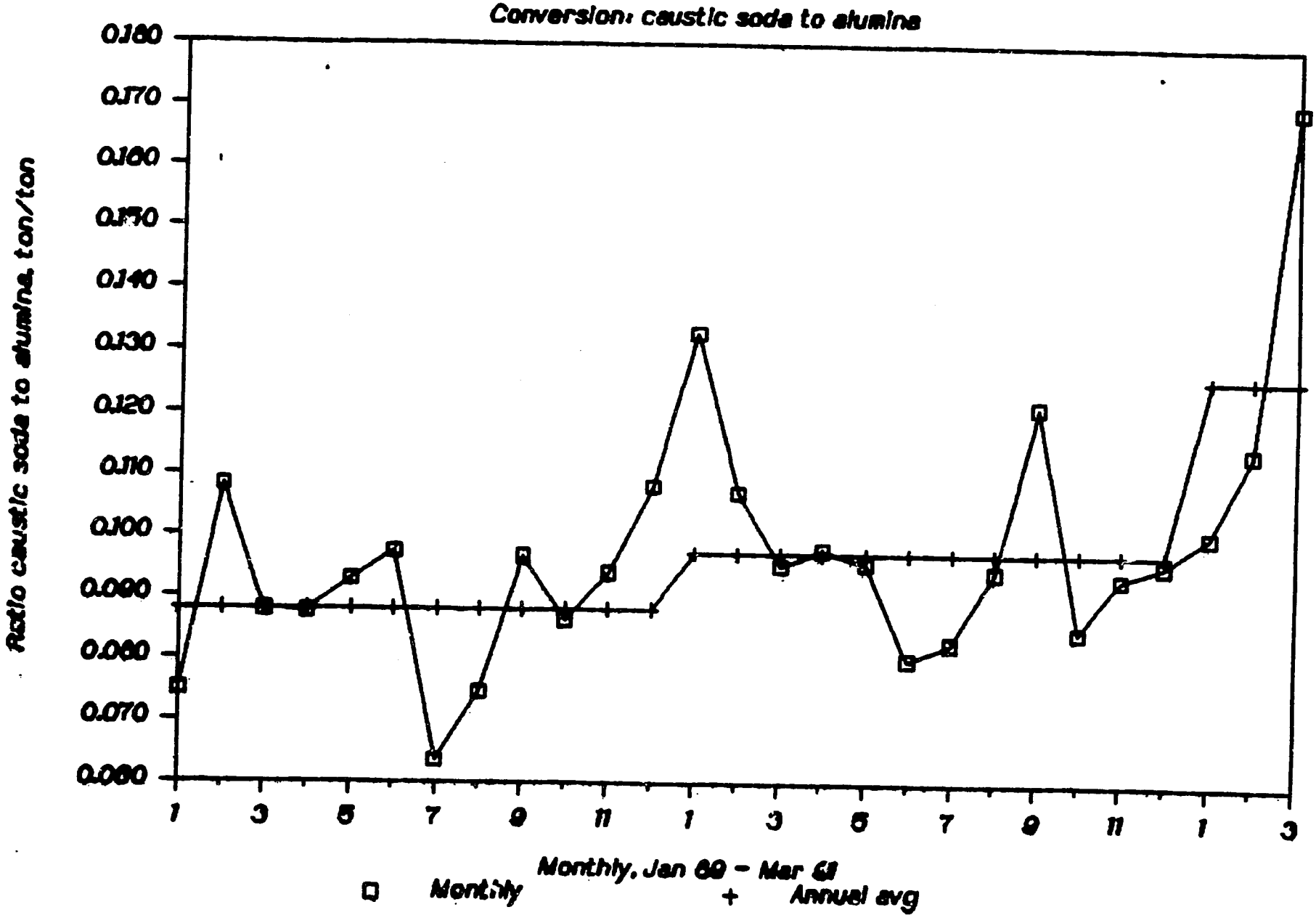
67

KAT - Alumina

Conversion: caustic soda to hydrate

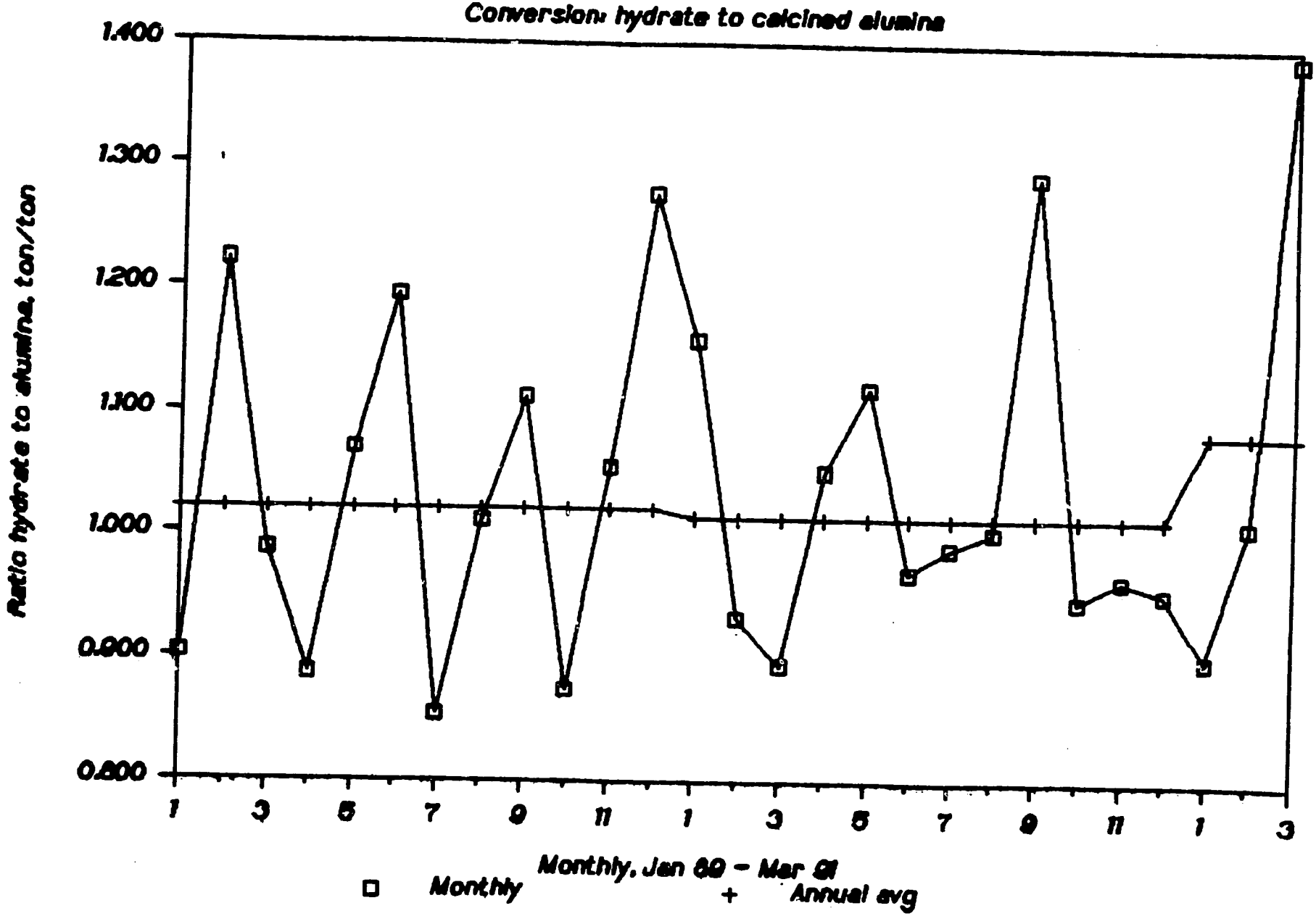


KAT - Alumina

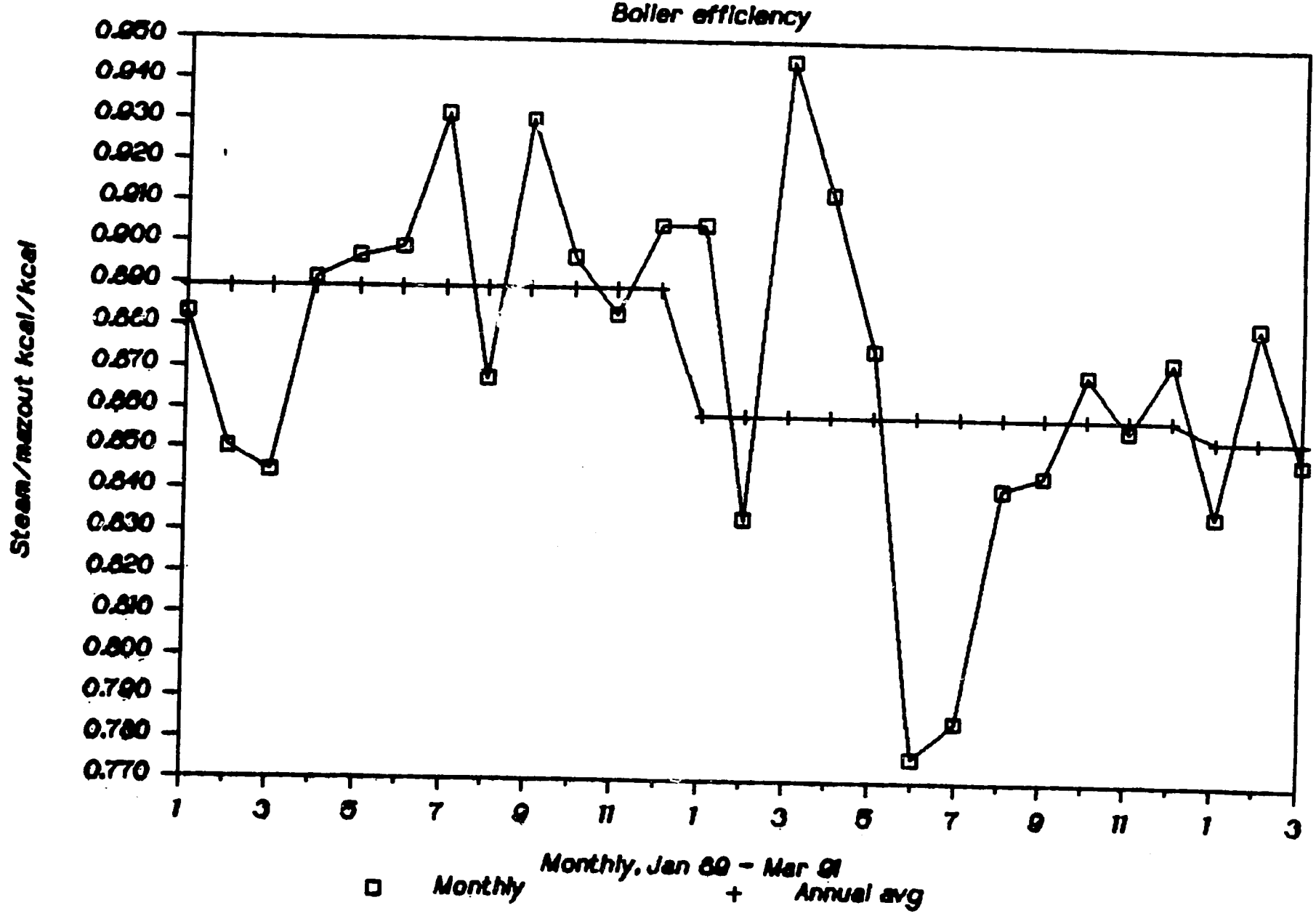


24.

KAT - Alumina

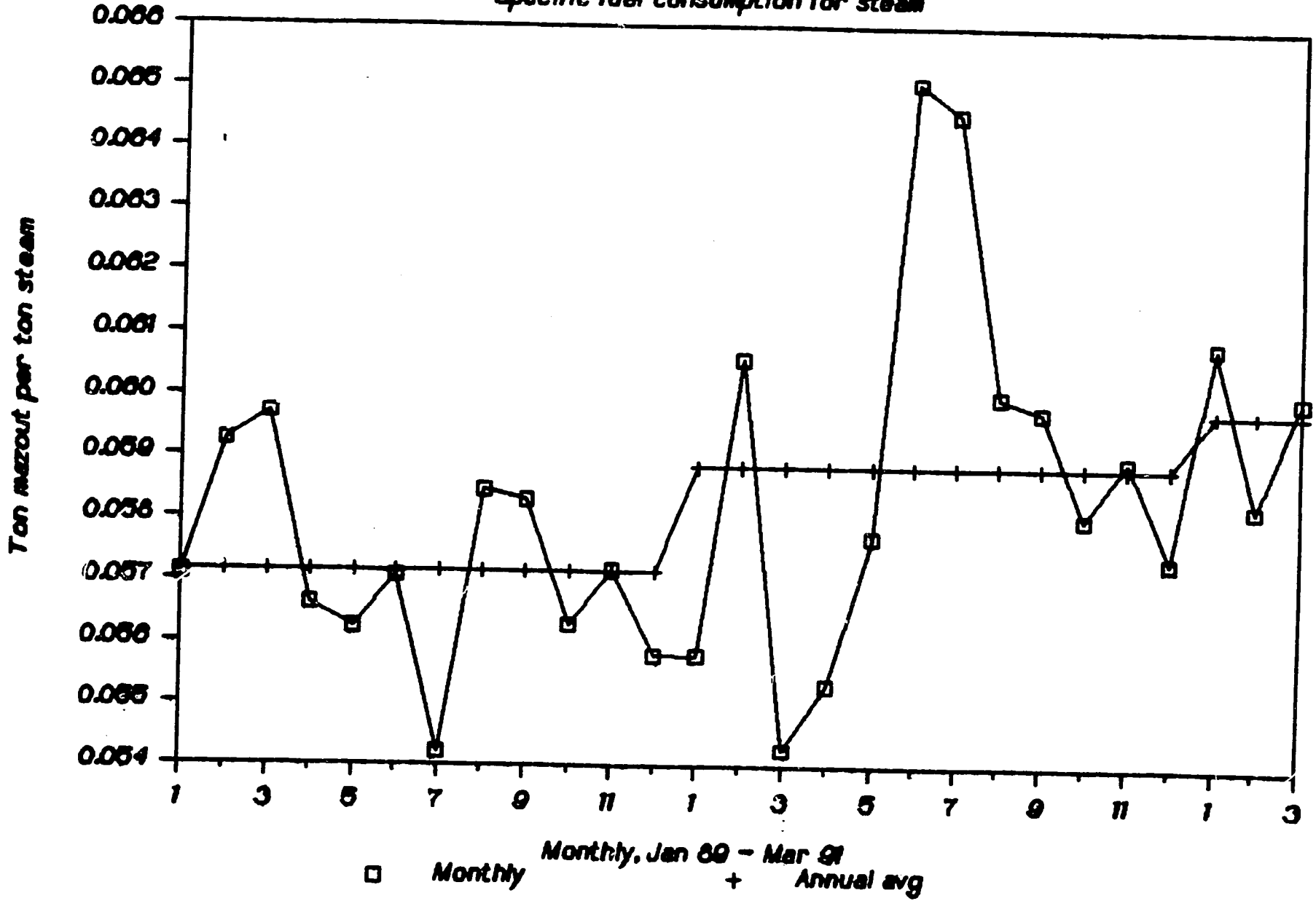

Conversion: hydrate to calcined alumina
Ratio hydrate to alumina, ton/ton
1.400
1.300
1.200
1.100
1.000
0.900
0.800
1
3
5
7
9
11
1
3
5
7
9
11
1
3
Monthly, Jan 89 - Mar 91
Monthly
Annual avg

KAT - Power Plant

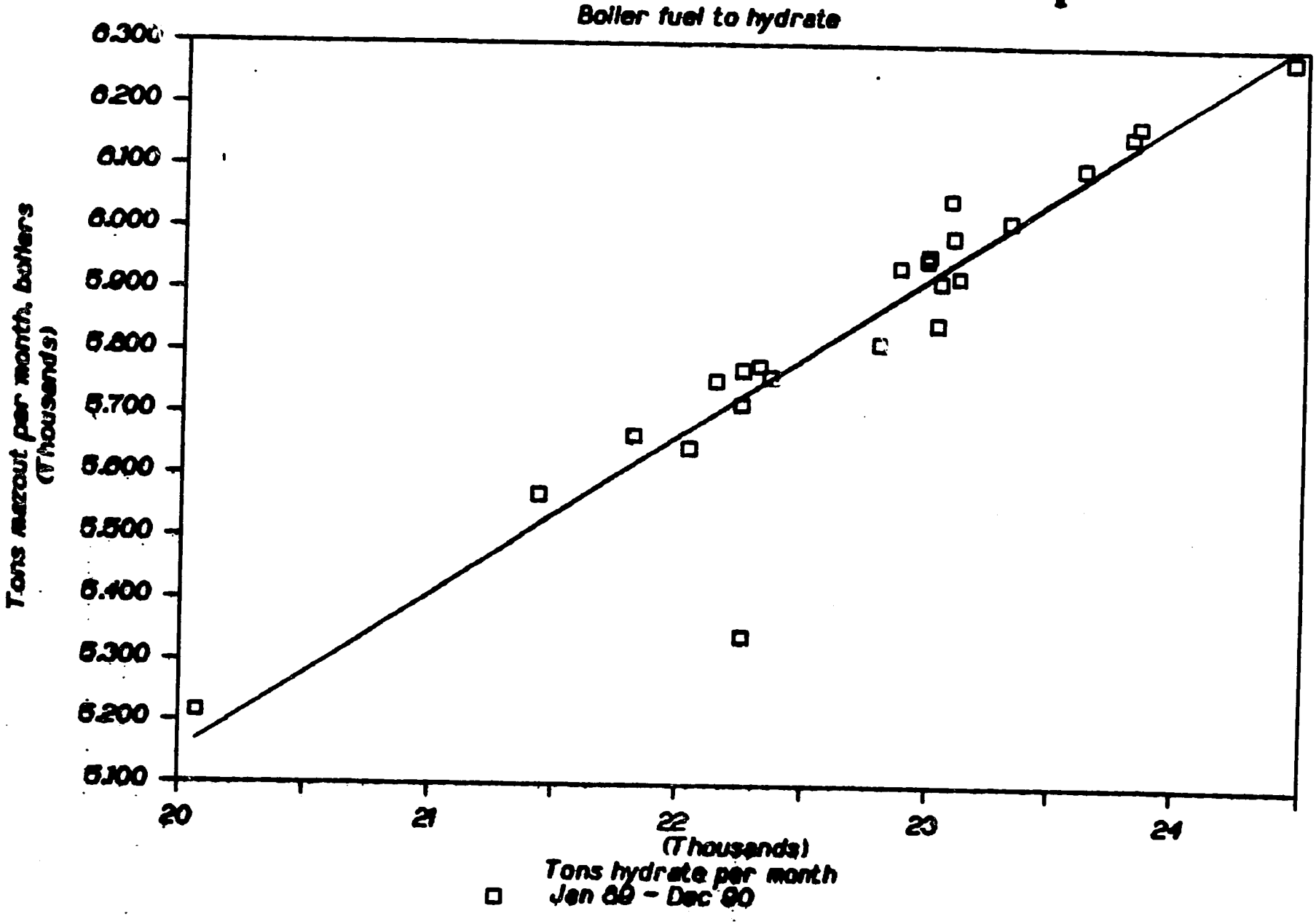


KAT - Power Plant

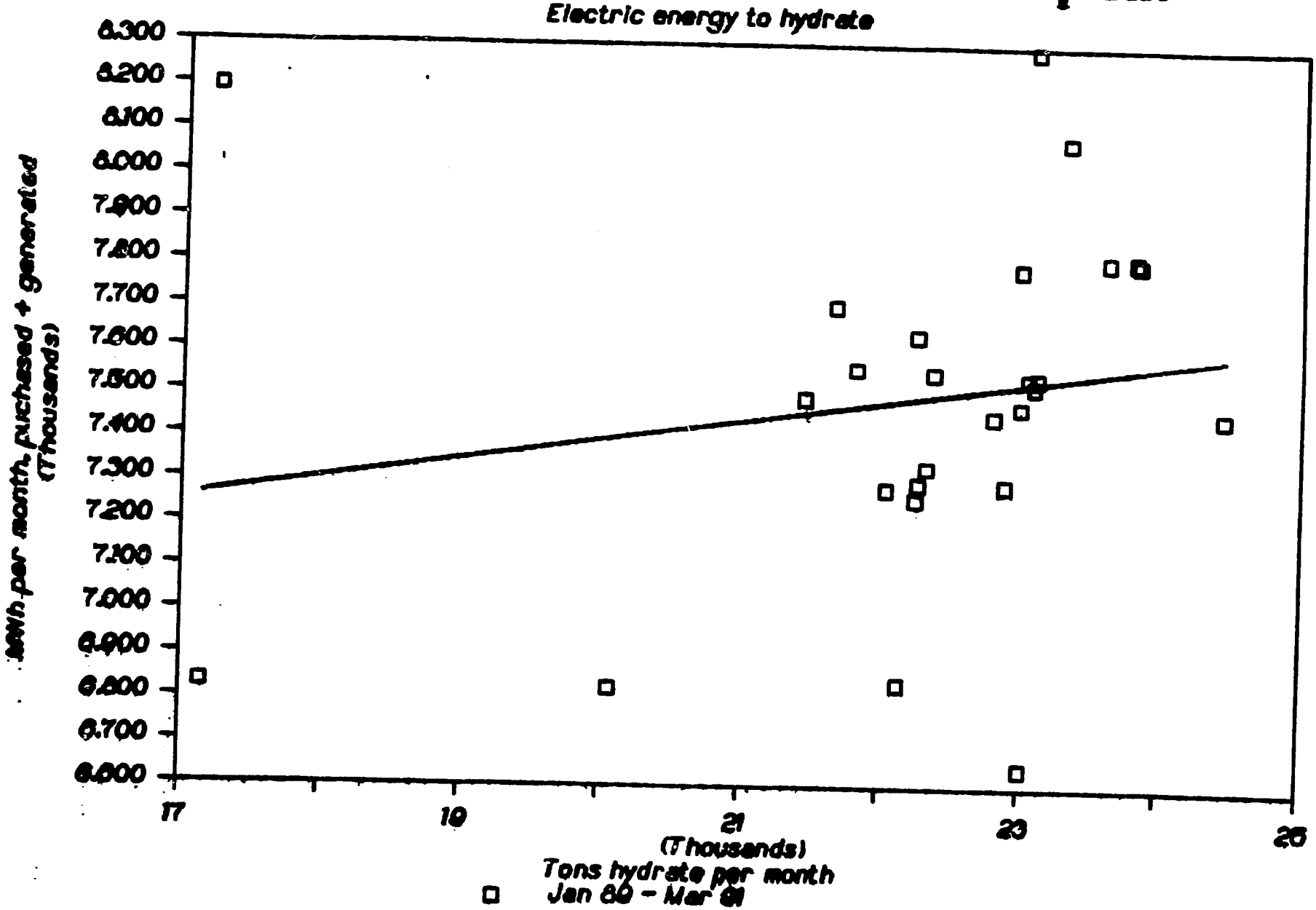
Specific fuel consumption for steam



KAT - Alumina, Hydrate & Powerplant

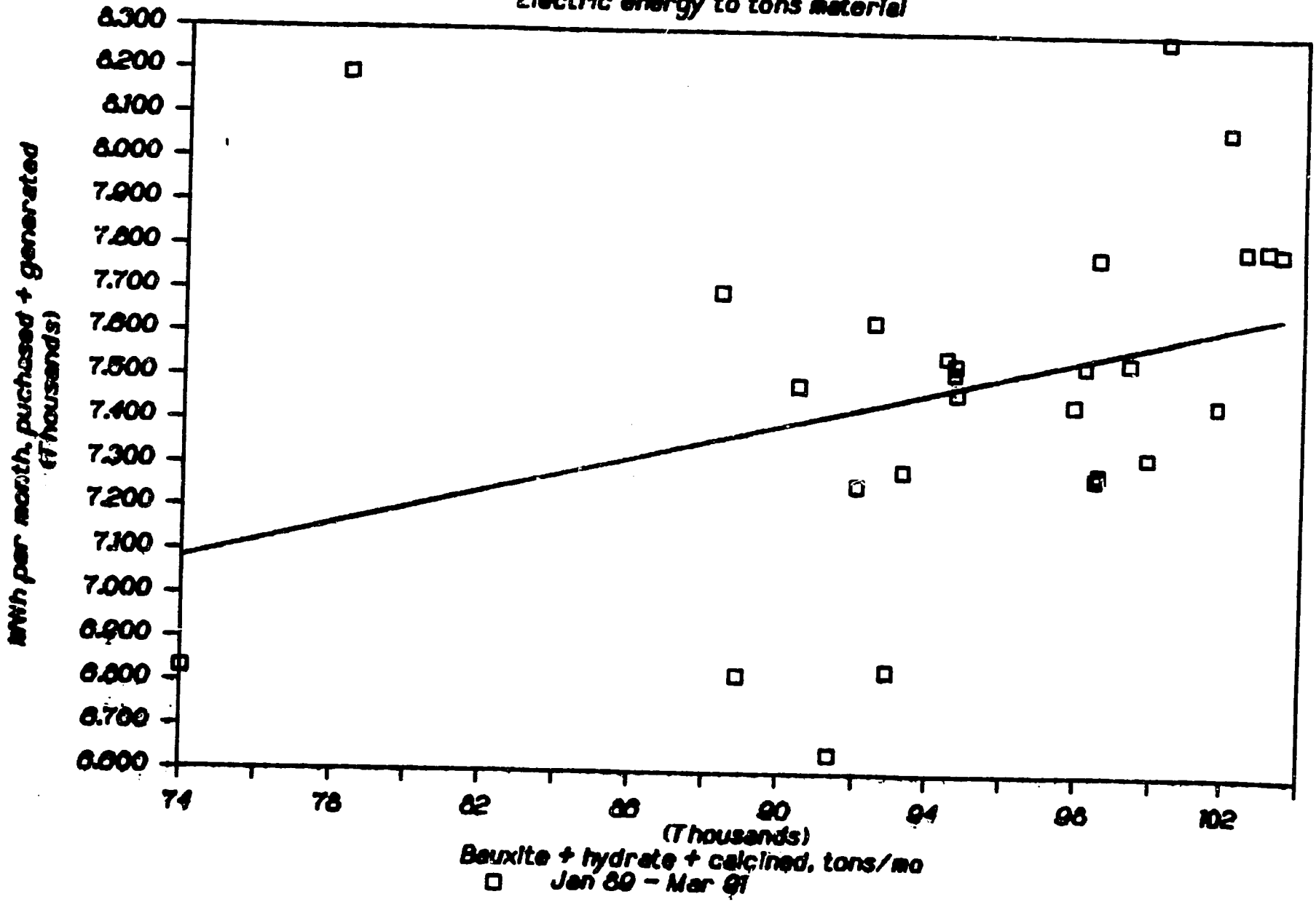


KAT - Alumina, Hydrate & Powerplant



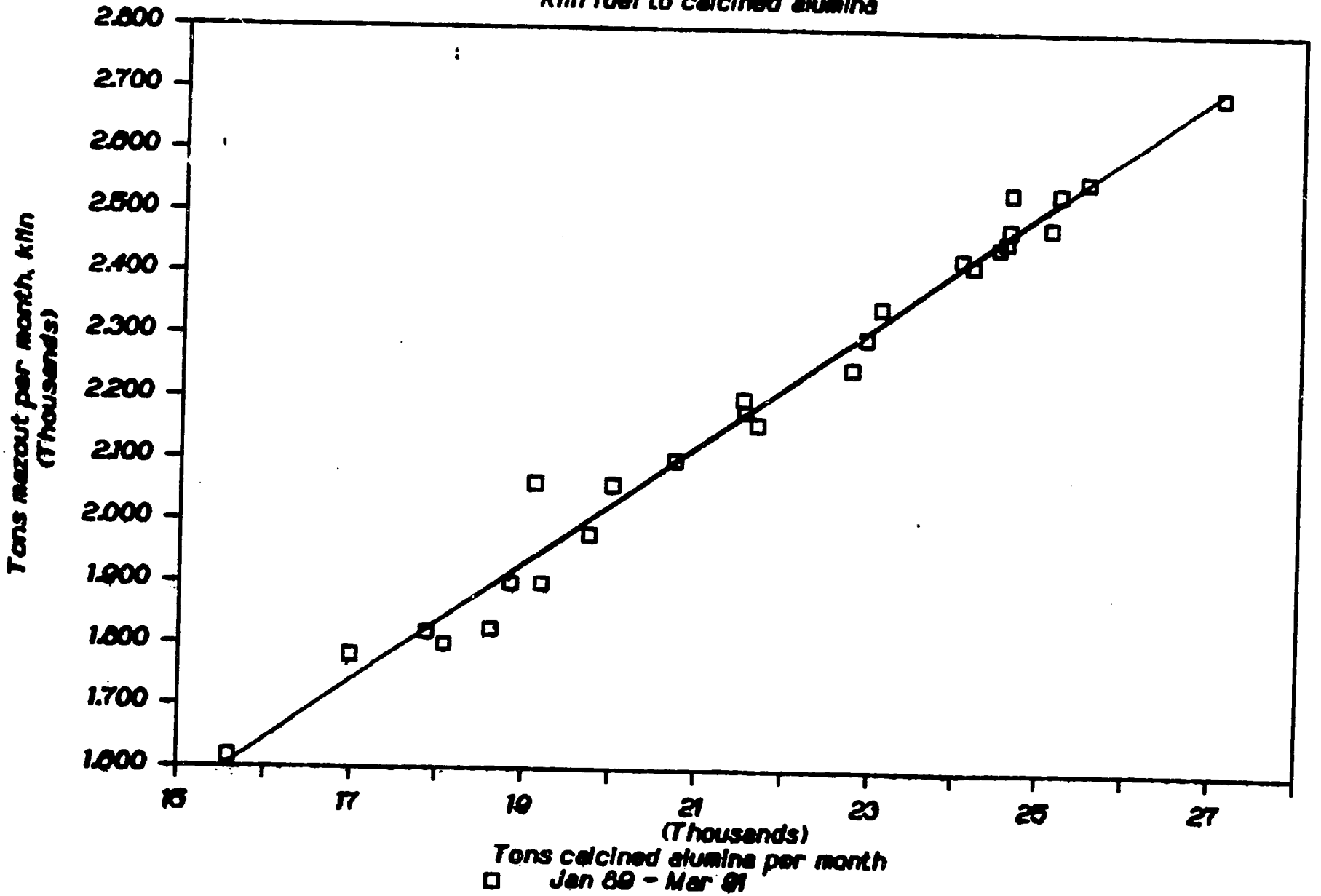
KAT - Alumina, Hydrate & Powerplant

Electric energy to tons material



KAT - Alumina

Kiln fuel to calcined alumina



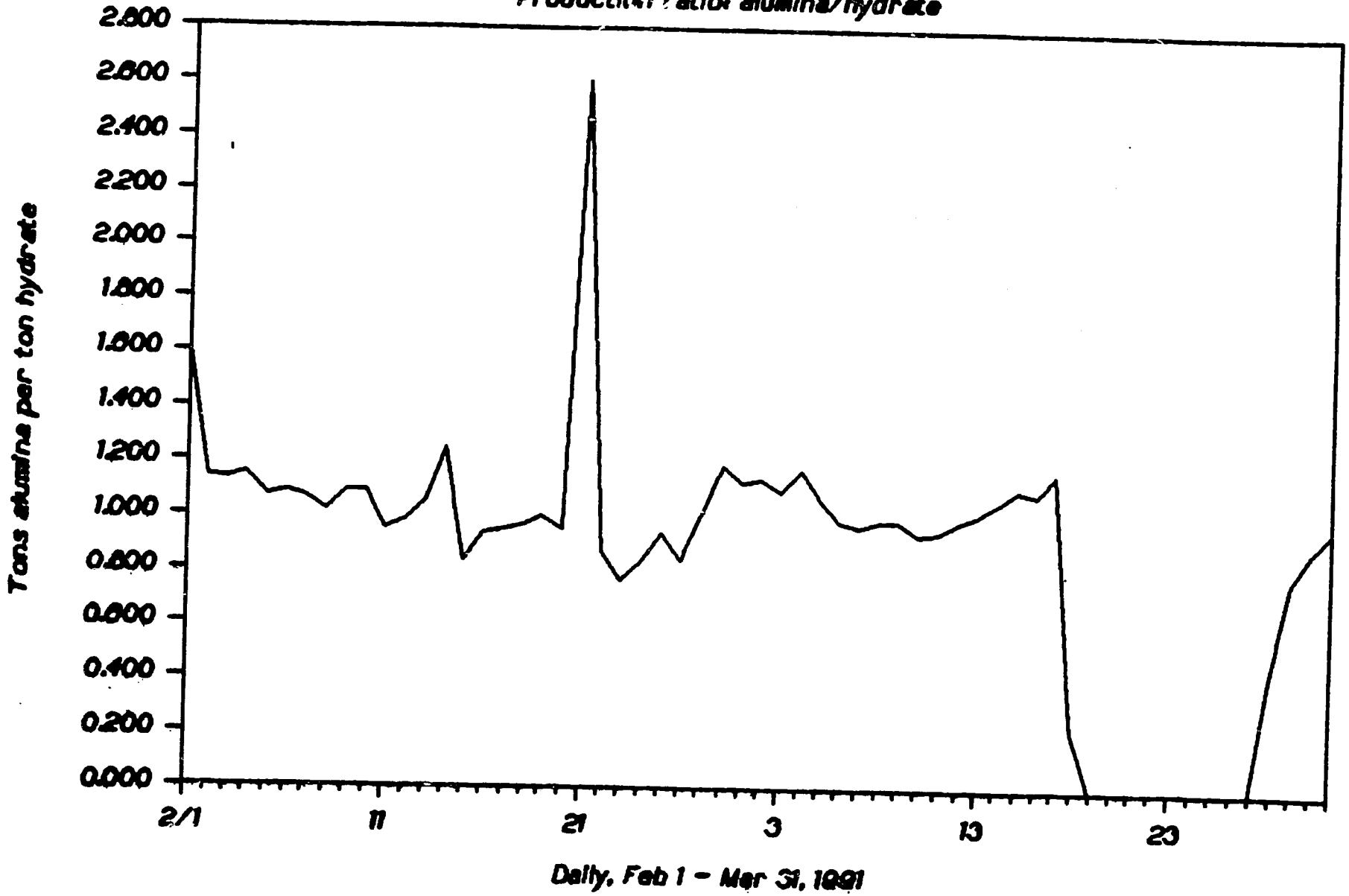
APPENDIX 2
GRAPHICAL PRESENTATION OF HISTORICAL ENERGY CONSUMPTION AND EFFICIENCY DATA

DAILY DATA

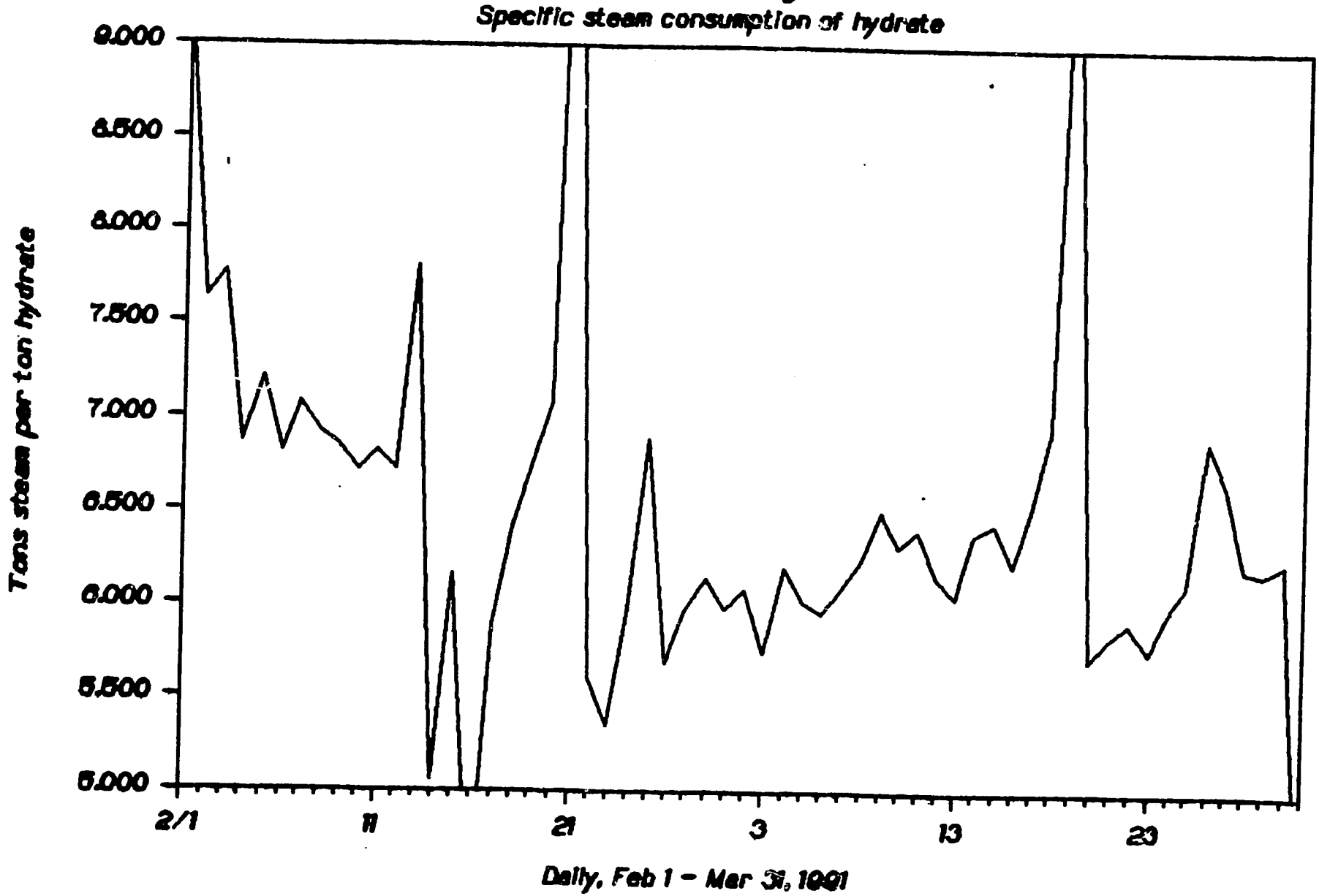
KOMBINAT ALUMINUJUMA TITOGRAD (KAT)
ALUMINA PLANT AND POWER PLANT

KAT - Alumina Calciner

Production ratio: alumina/hydrate

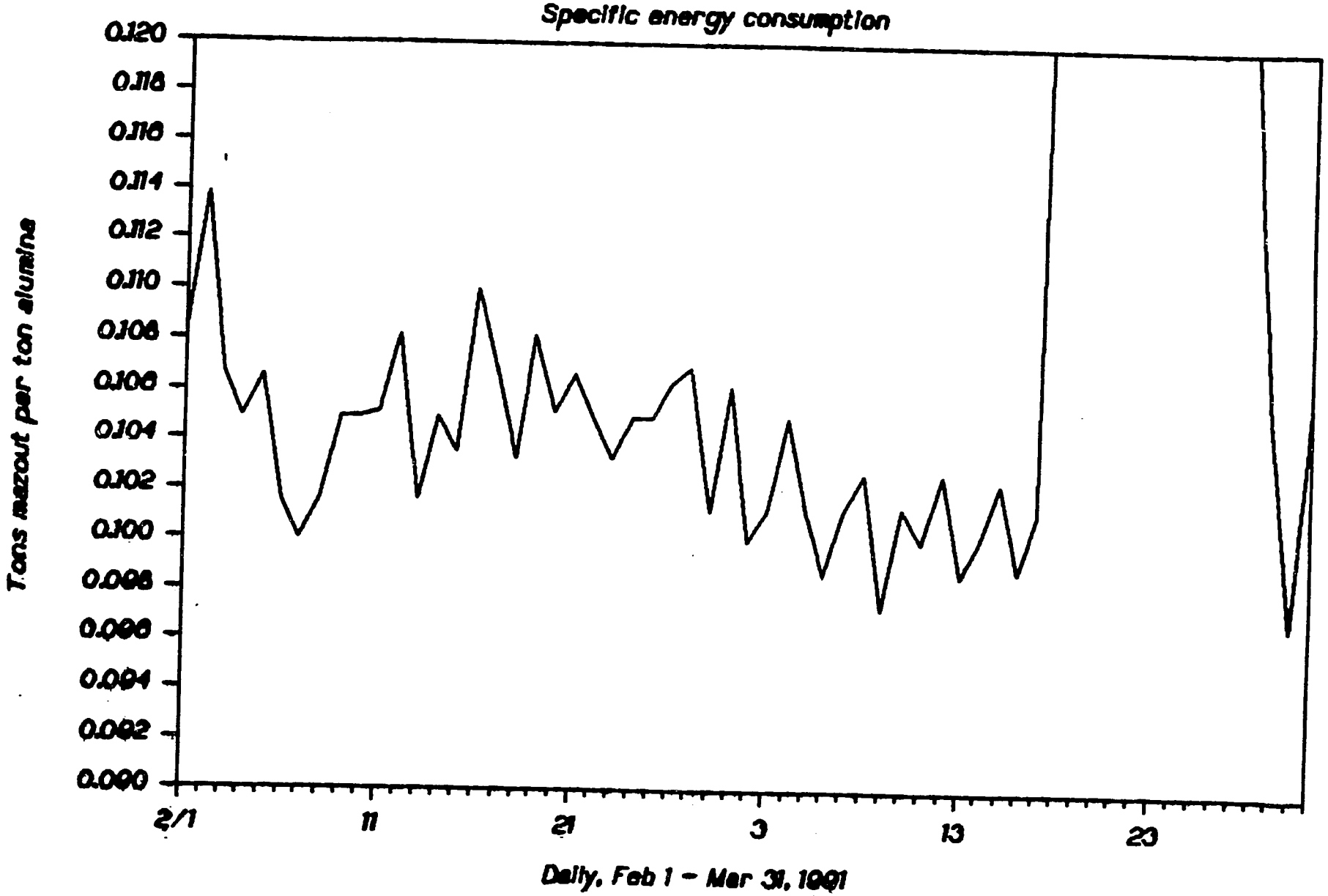


KAT - Alumina, Hydrate Plant



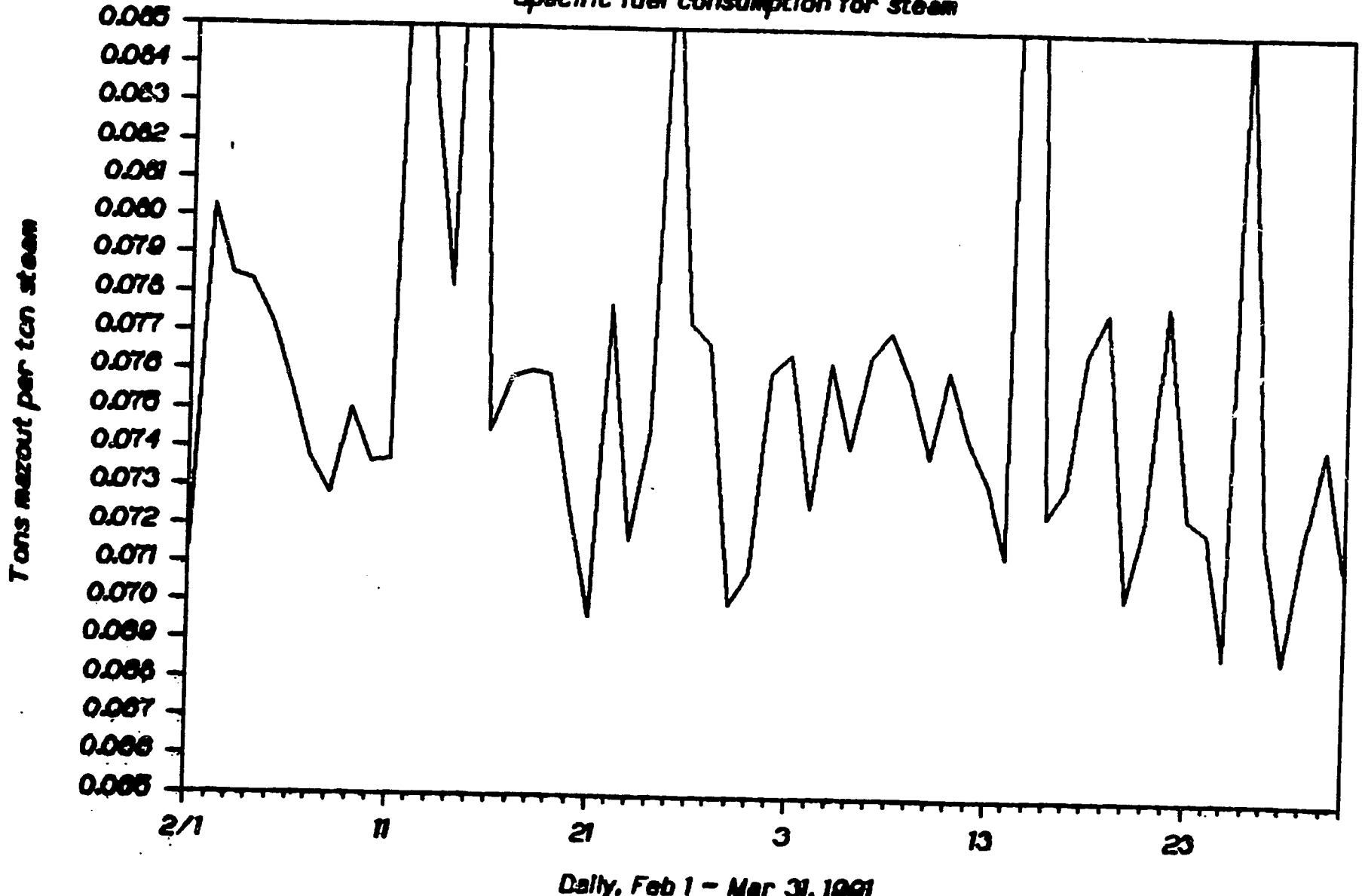
64

KAT - Alumina Calciner



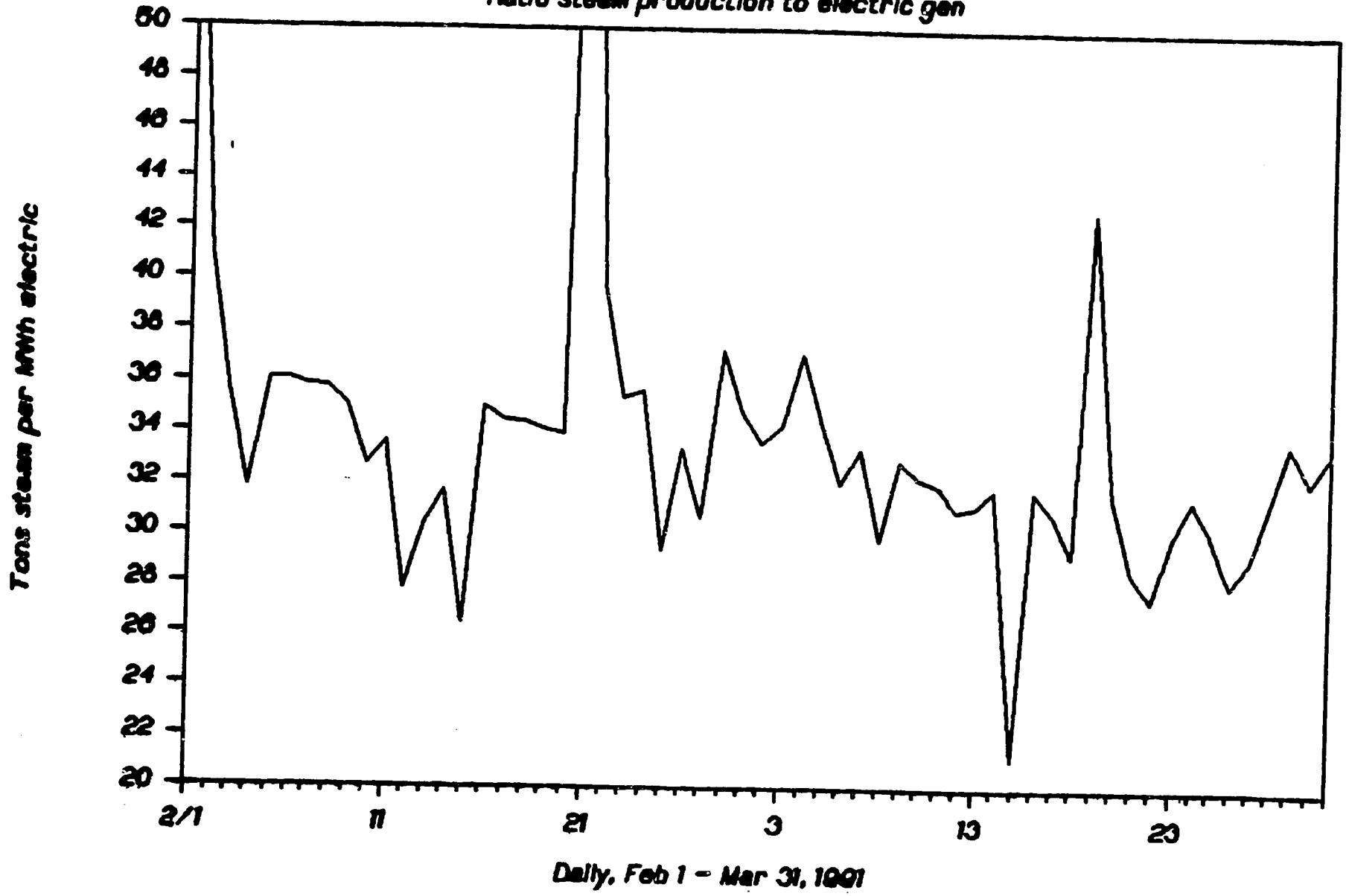
KAT - Power Plant

Specific fuel consumption for steam



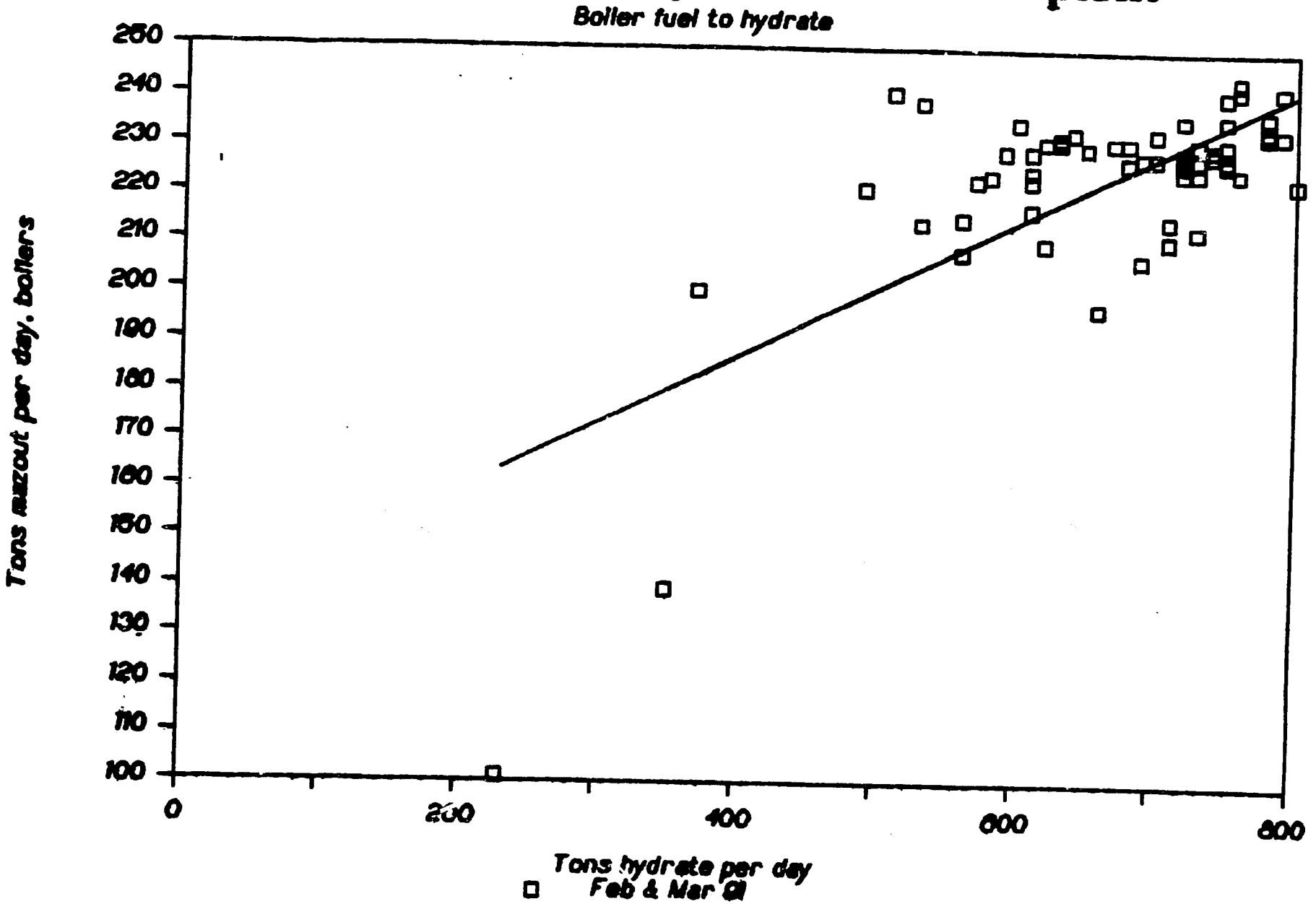
KAT - Power Plant

Ratio steam production to electric gen



67

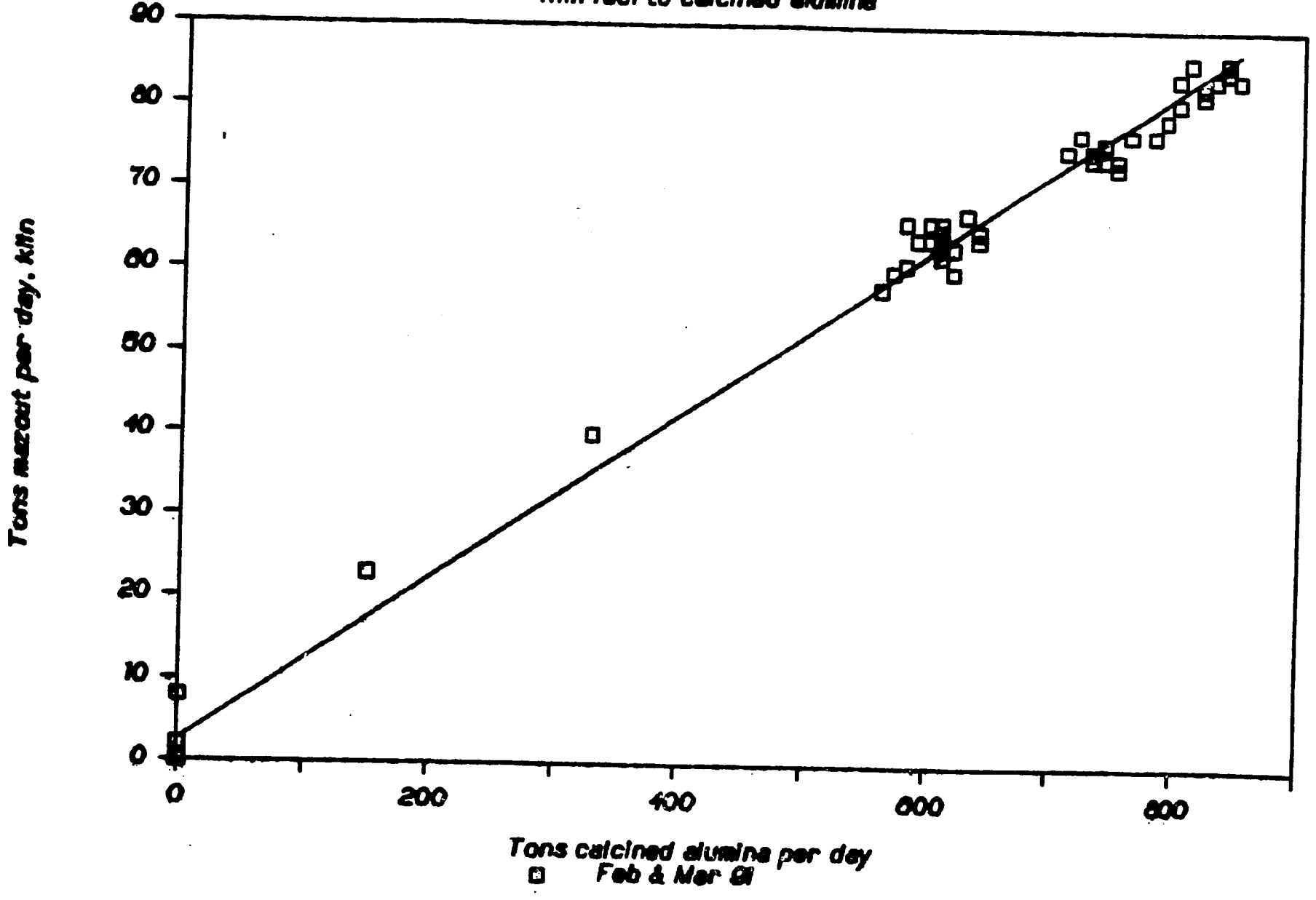
KAT - Alumina, Hydrate & Powerplant



68.

KAT - Alumina

Kiln fuel to calcined alumina



69

APPENDIX 3
DETAILED CALCULATION OF COMBUSTION EFFICIENCY BEFORE AND AFTER IMPROVEMENTS

BOILERS

KOMBINAT ALUMINUJUMA TITOGRAD (KAT)
ALUMINA PLANT AND POWER PLANT

Kombinat Aluminijuma Titograd – Boiler #1
Combustion Calculations – Molal Basis

Date of test: 3 April 91
Time of test: 0930

RCG/Hagler, Bailly, Inc.
Steam rate: 48 ton/hr Air: 260 mm H2O Fuel: 3500 l/hr

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	Flue Gas Composition, Moles per Fuel Unit: CO2 + SO	O2	N2	H2O	CO
1	C to CO2	84.87	12.00	7.07	1.00	7.07	7.07				
2	C to CO	0.80	12.00	0.07	0.50	0.03					0.07
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.53	12.00	0.04	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	-0.50	32.00	-0.02	1.00	-0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.96		12.28		9.66					
	Total air =		123.0% (from stack test)								
13	O2 (theo) reqd = O2, line 12					9.66					
14	O2 (excess) = (Total air -1) * line 12					2.22					
15	O2 (total) supplied = lines 13+14					11.88		2.22			
	Total Air (TA) = line 15/line 13					123.0%					
16	N2 supplied = 3.76*O2,line 15					44.69			44.69		
17	Air (dry) supplied = O2+N2					56.57					
18	H2O in air = moles dry air *A/(B-A)					1.20				1.20	
19	Air (wet) supplied = lines 17+18					57.77					
20	Flue gas constituents = lines 1 to 18, total						7.14	2.22	44.69	6.24	0.07

Fuel, O2, and Air per Unit of Fuel

LINE MAZOUT

a Fuel analysis as fired (AF), % by wt or vol
C= 86.2% CO= 0.0%
H2= 10.0%
S= 2.3%
b O2= 0.5%
N2= 0.1%
H2O= 0.7%
Ash= 0.1%
TOTAL= 99.98%
Flue gas analysis by test
CO2= 12.8%
c CO= 1200 PPM, = 0.120%
O2= 4.0% CMBSTBL 0.08%
d Total air (TA), based on above O2 test
TA= 123%
e Lines f,g,h for gaseous fuels only
f Wt, fuel unit + sum (moles each * mol wt), lb
g Mol wt of fuel + line f / 100
h Density of fuel = line g/384 (lb/cuft)
i Higher heat value, fuel 10146 , Btu/lb = 18300
j %C in refuse
k Combustibles unburned, % of fuel 0.62%
l Stack temp, degrees C a 160
m Ambient temp, dry bulb, degrees C 15

	Wet Flue Gas	Dry Flue Gas
Total Moles	60.353144	54.122741

21 Note: for air at 80F and 60%RH, A/(B-A)=0.0212 is used as a standard

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

		Flue gas constituents:	CO2 + SO	O2	N2	H2O	CO	Btu Total	Conversion to metric units: kcal total	kJoules total
22	Fuel unit 100.00 lb									
23	MCp, Molal specific heat, mean, t2 to t1		9.87	8.16	7.19	7.06	7.10			
24	In dry flue gas, moles each, line 20*MCp*(t2-t1)		18413	4733	83887		122.81	107156	27003	113049
25	In H2O in air, moles H2O, line 18*MCp*(t2-t1)					2211		2211	557	2333
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2-t1)					9294		9294	2342	9806
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18					94370		94370	23781	99560
28	Total in wet flue gas							213031	53684	224747
29	Due to unburned combustibles, line k*14,100 Btu/lb							8677	2187	9154
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb							7762	1956	8189
31	Total flue gas losses + unburned combustible = lines 28+29+30							229470	57828	242090
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels							1830000	461160	1930850
	= 384 * line i * 100 for gaseous fuels									
33	Stack and combustible loss, % of heat input, 100*line 31/line 32							12.5%	12.5%	12.5%
34	Combustion efficiency, HHV, % of heat input 100-line 33							87.5%	87.5%	87.5%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)							92.2%	92.2%	92.2%

Kombinat Aluminijuma Titograd – Boiler #1
Combustion Calculations – Moist Basis

Date of test: 3 April 91
Time of test: 1030

RCQ/Hagler, Bailly, Inc.
Steam rate: 44.5 ton/hr Air: 265 mm H2O Fuel: 3000 l/hr

Fuel, O2, and Air per Unit of Fuel / **Flue Gas Composition, Moles per Fuel Unit**

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	CO2 + SO	O2	N2	H2O	CO
1	C to CO2	86.19	12.00	7.18	1.00	7.18	7.18				
2	C to CO	0.01	12.00	0.00	0.50	0.00					0.00
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.00	12.00	0.00	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	–0.50	32.00	–0.02	1.00	–0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.96		12.29		9.74					
	Total air =		126.0% (from stack test)								
13	O2 (theo) reqd = O2, line 12					9.74					
14	O2 (excess) = (Total air –1) * line 12					2.53					
15	O2 (total) supplied = lines 13+14					12.27		2.53			
	Total Air (TA) = line 15/line 13					126.0%					
16	N2 supplied = 3.78*O2, line 15					46.14			46.14		
17	Air (dry) supplied = O2+N2					58.41					
18	H2O in air = moles dry air *A/(B–A)					1.24				1.24	
19	Air (wet) supplied = lines 17+18					59.65					
20	Flue gas constituents = lines 1 to 13, total						7.25	2.53	46.14	6.28	0.00

LINE					
	MAZOUT				
a	Fuel analysis as fired (AF), % by wt or vol				
	C=	86.2%	CO=	0.0%	
	H2=	10.0%			
	S=	2.3%			
b	O2=	0.5%			
	N2=	0.1%			
	H2O=	0.7%			
	Ash=	0.1%			
	TOTAL=	99.98%			
	Flue gas analysis by test				
	CO2=	12.5%			
c	CO=	12 PPM, =	0.001%		
	O2=	4.4%	CMBSTBL	0.00%	
d	Total air (TA), based on above O2 test				
	TA=	126%			
e	Lines f,g,h for gaseous fuels only				
f	Wt, fuel unit = sum (moles each * mol wt), lb				
g	Mol wt of fuel = line f / 100				
h	Density of fuel = line g/394 (lb/cuft)				
i	Higher heat value, fuel	10146	, Btu/lb =		18300
j	%C in refuse				
k	Combustibles unburned, % of fuel				0.00%
l	Stack temp, degrees C		a		160
m	Ambient temp, dry bulb, degrees C				15

	Wet Flue Gas	Dry Flue Gas
Total Moles	62.211045	55.931598

21 Note: for air at 80F and 60%RH, A/(B–A)=7.0212 is used as a standard

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

							Btu Total	Conversion to metric units: kcal total	kJoules total
22	Fuel unit 100.00 lb	Flue gas constituents:	CO2 + SO	O2	N2	H2O	CO			
23	MCp, Moist specific heat, mean, t2 to t1		9.87	8.16	7.19	7.06	7.10			
24	In dry flue gas, moles each, line 20*MCp*(t2–t1)		19696	5393	56618		1.28	110706	27898	116797
25	In H2O in air, moles H2O, line 18*MCp*(t2–t1)					2263		2263	575	2409
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2–t1)					9294		9294	2342	9806
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18					94370		94370	23781	99580
28	Total in wet flue gas							216655	54597	228571
29	Due to unburned combustibles, line k*14,100 Btu/lb							0	0	0
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb							81	20	85
31	Total flue gas losses + unburned combustible = lines 28+29+30							216736	54617	228656
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels							1830000	461160	1930650
	= 394 * line i * 100 for gaseous fuels									
33	Stack and combustible loss, % of heat input, 100*line 31/line 32							11.8%	11.8%	11.8%
34	Combustion efficiency, HHV, % of heat input 100–line 33							88.2%	88.2%	88.2%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)							92.9%	92.9%	92.9%

Kombinat Aluminijuma Titograd – Boiler #2
Combustion Calculations – Molal Basis

Date of test: 3 April 91
Time of test: 1130

RCG/Hagler, Bailly, Inc.
Steam rate: 42 ton/hr Air: 355 mm H2O Fuel: 3000 l/hr

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	Flue Gas Composition, Moles per Fuel Unit: CO2 + SO	O2	N2	H2O	CO
1	C to CO2	86.19	12.00	7.18	1.00	7.18	7.18				
2	C to CO	0.01	12.00	0.00	0.50	0.00					0.00
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.00	12.00	0.00	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	-0.50	32.00	-0.02	1.00	-0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.98		12.28		9.74					
	Total air =		162.0% (from stack test)								
13	O2 (theo) reqd = O2, line 12					9.74					
14	O2 (excess) = (Total air -1) * line 12					6.04					
15	O2 (total) supplied = lines 13+14					15.78		6.04			
	Total Air (TA) = line 15/line 13					162.0%					
16	N2 supplied = 3.76*O2,line 15					59.32			59.32		
17	Air (dry) supplied = O2+N2					75.10					
18	H2O in air = moles dry air *A/(B-A)					1.59				1.59	
19	Air (wet) supplied = lines 17+18					76.69					
20	Flue gas constituents = lines 1 to 18, total						7.25	6.04	59.33	6.63	0.00

LINE		MAZOUT		
a	Fuel analysis as fired (AF), % by wt or vol			
	C=	86.2%	CO=	0.0%
	H2=	10.0%		
	S=	2.3%		
b	O2=	0.5%		
	N2=	0.1%		
	H2O=	0.7%		
	Ash=	0.1%		
	TOTAL=	99.98%		
	Flue gas analysis by test			
	CO2=	8.5%		
c	CO=	6 PPM, =	0.001%	
	O2=	8.2%	CMBSTBL	0.00%
d	Total air (TA), based on above O2 test			
	TA=	162%		
e	Lines f,g,h for gaseous fuels only			
f	Wt, fuel unit + sum (moles each * mol wt), lb			
g	Mol wt of fuel + line f / 100			
h	Density of fuel = line g/394 (lb/cuft)			
i	Higher heat value, fuel	10146	, Btu/lb =	18300
j	%C in refuse			
k	Combustibles unburned, % of fuel			0.00%
l	Stack temp, degrees C		a	160
m	Ambient temp, dry bulb, degrees C			15

	Wet Flue Gas	Dry Flue Gas
Total Moles	79.254641	72.621370

21 Note: for air at 80F and 60%RH, A/(B-A)=0.0212 is used as a standard

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

							Btu Total	Conversion to metric units: kcal total	kJoules total
22	Fuel unit 100.00 lb	Flue gas constituents:	CO2 + SO	O2	N2	H2O	CO			
23	MCp, Molal specific heat, mean, t2 to t1		9.87	8.18	7.19	7.06	7.10			
24	In dry flue gas, moles each, line 20*MCp*(t2-t1)		18696	12660	111365		0.94	142922	38016	160783
25	In H2O in air, moles H2O, line 18*MCp*(t2-t1)					2935		2935	740	3097
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2-t1)					9294		9294	2342	9806
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18					94370		94370	23781	99580
28	Total in wet flue gas							249522	62879	263245
29	Due to unburned combustibles, line k*14,100 Btu/lb							0	0	0
30	Due to unburned CO in flue gas; moles C to CO *12*9755 Btu/lb							59	15	63
31	Total flue gas losses + unburned combustible = lines 28+29+30							249581	62894	263308
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels							1830000	461160	1930650
	= 394 * line i * 100 for gaseous fuels									
33	Stack and combustible loss, % of heat input, 100*line 31/line 32							13.6%	13.6%	13.6%
34	Combustion efficiency, HHV, % of heat input 100-line 33							86.4%	86.4%	86.4%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)							91.1%	91.1%	91.1%

Kombinat Aluminijuma Thograd – Boiler #2
Combustion Calculations – Molal Basis

Date of test: 3 April 91
Time of test: 1300

RCG/Hagler, Bailly, Inc.
Steam rate: 43.5 ton/hr
Air: 300 mm H2O
Fuel: 3000 l/hr

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	CO2 + SO	O2	N2	H2O	CO
	Fuel, O2, and Air per Unit of Fuel						Flue Gas Composition, Moles per Fuel Unit				
1	C to CO2	86.18	12.00	7.18	1.00	7.18	7.18				
2	C to CO	0.02	12.00	0.00	0.50	0.00					0.00
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.00	12.00	0.00	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	-0.50	32.00	-0.02	1.00	-0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.96		12.28		9.74					
	Total air =		132.0% (from stack test)								
13	O2 (theo) reqd = O2, line 12					9.74					
14	O2 (excess) = (Total air -1) * line 12					3.12					
15	O2 (total) supplied = lines 13+14					12.85		3.12			
	Total Air (TA) = line 15/line 13					132.0%					
16	N2 supplied = 3.76*O2,line 15					48.33			48.33		
17	Air (dry) supplied = O2+N2					61.19					
18	H2O in air = moins dry air *A/(B-A)					1.30				1.30	
19	Air (wet) supplied = lines 17+18					62.49					
20	Flue gas constituents = lines 1 to 18, total						7.25	3.12	48.34	6.34	0.00

21 Note: for air at 80F and 60%RH, A/(B-A)=0.0212 is used as a standard

LINE	MAZOUT			
a	Fuel analysis as fired (AF), % by wt or vol			
	C=	86.2%	CO=	0.0%
	H2=	10.0%		
	S=	2.3%		
b	O2=	0.5%		
	N2=	0.1%		
	H2O=	0.7%		
	Ash=	0.1%		
	TOTAL=	99.96%		
	Flue gas analysis by test			
	CO2=	11.6%		
c	CO=	32 PPM, =	0.003%	
	O2=	5.2%	CMBSTBL	0.00%
d	Total air (TA), based on above O2 test			
	TA=	132%		
e	Lines f,g,h for gaseous fuels only			
f	Wt, fuel unit ÷ sum (moles each * mol wt), lb			
g	Mol wt of fuel ÷ line f / 100			
h	Density of fuel = line g/394 (lb/cuft)			
i	Higher heat value, fuel	10146	, Btu/lb =	18300
j	%C in refuse			
k	Combustibles unburned, % of fuel			0.00%
l	Stack temp, degrees C		a	160
m	Ambient temp, dry bulb, degrees C			15

	Wet Flue Gas	Dry Flue Gas
Total Moles	65.048042	58.709713

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

		CO2 + SO	O2	N2	H2O	CO	Btu Total	Conversion to metric units: total	kJoules total
22	Fuel unit 100.00 lb — Flue gas constituents:								
23	MCp, Molal specific heat, mean, t2 to t1	9.87	8.16	7.19	7.06	7.10			
24	In dry flue gas, moles each, line 20*MCp*(t2-t1)	18692	6637	90736		3.67	116069	29249	122453
25	In H2O in air, moles H2O, line 18*MCp*(t2-t1)				2392		2392	603	2523
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2-t1)				9294		9294	2342	9806
27	In latent heat, H2O in fuel, moles, lines (5+10)*1050*18				94370		94370	23781	99560
28	Total in wet flue gas						222125	55975	234312
29	Due to unburned combustibles, line k*14,100 Btu/lb						0	0	0
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb						232	58	245
31	Total flue gas losses + unburned combustible = lines 28+29+30						222357	56034	234546
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels						1830000	461160	1930650
	= 394 * line i * 100 for gaseous fuels								
33	Stack and combustible loss, % of heat input, 100*line 31/line 32						12.2%	12.2%	12.2%
34	Combustion efficiency, HHV, % of heat input 100-line 33						87.8%	87.8%	87.8%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)						92.6%	92.6%	92.6%

Kombinat Aluminijuma Titograd – Boiler #3
Combustion Calculations – Molal Basis

Date of test: 3 April 1991
Time of test: 1130

RCG/Hagler, Bailly, Inc.
Steam rate: 60 t/hr (?)

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	CO2 + SO	O2	N2	H2O	CO
	Fuel, O2, and Air per Unit of Fuel						**Flue Gas Composition, Moles per Fuel Unit**				
1	C to CO2	86.20	12.00	7.18	1.00	7.18	7.18				
2	C to CO	0.00	12.00	0.00	0.50	0.00					0.00
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.00	12.00	0.00	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	–0.50	32.00	–0.02	1.00	–0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.98		12.29		9.74					
	Total air =		128.0%	(from stack test)							
13	O2 (theo) reqd = O2, line 12					9.74					
14	O2 (excess) = (Total air –1) * line 12					2.73					
15	O2 (total) supplied = lines 13+14					12.47		2.73			
	Total Air (TA) = line 15/line 13					128.0%					
16	N2 supplied = 3.76*O2,line 15					46.87			46.87		
17	Air (dry) supplied = O2+N2					59.34					
18	H2O in air = moles dry air *A/(B–A)					1.26				1.26	
19	Air (wet) supplied = lines 17+18					60.60					
20	Flue gas constituents = lines 1 to 18, total						7.26	2.73	46.88	6.30	0.00

LINE					
		MAZOUT			
a	Fuel analysis as fired (AF), % by wt or vol				
	C=	86.2%	CO=	0.0%	
	H2=	10.0%			
	S=	2.3%			
b	O2=	0.5%			
	N2=	0.1%			
	H2O=	0.7%			
	Ash=	0.1%			
	TOTAL=	99.98%			
	Flue gas analysis by test				
	CO2=	12.0%			
c	CO=	3	PPM, =	0.000%	
	O2=	4.8%	CMBSTBL	0.00%	
d	Total air (TA), based on above O2 test				
	TA=	128%			
e	Lines f,g,h for gaseous fuels only				
f	Wt, fuel unit + sum (moles each * mol wt), lb				
g	Mol wt of fuel + line f / 100				
h	Density of fuel = line g/394 (lb/cuft)				
i	Higher heat value, fuel	10146	, Btu/lb =		18300
j	%C in refuse				
k	Combustibles unburned, % of fuel				0.00%
l	Stack temp, degrees C		a		180
m	Ambient temp, dry bulb, degrees C				15

	Wet Flue Gas	Dry Flue Gas
Total Moles	63.159206	56.860072

21 Note: for air at 80F and 60%RH, A/(B–A)=0.0212 is used as a standard

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

22 Fuel unit 100.00 lb

	Flue gas constituents:	CO2 + SO	O2	N2	H2O	CO	Btu Total	Conversion to metric units: kcal total	kJoules total
23	MCp, Molal specific heat, mean, t2 to t1	9.94	8.18	7.21	7.07	7.11			
24	In dry flue gas, moles each, line 20*MCp*(t2–t1)	21427	6624	100433		0.38	128484	32378	135551
25	In H2O in air, moles H2O, line 18*MCp*(t2–t1)				2642		2642	666	2787
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2–t1)				10587		10587	2668	11169
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18				94370		94370	23781	99560
28	Total in wet flue gas						236083	59493	249067
29	Due to unburned combustibles, line k*14,100 Btu/lb						0	0	0
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb						21	5	22
31	Total flue gas losses + unburned combustible = lines 28+29+30						236104	59498	249090
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels						1830000	461160	1930650
	= 394 * line i * 100 for gaseous fuels								
33	Stack and combustible loss, % of heat input, 100*line 31/line 32						12.9%	12.9%	12.9%
34	Combustion efficiency, HHV, % of heat input 100–line 33						87.1%	87.1%	87.1%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)						91.8%	91.8%	91.8%

Kombinat Aluminijuma Thograd – Boiler #4
Combustion Calculations – Molal Basis

Date of test: 5 April 91
Time of test: 1130

RCG/Hagler, Bailly, Inc.
Steam rate: 34 ton/hr Air: 15 mbar Fuel: 2500 l/hr

Fuel, O2, and Air per Unit of Fuel / Flue Gas Composition, Moles per Fuel Unit

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReq'd	CO2 + SO	O2	N2	H2O	CO
1	C to CO2	86.19	12.00	7.18	1.00	7.18	7.18				
2	C to CO	0.01	12.00	0.00	0.50	0.00					0.00
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.00	12.00	0.00	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	-0.50	32.00	-0.02	1.00	-0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.96		12.28		9.74					
	Total air =		150.0% (from stack test)								
13	O2 (theo) reqd = O2, line 12					9.74					
14	O2 (excess) = (Total air -1) * line 12					4.87					
15	O2 (total) supplied = lines 13+14					14.61		4.87			
	Total Air (TA) = line 15/line 13					150.0%					
16	N2 supplied = 3.76*O2,line 15					54.93			54.93		
17	Air (dry) supplied = O2+N2					69.54					
18	H2O in air = moles dry air *A/(B-A)					1.47				1.47	
19	Air (wet) supplied = lines 17+18					71.01					
20	Flue gas constituents = lines 1 to 18, total						7.25	4.87	54.93	6.52	0.00

21 Note: for air at 80F and 60%RH, A/(B-A)=0.0212 is used as a standard

LINE		MAZOUT		
a	Fuel analysis as fired (AF), % by wt or vol			
	C=	86.2%	CO=	0.0%
	H2=	10.0%		
	S=	2.3%		
b	O2=	0.5%		
	N2=	0.1%		
	H2O=	0.7%		
	Ash=	0.1%		
	TOTAL=	99.96%		
	Flue gas analysis by test			
	CO2=	10.8%		
c	CO=	12 PPM, =	0.001%	
	O2=	7.3%	CMBSTBL	0.00%
d	Total air (TA), based on above O2 test			
	TA=	150%		
e	Lines f,g,h for gaseous fuels only			
f	Wt, fuel unit + sum (moles each * mol wt), lb			
g	Mol wt of fuel + line f / 100			
h	Density of fuel = line g/394 (lb/cuft)			
i	Higher heat value, fuel	10146	, Btu/lb =	18300
j	%C in refuse			
k	Combustible unburned, % of fuel			0.00%
l	Stack temp, degrees C		a	160
m	Ambient temp, dry bulb, degrees C			15

	Wet Flue Gas	Dry Flue Gas
Total Moles	73.572683	67.057371

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

		Flue gas constituents:	CO2 + SO	O2	N2	H2O	CO	Btu Total	Conversion to metric units: kcal total	kJoules total
22	Fuel unit 100.00 lb									
23	MCp, Molal specific heat, mean, t2 to t1		9.87	8.16	7.19	7.06	7.10			
24	In dry flue gas, moles each, line 20*MCp*(t2-t1)		18695	10371	103115		1.46	132183	33310	139453
25	In H2O in air, moles H2O, line 18*MCp*(t2-t1)					2718		2718	685	2867
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2-t1)					9294		9294	2342	9806
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18					94370		94370	23781	99560
28	Total in wet flue gas							238564	60118	251686
29	Due to unburned combustibles, line k*14,100 Btu/lb							0	0	0
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb							93	24	99
31	Total flue gas losses + unburned combustible = lines 28+29+30							238658	60142	251784
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels							1830000	461160	1930650
	= 394 * line i * 100 for gaseous fuels									
33	Stack and combustible loss, % of heat input, 100*line 31/line 32							13.0%	13.0%	13.0%
34	Combustion efficiency, HHV, % of heat input 100-line 33							87.0%	87.0%	87.0%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)							91.7%	91.7%	91.7%

Kombinat Aluminijuma Titograd – Boiler #4
Combustion Calculations – Molal Basis

Date of test: 5 April 91
Time of test: 1300

RCG/Hagler, Bailly, Inc.
Steam rate: 44 ton/hr Air: 18.5 mbar Fuel: 3200 l/hr

Fuel, O2, and Air per Unit of Fuel / **Flue Gas Composition, Moles per Fuel Unit**

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	CO2 + SO	O2	N2	H2O	CO
1	C to CO2	86.18	12.00	7.18	1.00	7.18	7.18				
2	C to CO	0.02	12.00	0.00	0.50	0.00					0.00
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.00	12.00	0.00	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	-0.50	32.00	-0.02	1.00	-0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.96		12.28		9.74					
	Total air =		134.0% (from stack test)								
13	O2 (theo) reqd = O2, line 12					9.74					
14	O2 (excess) = (Total air -1) * line 12					3.31					
15	O2 (total) supplied = lines 13+14					13.05		3.31			
	Total Air (TA) = line 15/line 13					134.0%					
16	N2 supplied = 3.76*O2,line 15					49.07			49.07		
17	Air (dry) supplied = O2+N2					62.12					
18	H2O in air = moles dry air *A/(B-A)					1.32				1.32	
19	Air (wet) supplied = lines 17+18					63.44					
20	Flue gas constituents = lines 1 to 18, total						7.25	3.31	49.07	6.36	0.00

LINE	MAZOUT			
a	Fuel analysis as fired (AF), % by wt or vol			
	C=	86.2%	CO=	0.0%
	H2=	10.0%		
	S=	2.3%		
b	O2=	0.5%		
	N2=	0.1%		
	H2O=	0.7%		
	Ash=	0.1%		
	TOTAL=	99.96%		
	Flue gas analysis by test			
	CO2=	12.3%		
c	CO=	24 PPM, =	0.002%	
	O2=	5.5%	CMBSTBL	0.00%
d	Total air (TA), based on above O2 test			
	TA=	134%		
e	Lines f,g,h for gaseous fuels only			
f	Wt, fuel unit + sum (moles each * mol wt), lb			
g	Mol wt of fuel + line f / 100			
h	Density of fuel = line g/394 (lb/cuft)			
i	Higher heat value, fuel	10146	, Btu/lb =	18300
j	%C in refuse			
k	Combustibles unburned, % of fuel			0.00%
l	Stack temp, degrees C		a	160
m	Ambient temp, dry bulb, degrees C			15

	Wet Flue Gas	Dry Flue Gas
Total Moles	65.996409	59.636386

21 Note: for air at 80F and 60%RH, A/(B-A)=0.0212 is used as a standard

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

		Flue gas constituents:	CO2 + SO	O2	N2	H2O	CO	Btu Total	Conversion to metric units: kcal total	kJoules total
22	Fuel unit 100.00 lb									
23	MCp, Molal specific heat, mean, t2 to t1		9.87	8.16	7.19	7.06	7.10			
24	In dry flue gas, moles each, line 20*MCp*(t2-t1)		18694	7052	92114		2.60	117862	29701	124345
25	In H2O in air, moles H2O, line 18*MCp*(t2-t1)					2426		2426	612	2562
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2-t1)					9294		9294	2342	9806
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18					94370		94370	23781	99660
28	Total in wet flue gas							223954	56436	236272
29	Due to unburned combustibles, line k*14,100 Btu/lb							0	0	0
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb							164	41	173
31	Total flue gas losses + unburned combustible = lines 28+29+30							224118	56478	236445
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels							1830000	461160	1930650
	= 394 * line i * 100 for gaseous fuels									
33	Stack and combustible loss, % of heat input, 100*line 31/line 32							12.2%	12.2%	12.2%
34	Combustion efficiency, HHV, % of heat input 100-line 33							87.8%	87.8%	87.8%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)							92.5%	92.5%	92.5%

Kombinat Aluminijuma Titograd – Boiler #3
Combustion Calculations – Molal Basis

Date of test: CLEAN TUBES
Time of test:

RCG/Hagler, Bailly, Inc.
Steam rate: Air: Fuel:

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	CO2 + SO	O2	N2	H2O	CO
	Fuel, O2, and Air per Unit of Fuel						Flue Gas Composition, Moles per Fuel Unit				
1	C to CO2	86.20	12.00	7.18	1.00	7.18	7.18				
2	C to CO	0.00	12.00	0.00	0.50	0.00					0.00
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.00	12.00	0.00	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	–0.50	32.00	–0.02	1.00	–0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.96		12.28		9.74					
	Total air =		132.0% (from stack test)								
13	O2 (theo) reqd = O2, line 12					9.74					
14	O2 (excess) = (Total air –1) * line 12					3.12					
15	O2 (total) supplied = lines 13+14					12.86		3.12			
	Total Air (TA) = line 15/line 13					132.0%					
16	N2 supplied = 3.76*O2,line 15					48.34			48.34		
17	Air (dry) supplied = O2+N2					61.20					
18	H2O in air = moles dry air *A/(B–A)					1.30				1.30	
19	Air (wet) supplied = lines 17+18					62.49					
20	Flue gas constituents = lines 1 to 18, total						7.26	3.12	48.34	6.34	0.00

LINE					
	MAZOUT				
a	Fuel analysis as fired (AF), % by wt or vol				
	C=	86.2%	CO=	0.0%	
	H2=	10.0%			
	S=	2.3%			
b	O2=	0.5%			
	N2=	0.1%			
	H2O=	0.7%			
	Ash=	0.1%			
	TOTAL=	99.96%			
	Flue gas analysis by test				
	CO2=	12.0%			
c	CO=	3 PPM, =		0.000%	
	O2=	4.8%	CMBSTBL	0.00%	
d	Total air (TA), based on above O2 test				
	TA=	132%			
e	Lines f,g,h for gaseous fuels only				
f	Wt, fuel unit + sum (moles each * mol wt), lb				
g	Mol wt of fuel + line f / 100				
h	Density of fuel = line g/394 (lb/cuft)				
i	Higher heat value, fuel	10146	, Btu/lb =		18300
j	%C in refuse				
k	Combustibles unburned, % of fuel				0.00%
l	Stack temp, degrees C			a	165
m	Ambient temp, dry bulb, degrees C				15

	Wet Flue Gas	Dry Flue Gas
Total Moles	65.052921	58.714472

21 Note: for air at 80F and 60%RH, A/(B–A)=0.0212 is used as a standard

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

		CO2 + SO	O2	N2	H2O	CO	Btu Total	Conversion to metric units: kcal total	kJoules total
22	Fuel unit 100.00 lb — Flue gas constituents:								
23	MCp, Molal specific heat, mean, t2 to t1	9.89	8.16	7.20	7.07	7.10			
24	In dry flue gas, moles each, line 20*MCp*(t2–t1)	19376	6870	93944		0.34	120191	30288	126801
25	In H2O in air, moles H2O, line 18*MCp*(t2–t1)				2475		2475	624	2611
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2–t1)				9617		9617	2424	10146
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18				94370		94370	23781	99560
28	Total in wet flue gas						226653	57117	239119
29	Due to unburned combustibles, line k*14,100 Btu/lb						0	0	0
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb						21	5	22
31	Total flue gas losses + unburned combustible = lines 28+29+30						226674	57122	239141
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels						1830000	461160	1930650
	= 394 * line i * 100 for gaseous fuels								
33	Stack and combustible loss, % of heat input, 100*line 31/line 32						12.4%	12.4%	12.4%
34	Combustion efficiency, HHV, % of heat input 100–line 33						87.6%	87.6%	87.6%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)						92.4%	92.4%	92.4%

78

Kombinat Aluminijuma Titograd – Boiler #3
Combustion Calculations – Molal Basis

Date of test: CLOSE PORTS
Time of test:

RCG/Hagler, Bailly, Inc.
Steam rate: Air: Fuel:

Fuel, O2, and Air per Unit of Fuel / Flue Gas Composition, Moles per Fuel Unit

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	CO2 + SO	O2	N2	H2O	CO
1	C to CO2	86.20	12.00	7.18	1.00	7.18	7.18				
2	C to CO	0.00	12.00	0.00	0.50	0.00					0.00
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.00	12.00	0.00	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	–0.50	32.00	–0.02	1.00	–0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.96		12.28		9.74					
	Total air =		115.0% (from stack test)								
13	O2 (theo) reqd = O2, line 12					9.74					
14	O2 (excess) = (Total air –1) * line 12					1.46					
15	O2 (total) supplied = lines 13+14					11.20		1.46			
	Total Air (TA) = line 15/line 13					115.0%					
16	N2 supplied = 3.76*O2,line 15					42.11			42.11		
17	Air (dry) supplied = O2+N2					53.31					
18	H2O in air = moles dry air *A/(B–A)					1.13				1.13	
19	Air (wet) supplied = lines 17+18					54.44					
20	Flue gas constituents = lines 1 to 18, total						7.26	1.46	42.12	6.17	0.00

21 Note: for air at 80F and 60%RH, A/(B–A)=0.0212 is used as a standard

LINE					
		MAZOUT			
a	Fuel analysis as fired (AF), % by wt or vol				
	C=	86.2%	CO=	0.0%	
	H2=	10.0%			
	S=	2.3%			
b	O2=	0.5%			
	N2=	0.1%			
	H2O=	0.7%			
	Ash=	0.1%			
	TOTAL=	99.98%			
	Flue gas analysis by test				
	CO2=	13.5%			
c	CO=	0 PPM, =		0.000%	
	O2=	3.0%	CMBSTBL	0.00%	
d	Total air (TA), based on above O2 test				
	TA=	115%			
e	Lines i,g,h for gaseous fuels only				
f	Wt, fuel unit + sum (moles each * mol wt), lb				
g	Mol wt of fuel + line f / 100				
h	Density of fuel = line g/394 (lb/cuft)				
i	Higher heat value, fuel	10146	, Btu/lb =		18300
j	%C in refuse				
k	Combustibles unburned, % of fuel				0.00%
l	Stack temp, degrees C			a	170
m	Ambient temp, dry bulb, degrees C				15

	Wet Flue Gas	Dry Flue Gas
Total Moles	57.005053	50.833675

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

		Flue gas constituents: CO2 + SO	O2	N2	H2O	CO	Btu Total	Conversion to metric units: kcal total	kJoules total
22	Fuel unit 100.00 lb								
23	MCp, Molal specific heat, mean, t2 to t1	9.91	8.17	7.20	7.07	7.10			
24	In dry flue gas, moles each, line 20*MCp*(t2–t1)	20055	3330	84639		0.00	108026	27223	113966
25	In H2O in air, moles H2O, line 18*MCp*(t2–t1)				2229		2229	562	2351
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2–t1)				9940		9940	2505	10487
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18				94370		94370	23781	99560
28	Total in wet flue gas						214565	54070	226366
29	Due to unburned combustibles, line k*14,100 Btu/lb						0	0	0
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb						0	0	0
31	Total flue gas losses + unburned combustible = lines 28+29+30						214565	54070	226366
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels						1830000	461160	1930650
	= 394 * line i * 100 for gaseous fuels								
33	Stack and combustible loss, % of heat input, 100*line 31/line 32						11.7%	11.7%	11.7%
34	Combustion efficiency, HHV, % of heat input 100–line 33						88.3%	88.3%	88.3%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)						93.1%	93.1%	93.1%

APPENDIX 4
DETAILED CALCULATION OF COMBUSTION EFFICIENCY BEFORE AND AFTER IMPROVEMENTS

ALUMINA CALCINER

KOMBINAT ALUMINUJUMA TITOGRAD (KAT) ALUMINA PLANT AND POWER PLANT

Kombinat Aluminijuma Titograd – Alumina Calciner
Combustion Calculations – Molal Basis

Date of test: 4 April 1991
Time of test: 1030

RCG/Hagler, Bailly, Inc.
Hydrate feed: 56 t/hr

Air: primary 90% open, 230 mm H2O, secondary #9

Fuel 3800 l/hr

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	Flue Gas Composition, Moles per Fuel Unit: CO2 + SO	O2	N2	H2O	CO
1	C to CO2	81.16	12.00	6.76	1.00	6.76	6.76				
2	C to CO	1.86	12.00	0.15	0.50	0.08					0.15
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	3.18	12.00	0.27	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	-0.50	32.00	-0.02	1.00	-0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.96		12.28		9.40					
	Total air =		107.0% (from stack test)								
13	O2 (theo) reqd = O2, line 12					9.40					
14	O2 (excess) = (Total air -1) * line 12					0.66					
15	O2 (total) supplied = lines 13+14					10.05		0.66			
	Total Air (TA) = line 15/line 13					107.0%					
16	N2 supplied = 3.76*O2,line 15					37.81			37.81		
17	Air (dry) supplied = O2+N2					47.86					
18	H2O in air = moles dry air *A/(B-A)					1.01				1.01	
19	Air (wet) supplied = lines 17+18					48.88					
20	Flue gas constituents = lines 1 to 18, total						6.84	0.66	37.81	6.06	0.15

21 Note: for air at 80F and 60%RH, A/(B-A)=0.0212 is used as a standard

LINE	MAZOUT			
a	Fuel analysis as fired (AF), % by wt or vol			
	C=	86.2%	CO=	0.0%
	H2=	10.0%		
	S=	2.3%		
b	O2=	0.5%		
	N2=	0.1%		
	H2O=	0.7%		
	Ash=	0.1%		
	TOTAL=	99.96%		
	Flue gas analysis by test			
	CO2=	15.3%		
c	CO=	3500 PPM, =	0.350%	
	O2=	1.5%	CMBSTBL	0.60%
d	Total air (TA), based on above O2 test			
	TA=	107%		
e	Lines f,g,h for gaseous fuels only			
f	Wt, fuel unit + sum (moles each * mol wt), lb			
g	Mol wt of fuel + line f / 100			
h	Density of fuel = line g/394 (lb/cuft)			
i	Higher heat value, fuel	10146	, Btu/lb =	18300
j	%C in refuse			
k	Combustibles unburned, % of fuel			3.69%
l	Stack temp, degrees C		a	230
m	Ambient temp, dry bulb, degrees C			15

	Wet Flue Gas	Dry Flue Gas
Total Moles	51.513082	45.457323

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

Line		Flue gas constituents:	CO2 + SO	O2	N2	H2O	CO	Btu Total	Conversion to metric units: kcal total	kJoules total
22	Fuel unit 100.00 lb									
23	MCp, Molal specific heat, mean, t2 to t1		10.12	6.22	7.27	7.09	7.13			
24	In dry flue gas, moles each, line 20*MCp*(t2-t1)		28769	2093	106342		427.14	135631	34179	143091
25	In H2O in air, moles H2O, line 18*MCp*(t2-t1)					2784		2784	701	2937
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2-t1)					13830		13830	3485	14591
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18					94370		94370	23781	99560
28	Total in wet flue gas							246615	62147	260179
29	Due to unburned combustibles, line k*14,100 Btu/lb							52062	13120	54925
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb							18111	4564	19107
31	Total flue gas losses + unburned combustible = lines 28+29+30							316788	79831	334211
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels							1830000	461160	1[illegible]250
	= 394 * line i * 100 for gaseous fuels									
33	Stack and combustible loss, % of heat input, 100*line 31/line 32							17.3%	17.3%	17.3%
34	Combustion efficiency, HHV, % of heat input 100-line 33							82.7%	82.7%	82.7%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)							87.2%	87.2%	87.2%

Kombinat Aluminijuma Titograd – Alumina Calciner
Combustion Calculations – Molal Basis

Date of test: 4 April 1991
Time of test: 1245

RCG/Hagler, Bailly, Inc.
Hydrate feed: 56 t/hr

Air: primary 100% open, 240 mm H2O, secondary #13

Fuel 3800 l/hr

Fuel, O2, and Air per Unit of Fuel

Line	Fuel Constit	Per Fuel Unit, lb	Mol. Wt Divisor	MolesFuel Constit	O2 Multiplr	O2 Moles TheoReqd	Flue Gas Composition, Moles per Fuel Unit: CO2 + SO	O2	N2	H2O	CO
1	C to CO2	86.18	12.00	7.18	1.00	7.18	7.18				
2	C to CO	0.02	12.00	0.00	0.50	0.00					0.00
3	CO to CO2	0.00	28.00	0.00	0.50	0.00	0.00				
4	C unburnd	0.00	12.00	0.00	0.00	0.00					
5	H2	10.00	2.00	5.00	0.50	2.50				5.00	
6	S	2.30	32.00	0.07	1.00	0.07	0.07				
7	O2 deduct	-0.50	32.00	-0.02	1.00	-0.02					
8	N2	0.10	28.00	0.00		0.00			0.00		
9	CO2		44.00	0.00		0.00	0.00				
10	H2O	0.74	18.00	0.04		0.00				0.04	
11	Ash	0.12		0.00		0.00					
12	Sum	99.96		12.28		9.74					
	Total air =		118.0% (from stack wet)								
13	O2 (theo) reqd = O2, line 12					9.74					
14	O2 (excess) = (Total air -1) * line 12					1.75					
15	O2 (total) supplied = lines 13+14					11.49		1.75			
	Total Air (TA) = line 15/line 13					118.0%					
16	N2 supplied = 3.76*O2 line 15					43.21			43.21		
17	Air (dry) supplied = O2+N2					54.70					
18	H2O in air = moles dry air *A/(B-A)					1.16				1.16	
19	Air (wet) supplied = lines 17+18					55.86					
20	Flue gas constituents = lines 1 to 18, total						7.25	1.75	43.21	6.20	0.00

LINE	MAZOUT			
a	Fuel analysis as fired (AF), % by wt or vol			
	C=	86.2%	CO=	0.0%
	H2=	10.0%		
	S=	2.3%		
b	O2=	0.5%		
	N2=	0.1%		
	H2O=	0.7%		
	Ash=	0.1%		
	TOTAL=	99.96%		
	Flue gas analysis by test			
	CO2=	14.0%		
c	CO=	40 PPM, =	0.004%	
	O2=	3.2%	CMBSTBL	0.00%
d	Total air (TA), based on above O2 test			
	TA=	118%		
e	Lines f,g,h for gaseous fuels only			
f	Wt, fuel unit + sum (moles each * mol wt), lb			
g	Mol wt of fuel + line f / 100			
h	Density of fuel = line g/394 (lb/cuft)			
i	Higher heat value, fuel	10146	, Btu/lb =	18300
j	%C in refuse			
k	Combustibles unburned, % of fuel			0.00%
l	Stack temp, degrees C		a	255
m	Ambient temp, dry bulb, degrees C			15

	Wet Flue Gas	Dry Flue Gas
Total Moles	58.420492	52.219751

21 Note: for air at 80F and 60%RH, A/(B-A)=0.0212 is used as a standard

DETERMINATION OF FLUE GAS AND COMBUSTIBLE LOSSES IN BTU PER FUEL UNIT (AS FIRED)

							Btu Total	Conversion to metric units: kcal total	kJoules total
22	Fuel unit 100.00 lb	Flue gas constituents:	CO2 + SO	O2	N2	H2O	CO			
23	MCp, Molal specific heat, mean, t2 to t1		10.21	8.26	7.29	7.10	7.15			
24	In dry flue gas, moles each, line 20*MCp*(t2-t1)		31984	6244	136171		6.34	174405	43950	183996
25	In H2O in air, moles H2O, line 18*MCp*(t2-t1)					3556		3556	896	3751
26	In sens heat, H2O in fuel, moles, lines (5+10)*MCp*(t2-t1)					15458		15458	3895	16308
27	In latent heat, H2O in fuel, moles, lines (5+10)*1040*18					94370		94370	23781	99560
28	Total in wet flue gas							287789	72523	303617
29	Due to unburned combustibles, line k*14,100 Btu/lb							0	0	0
30	Due to unburned CO in flue gas; moles C to CO*12*9755 Btu/lb							240	61	253
31	Total flue gas losses + unburned combustible = lines 28+29+30							288029	72583	303871
32	Higher heat value (HHV) of fuel unit= 100 * line i for solid & liquid fuels							1830000	461160	1930650
	= 394 * line i * 100 for gaseous fuels									
33	Stack and combustible loss, % of heat input, 100*line 31/line 32							15.7%	15.7%	15.7%
34	Combustion efficiency, HHV, % of heat input 100-line 33							84.3%	84.3%	84.3%
35	Combustion efficiency, LHV basis (line 27 subtracted from heat value and losses)							88.8%	88.8%	88.8%

82