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EXPERIENCIAS OPERACIONALES y MANTENCION PLANTA SAG EL TENIENTE

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RESUMEN

El presente artículo contiene un resumen general de la evolución de los parámetros más importantes, tanto de la parte operativa como de mantención, de la planta de molienda SAG de Codelco Chile División El Teniente desde su puesta en marcha a la fecha.

Del análisis de los resultados obtenidos a través del tiempo en la operación del molino SAG se ha podido encontrar explicación a una serie de fenómenos que en él ocurren. A su vez, se muestra algunas de las modificaciones realizadas tanto en la configuración de la planta como en sus equipos, especialmente en el revestimiento del molino SAG, con lo cual se ha logrado grandes avances en la reducción de los tiempos de detención.

En la primera parte de este trabajo se muestran los parámetros operativos de la planta SAG. En la segunda parte, se muestra un estudio de la eficiencia energética relacionada con la adición de finos en la alimentación del molino SAG y, finalmente, se expone las experiencias relacionadas con la mantención.

Experiencias operacionales de la Planta SAG.

Gerencia Plantas División Teniente

La gerencia Plantas de la División el Teniente está ubicada a aproximadamente 50 Km. de la ciudad de Rancagua. Dentro de ésta, y en la parte superior del Concentrador, se localiza la planta SAG.

Diagrama de flujo

El diagrama de flujo de la planta es el siguiente:

- Un Stock-Pile de aprox. 130.000 ton, de las cuales 24.000 ton son carga viva.
- 4 alimentadores de velocidad variable que descargan en sentido longitudinal a la correa que alimenta el molino.
- En una correa de 60" de ancho y aproximadamente 120 mts. entre poleas, va ubicado un pesómetro de cuatro estaciones y un medidor de tamaño de partículas llamado PETRA.
- El molino SAG es de 36 pies de diámetro por 15 de largo, tiene un motor de 15.000 HP y parrillas de 2 1/2" de abertura.
- La descarga es clasificada en un harnero de 20 pies de largo por 8 pies de ancho con parrillas de 3/4".
- El sobre tamaño alimenta 2 chancadoras de 7 pies cabeza corta. Estos descargan un producto de entre 7 a 9 mm. el que se va como carga circulante al molino SAG.
- El bajo tamaño es clasificado en una batería de Hidrociclones del tipo Krebs D-26 compuesta por 8 unidades. Aquí se obtiene el primer producto final.
- La descarga de los ciclones de la batería primaria va a dos molinos de bolas. Estos tienen 28 pies de largo por 18 pies de diámetro con motores de 6.000 HP. Operan en circuito cerrado con sus respectivas baterías.

El producto final de la planta tiene un 18% + 100 M.

Antes de entrar a la canal de pulpa que alimenta la planta de Flotación todo el producto final pasa por una parrilla despiedradora de 8 mm de abertura que tiene como función retener cualquier piedra de tamaño inadecuado que eventualmente aparecen debido a sobrecarga de los ciclones.

Evaluación de alternativas

Durante una primera etapa se efectuaron una serie de pruebas con el objeto de determinar la mejor alternativa de operación de nuestro módulo SAG. Es así entonces que entre octubre y diciembre del año 91 se probaron varias configuraciones entre las que se destacan:

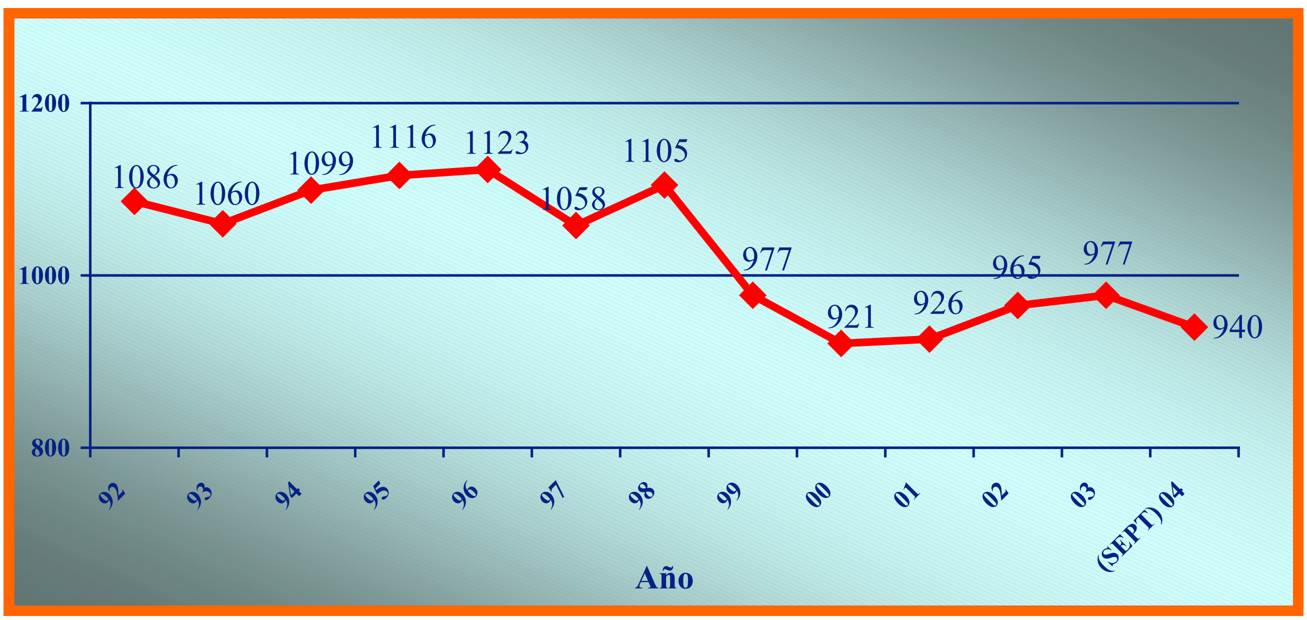
- Full autógeno: Molino SAG, 1 chancador y un molino de bolas.
- Semiautógeno con 4 a 5% de nivel de llenado de bolas (de 5") con el mismo equipo y finalmente
- Semiautógeno con 10.5% de nivel de llenado de bolas y mas e12ø molino de bolas.

Resultados

Los resultados obtenidos se muestran en esta tabla. Podemos destacar en ella el bajo rendimiento tenido con full autógeno respecto a semiautógeno con 10.5% de bolas.

	POWER (KW)		KWH/TMS			
LEVEL	SAG M.	BALLS M.	SAG M.	BALLS M.	TMS/HR	F 80 SAG
FULL AUTOG.	7095	3810	19,0	10,3	381	81283
SEMI AUT. 4%	8474	4204	12,3	6,0	700	53065
SEMI AUT.10.5%	10621	4232	8,9	7,4	1193	87871
SEMI AUT.12,3%	10998		11,3	8,0	976	108540

Rendimiento (TMS/HR).
Con la configuración elegida la evolución del tonelaje procesado desde el año 92 a la fecha fue la que se ve en este gráfico.



Se tuvo un continuo aumento hasta el año 96 bajando en el año 97 debido a dos hechos esenciales:

1. Falla del motor de un molino de bolas (Nº 411) el que debe ser reemplazado por uno de 5000 HP
2. Aumento de la granulometría de alimentación al molino SAG.

Con el objetivo de revertir esta situación de bajo rendimiento se creó un equipo multidisciplinario donde se juntaron representantes de toda la cadena del proceso.

Producto de una mejora considerable en las coordinaciones y en la gestión de cada proceso se logró subir nuevamente el rendimiento a niveles normales desde el mes de Mayo del 97 a Septiembre del 98. Pero, debido al cambio del pesómetro existente hasta ese momento por uno de cuatro estaciones de polines, se detectó que el tonelaje procesado estaba alterado en cerca de un 10%. También en esa oportunidad se instaló parrillas con una abertura de 2" en vez de 2 1/2" lo que conjugado con lo anterior produjo desde esa fecha una disminución en el tonelaje procesado en esta planta.

Variación del F-80 SAG

Pero, indudablemente lo que mas ha influido en la baja del rendimiento de nuestra planta ha sido el aumento del tamaño grueso alimentado al molino SAG.

Podemos ver que de 70.000 micrones tenidos hasta el año 96 se fue aumentando hasta 140.000 en el año 2000 para bajar niveles de 109.000 al presente año.

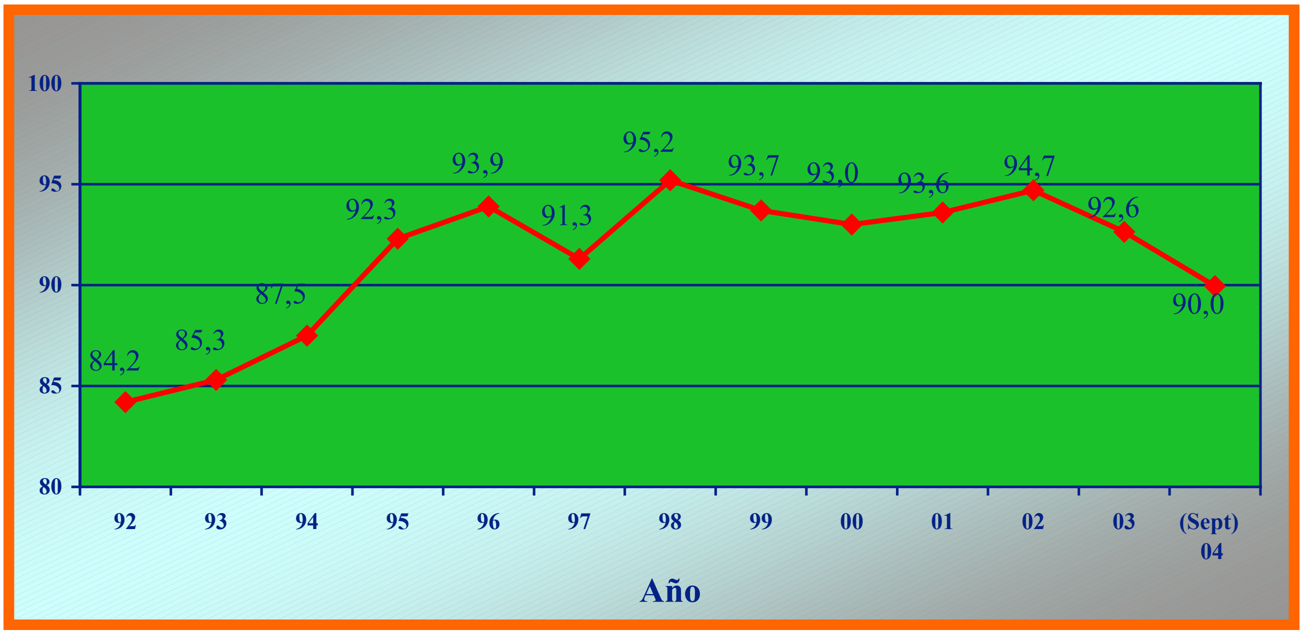
Principales indicadores de gestión operación

Los principales indicadores de gestión que ocupamos son:

- % de utilización
- Costos
- Taza de frecuencia de accidentes
- Productividad

% de utilización

La utilización de nuestra planta ha ido en constante aumento, la baja que experimentó en el año 97 se debió al evento climático mencionado anteriormente (88 hr. de detención) y a un problema en la fabricación de los pulp lifters cambiados en esa oportunidad, lo que produjo una demora de 55 hr sobre lo programado.
La baja experimentada en el año 2000 se debió a que por primera vez se efectuó la mantención mayor del motor del molino SAG la que incluía el desplazamiento del estator del motor.

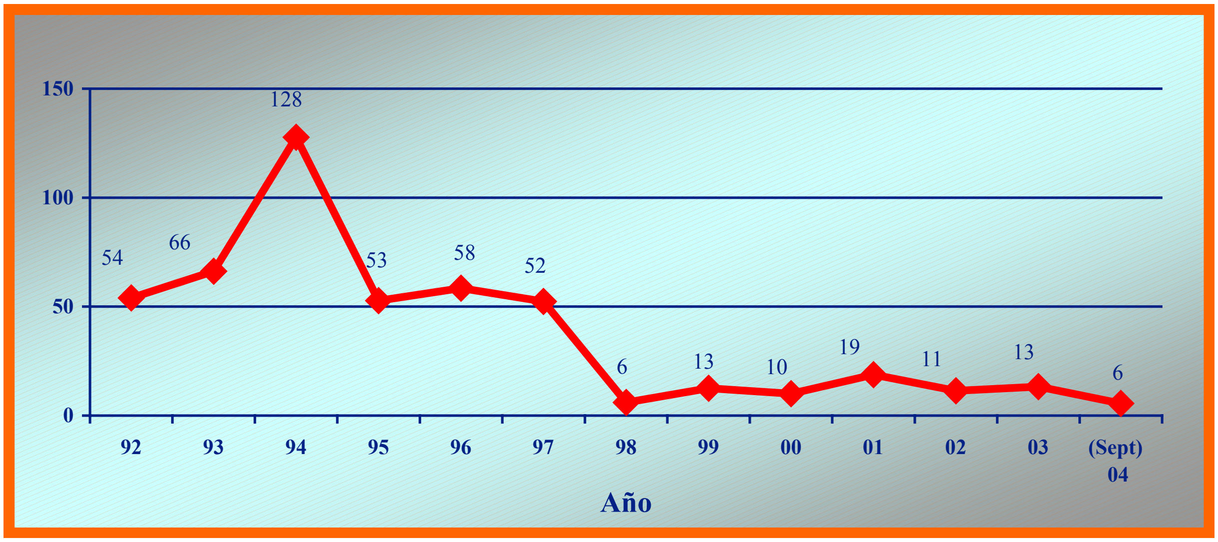


Razones de la mejora en la utilización

- Modificación chutes de traspaso por diseño inapropiado
- Modificación chute de alimentación SAG
- Modificación de diseño de correas de traspaso
- Modificación de diseño de piolas de parada de emergencia

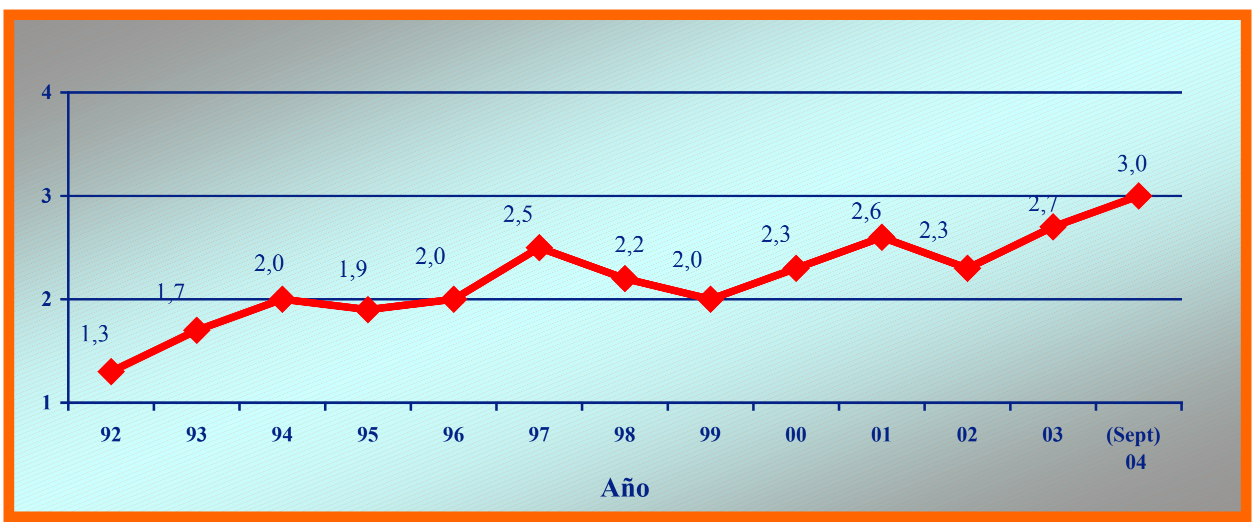
Detención planta por atollos de chutes de traspaso y/o correas y piolas de seguridad

Las horas de detención por atollos y piolas de seguridad bajaron desde 143 hr en el peor año (94) a cerca de 62 hr el año 95. El año 97 se efectúa una nueva mejora esta vez en el chute de alimentación lo que nos ha llevado en el año 2000 a solo 12 hr. de detención.



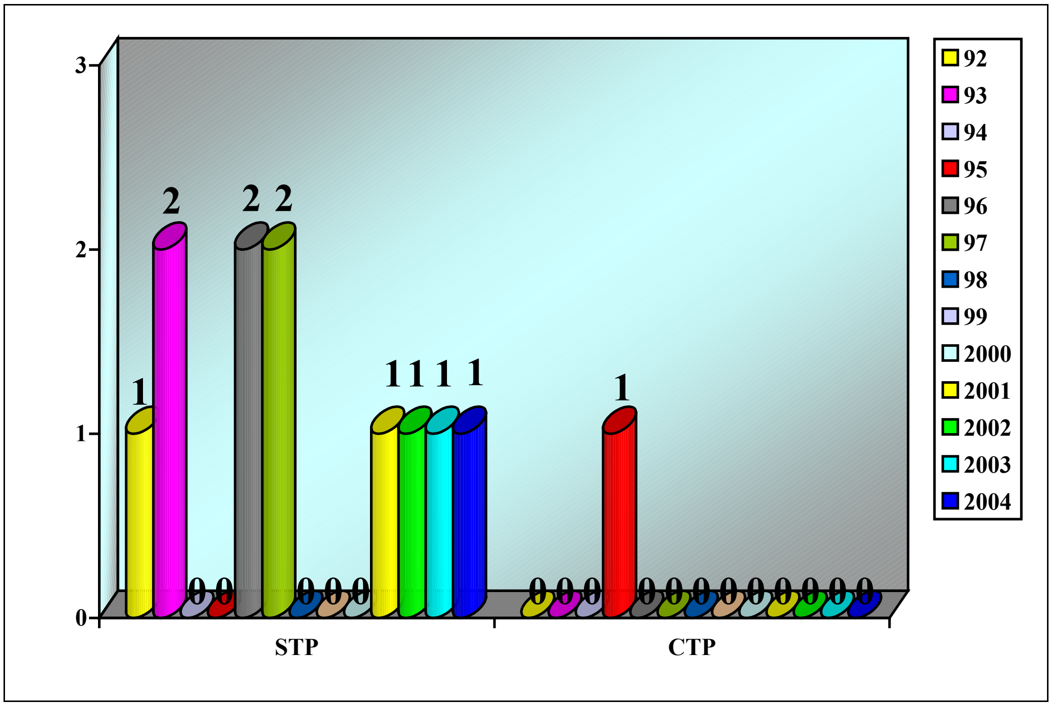
Costos planta SAG (US$/TMS Molida)

Respecto a los costos tenemos que este fluctúa entre 2 y 3 dólares por tonelada molida dependiendo de las perturbaciones que aparezcan y que influyen principalmente sobre el tonelaje procesado.



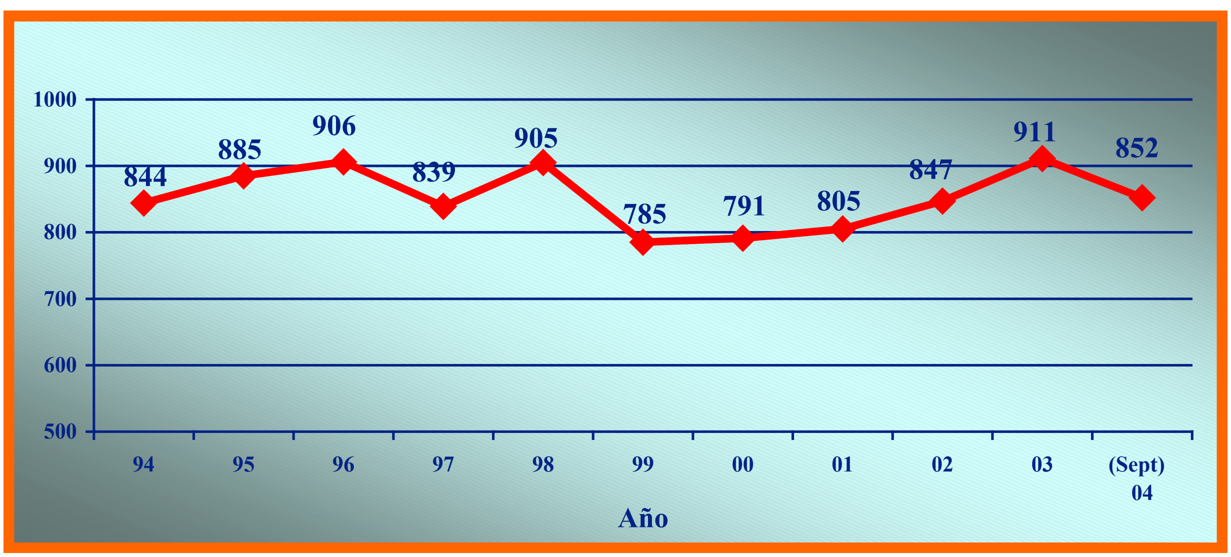
Nº de accidentes por año

En cuanto a los accidentes ocurridos en los años 13 que llevamos corriendo solo hemos tenido 1 accidente con tiempo perdido (marzo 1995).



Productividad (TMS/Hombre inscrito)

La productividad ha bajado notoriamente, influida por la baja de tonelaje tenida los últimos años.



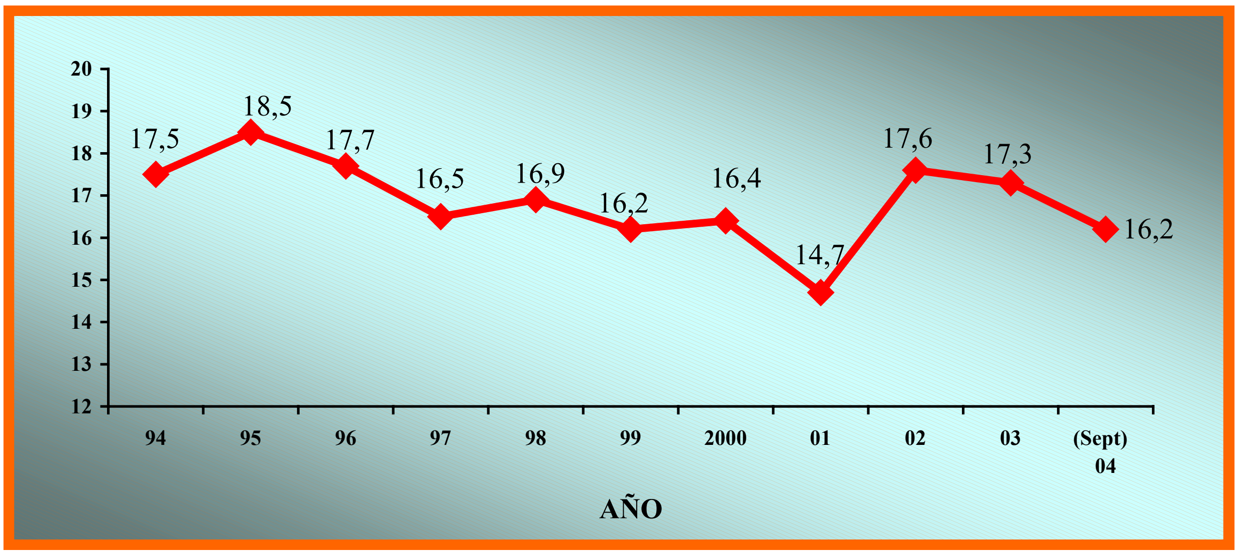
Parámetros de operación

Los parámetros de operación más importantes de nuestro proceso son:

- El porcentaje de +100 M
- El consumo de bolas
- El consumo de energía

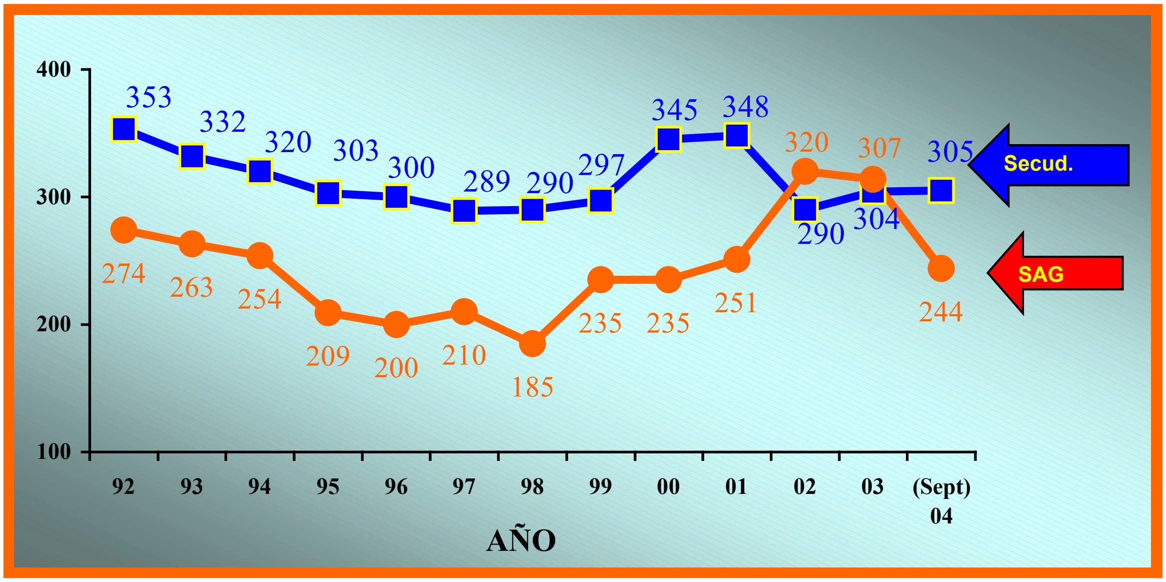
% de +100 M

El % +100 M ha ido bajando producto de algunas mejoras realizadas especialmente en el área de la clasificación, pero la tendencia a la baja de los valores de los últimos años están influenciadas por el bajo tonelaje procesado.



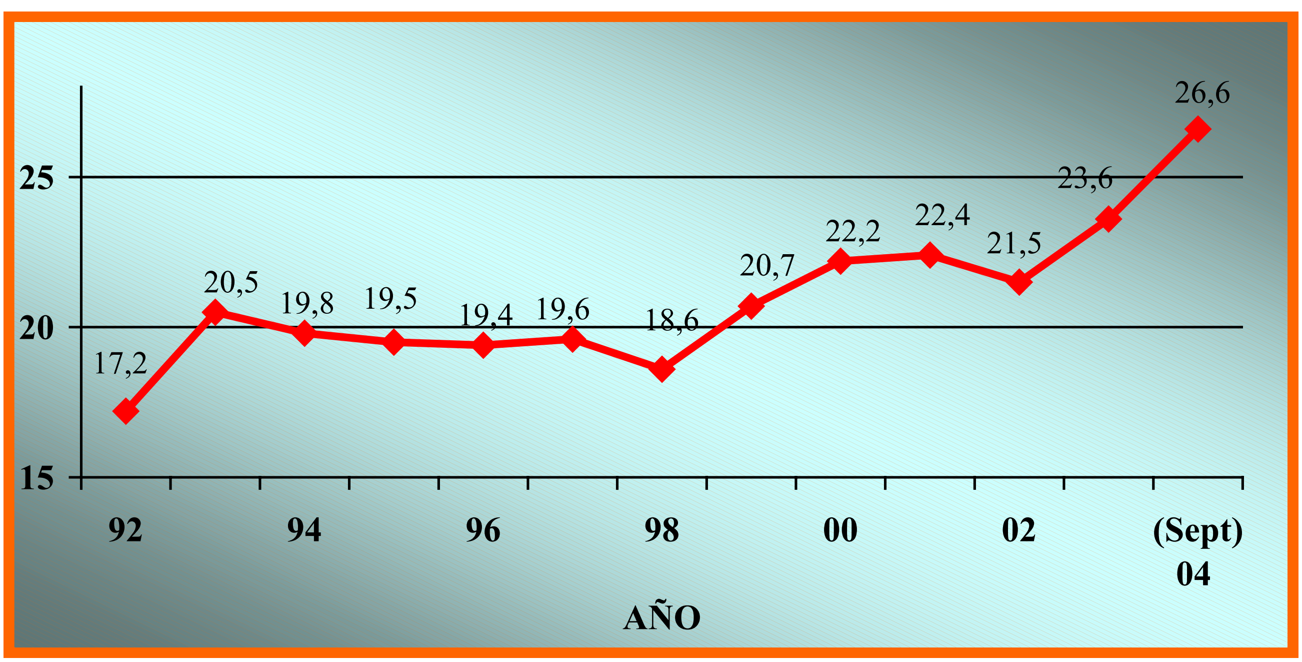
Consumo de bolas

El consumo de bolas para el SAG ha variado según se muestra en la gráfica teniéndose como promedio 245 gr/ton para le molino SAG y 314 gr/ton para los molinos secundarios. En el molino SAG se experimenta una baja en el año 2004 debido posiblemente al cambio de bola 5" por la bola de 6".



Consumo de energía planta

El consumo especifico de energía de la planta permaneció casi estable en aprox. 19,5 kWhr/ton entre los años 1993 al 1997,pero se ha incrementado hasta 26,6 kWhr/ton en los últimos años influido principalmente por la mayor presencia de mineral grueso.

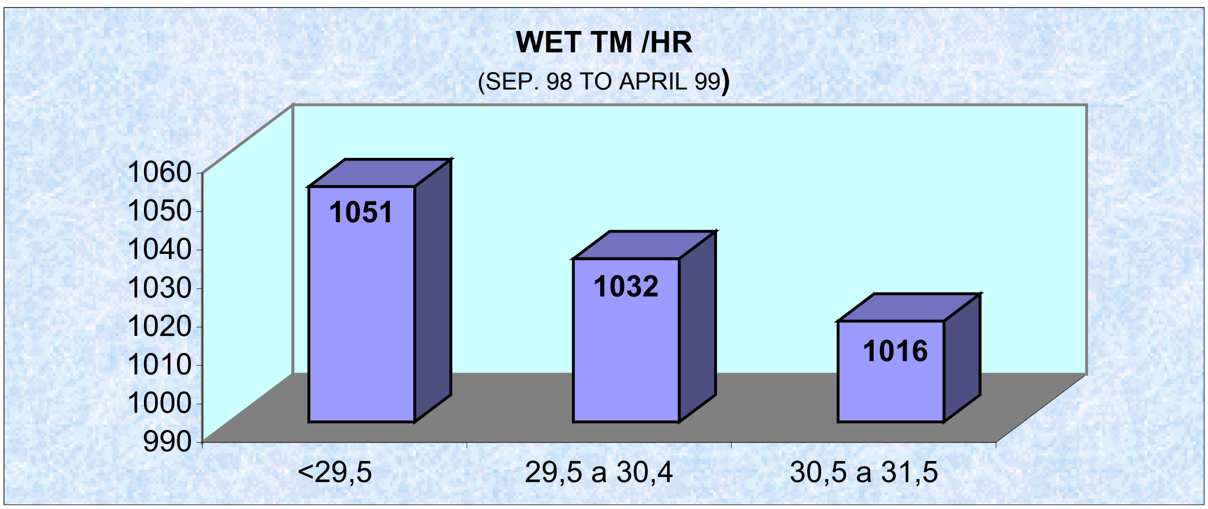


Estrategia operacional

La estrategia ocupada para operar esta planta se fundamenta en dos principios básicos: Procesar el máximo tonelaje para lograr el mejor producto final (máximo 18% + 100 M). Esto se logra al operar con un nivel de llenado de 25 a 28 %, al máximo de velocidad, 10.3 RPM. Variando el %de sólido de alimentación al molino según sea la granulometría que esté entrando al molino y ocupando permanentemente el control experto Súper- SAG

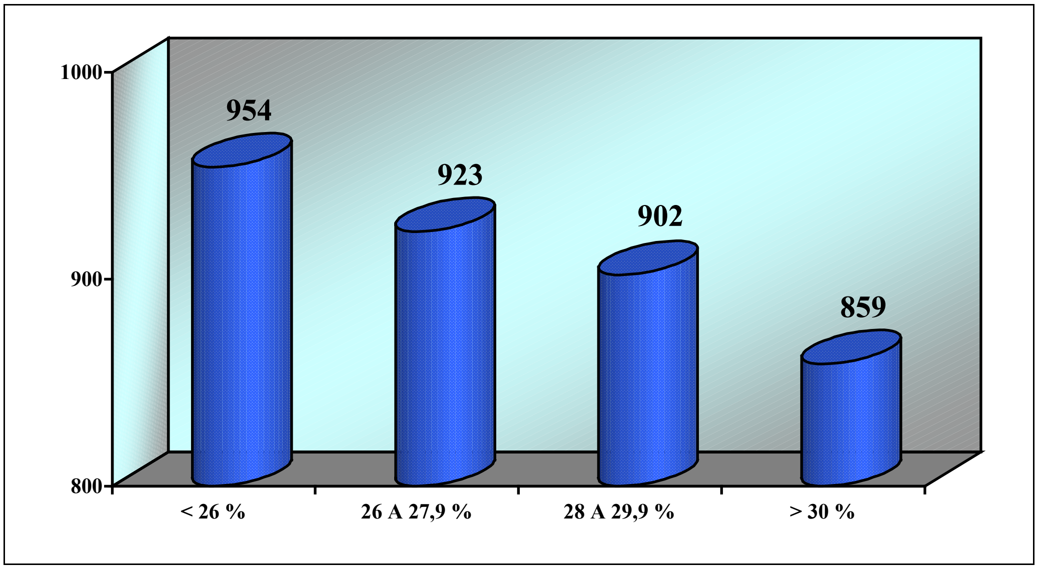
Rendimiento v/s nivel de llenado

Analizando los resultados obtenidos en el período comprendido entre Septiembre del año 98 a Abril del 99 se observa claramente el mayor rendimiento obtenido cuando se operó con niveles inferiores a 29. 5%, produciéndose una diferencia de 31 t/hr respecto a operar con un nivel de sobre 30.5%. Esta diferencia de tonelaje equivale, en el mes, a casi un día de operación.



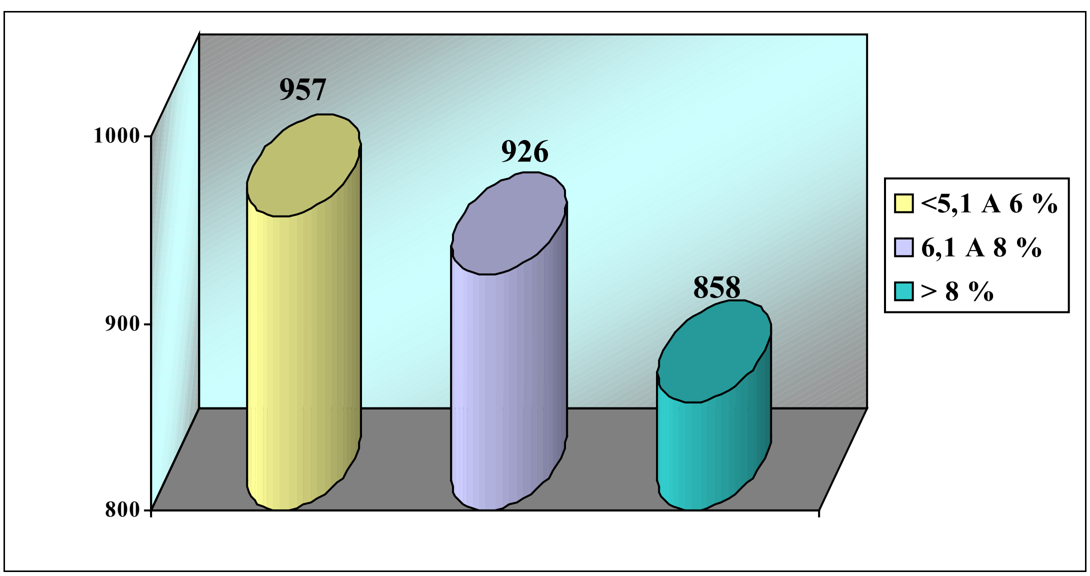
Rendimiento v/s nivel de llenado

Lo mismo sucede al examinar los resultados del período Enero - Octubre del año 2000 donde, producto de una menor cantidad de mineral fino, se hace más elocuente esta diferencia incluso operando con niveles más bajos que en el período anterior. En este caso la diferencia es de 87 t/h



Rendimiento v/s % de mineral grueso (se considera grueso los tamaños sobre 6")

Sin lugar a dudas la variable granulometría es la que más influye sobre el rendimiento de un molino SAG. En el gráfico que se muestra podemos ver los rendimientos obtenidos en el período Enero - Octubre del año 2000, referidos al % de gruesos (partículas de tamaño > 6") presente en la alimentación. Se ve claramente que en la medida que aumenta el % de fracción gruesa disminuye el tonelaje procesado por hr. Cuando se tiene menos que 6% de grueso se logra 957 t/h y cuando este % aumenta tan sólo en 2% baja el rendimiento a 858 t/h. Lo que equivale a un 10% de menor producción.



¿Como revertir situación de bajo rendimiento?

- Cambiando diámetro de bola usada en el molino SAG
- Modificando granulometría de alimentación planta SAG, mediante proceso de prechancado

Fecha de puesta en marcha

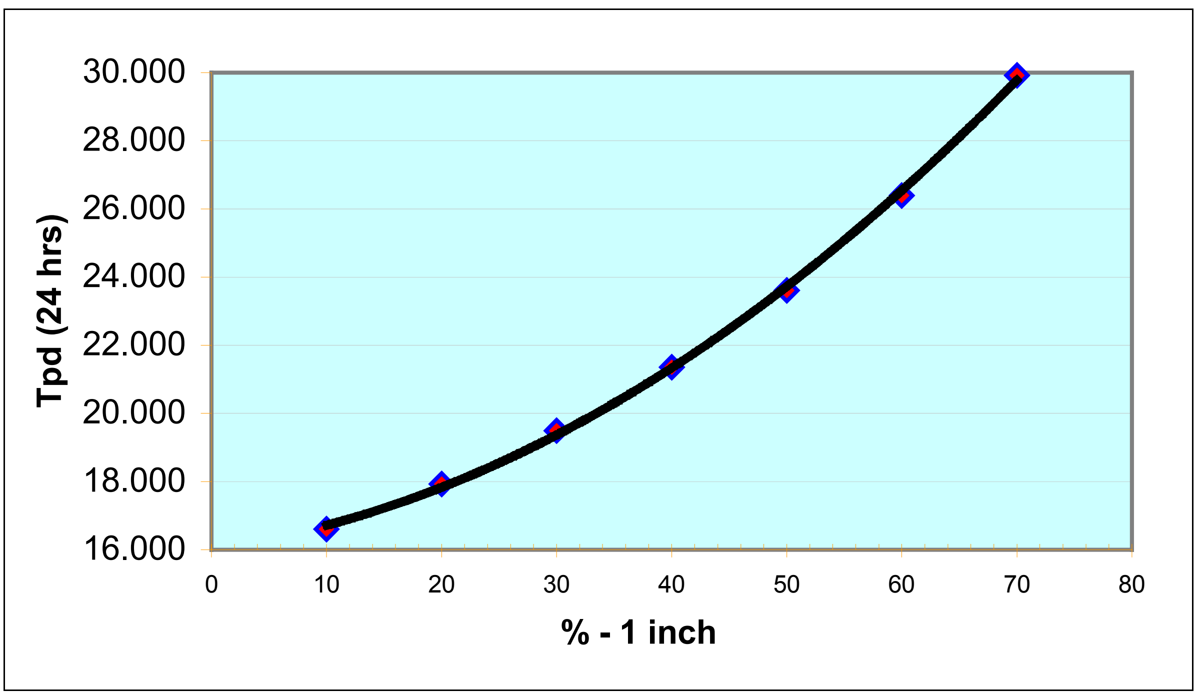
- Cambiando diámetro de bola usada en el molino SAG año 2004
- Proceso de prechancado año 2006

ESTUDIO DEL EFECTO DEL % DE FINO EN EL PROCESAMIENTO DE PLANTA SAG

Efecto del fino en el procesamiento SAG

En la dirección de modificar la granulometría de alimentación se realizó un estudio que ratifica lo observado en la práctica, en el sentido de que los mejores rendimientos (MTR/HR) y menor Consumo Específico de Energía se logran cuando en el mineral alimentado al molino SAG viene con una mayor presencia de finos.

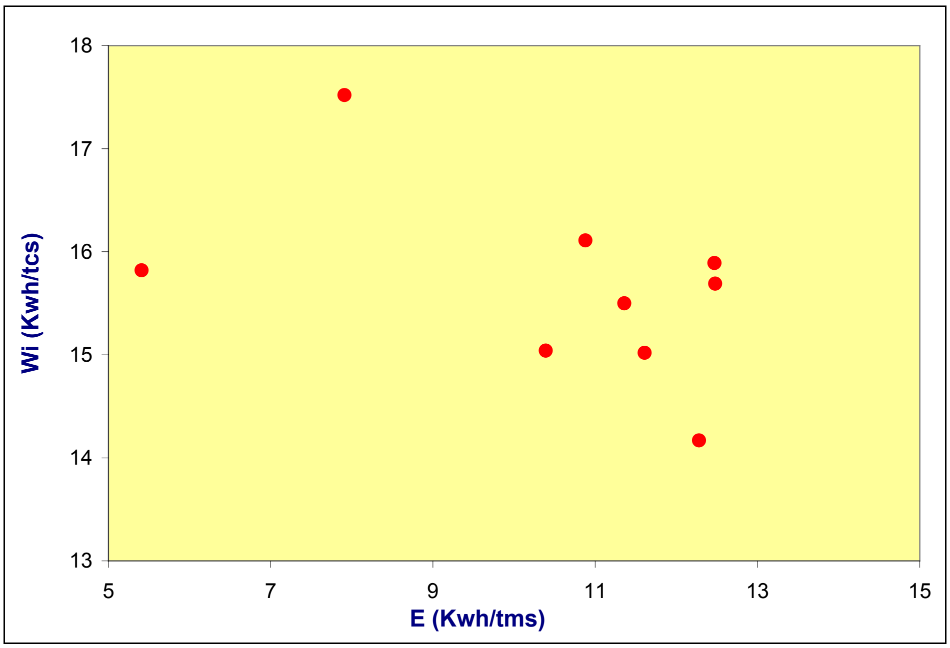
Concordante con lo anterior tomando el % de fino (partículas de mineral < 1 ") presentes en la alimentación al molino SAG se puede ver que, para aprox. 46% de fino, se logra procesar 23508 t/d, con 51 % se procesa 24150 t/d y con sobre 54% se llega a 26600 t/d



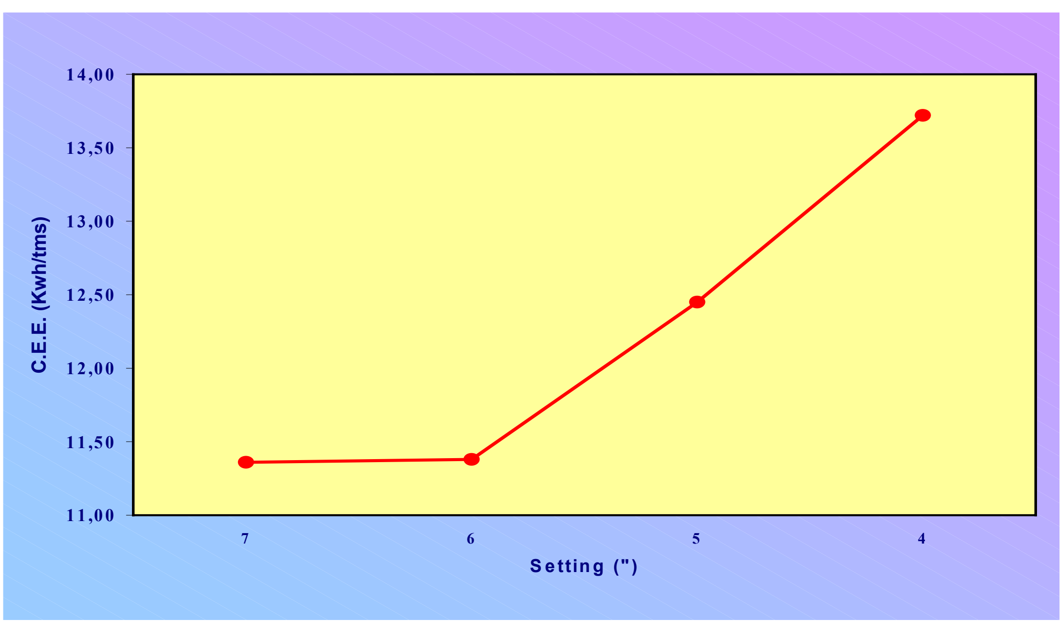
SECTORES ESTUDIADOS EN PRUEBA PILOTOS MOLIENDA SAG

Sector	Litología	C.E.E. (KWH/TMS)
Quebrada Tte.	Andesita Secundaria	5.63
Sub-6	Andesita Primaria	12.97
Esmeralda	Andesita Primaria-Brechas	11.03
Isla Martillo	Diorita Primaria	12.50

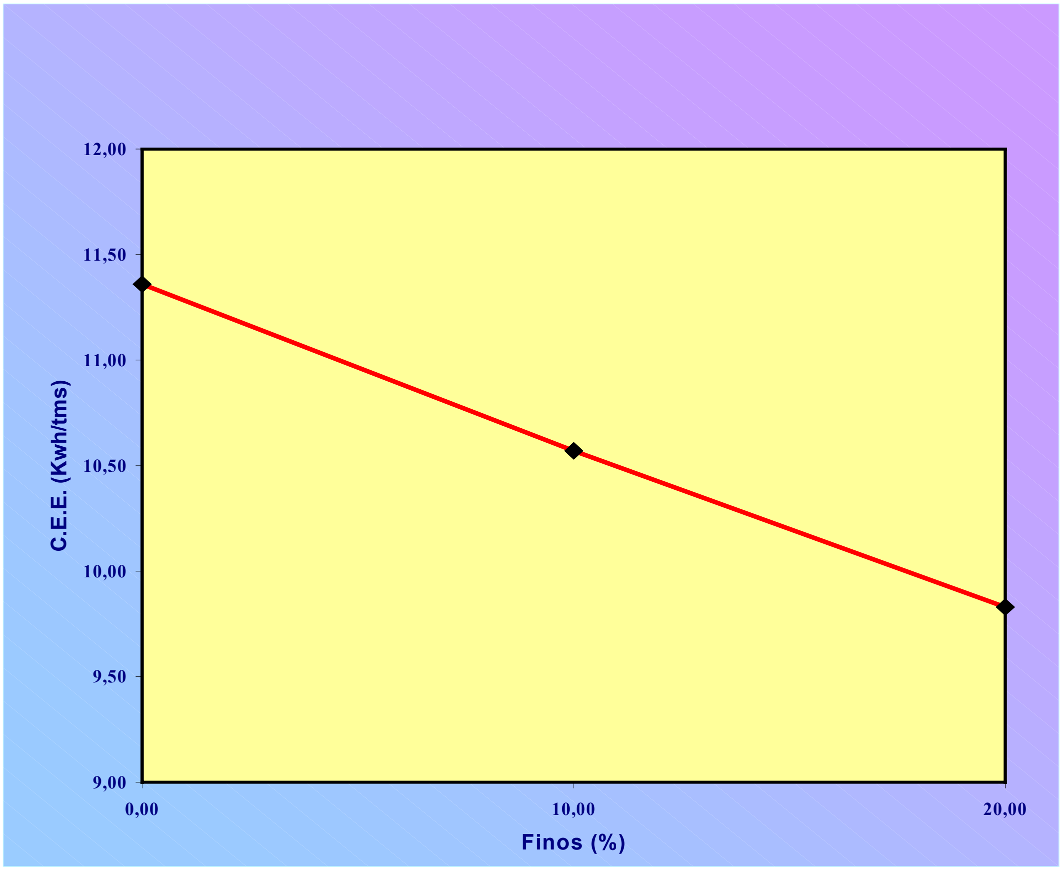
Relación C.E.E. SAG v/s Wi Bolas Bond



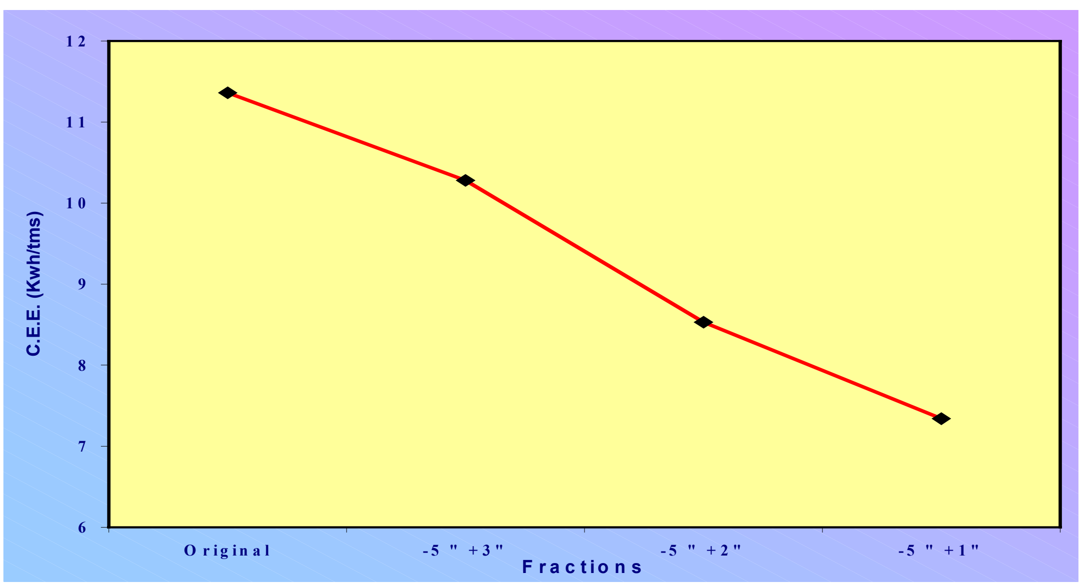
Variaciones del C.E.E SAG en función del setting del chancador primario



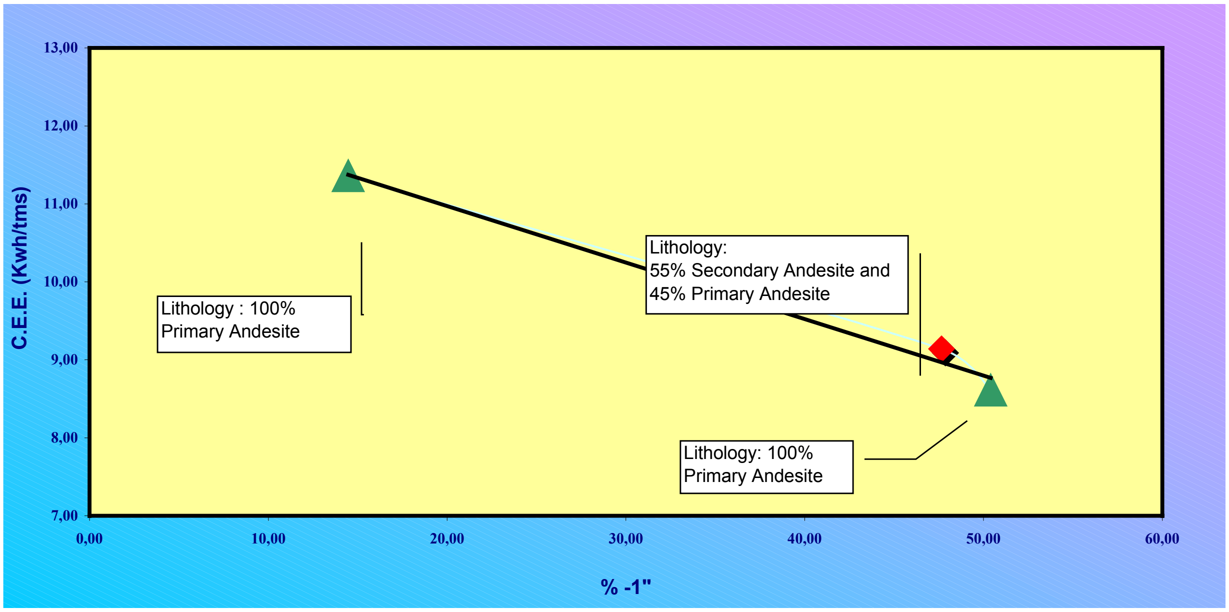
Variaciones del C.E.E SAG en función de la adición de finos



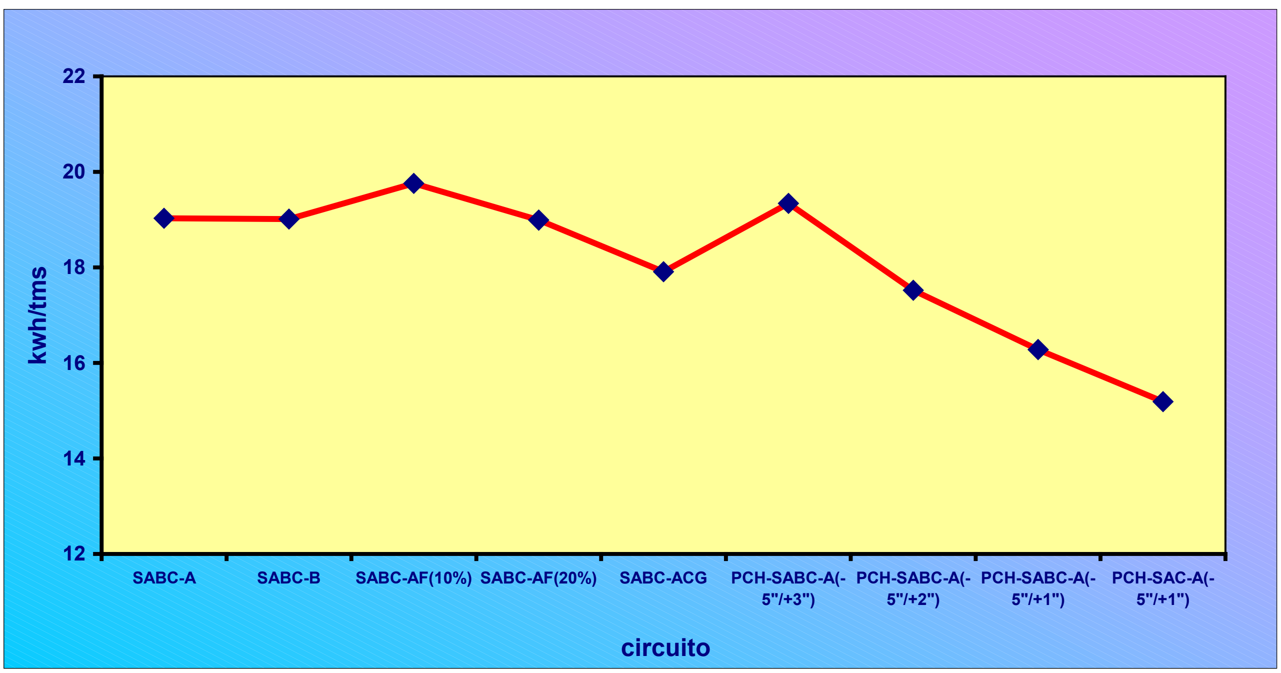
Variaciones del C.E.E SAG en función de la fracción intermedia chancada



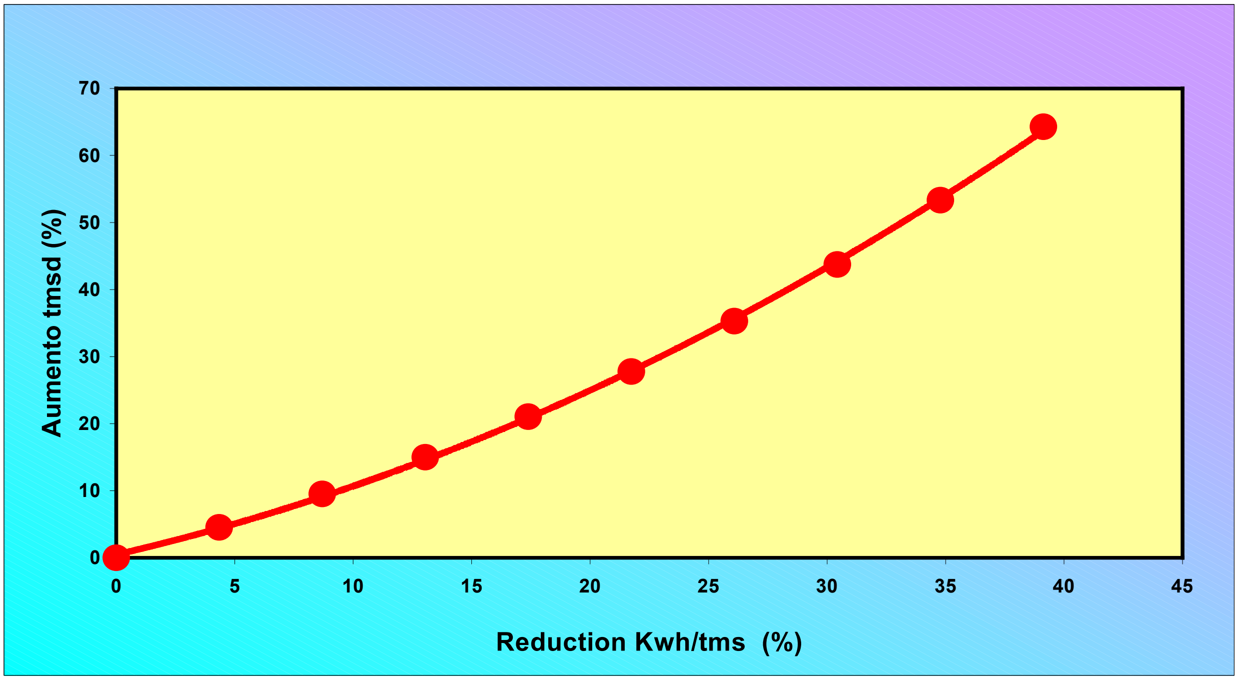
Variaciones del C.E.E SAG en función del perfil granulométrico y tipo de mezcla de mineral



Consumo específico de energía en circuitos alternativos para un producto de 20 %+100



Relación de disminución de e (%) v/s aumento de tonelaje (%)



Conclusiones

El perfil granulométrico de alimentación a la etapa de molienda SAG, es la variable de mayor incidencia en el rendimiento energético y metalúrgico del proceso.

El incremento porcentual de material fino (fracción -1") en la distribución granulométrica de alimentación, minimiza considerablemente el consumo especifico de energía en el molino SAG, aumentando significativamente su tasa de procesamiento dependiendo del criterio utilizado, para incrementar la presencia de finos en la granulometría de alimentación SAG. Es posible, para una misma mezcla litológica, disminuir el consumo especifico de energía entre 11% y un 35%.

De todos los criterios estudiados para la modificación del perfil granulométrico original, el más atractivo resulta ser, el que considera una etapa de pre-chancado de la fracción intermedia -6" /I +1".

Para mezclas litológicas de diferentes características de moliendabilidad SAG, es posible equiparar los consumos específicos de energía, y en consecuencia sus tasas de procesamiento, al procesar idénticas distribuciones granulométricas en la alimentación al molino SAG. En este caso particular, el Wi de bolas de Bond, usualmente utilizado en la etapa SAG para fundamentar mayores o menores durezas de los minerales procesados, no presenta ninguna correlación con el consumo específico de energía en esta etapa de molienda, por lo cual su utilización debe ser descartada con fines de dimensionamiento y calculo de tasas de procesamiento.

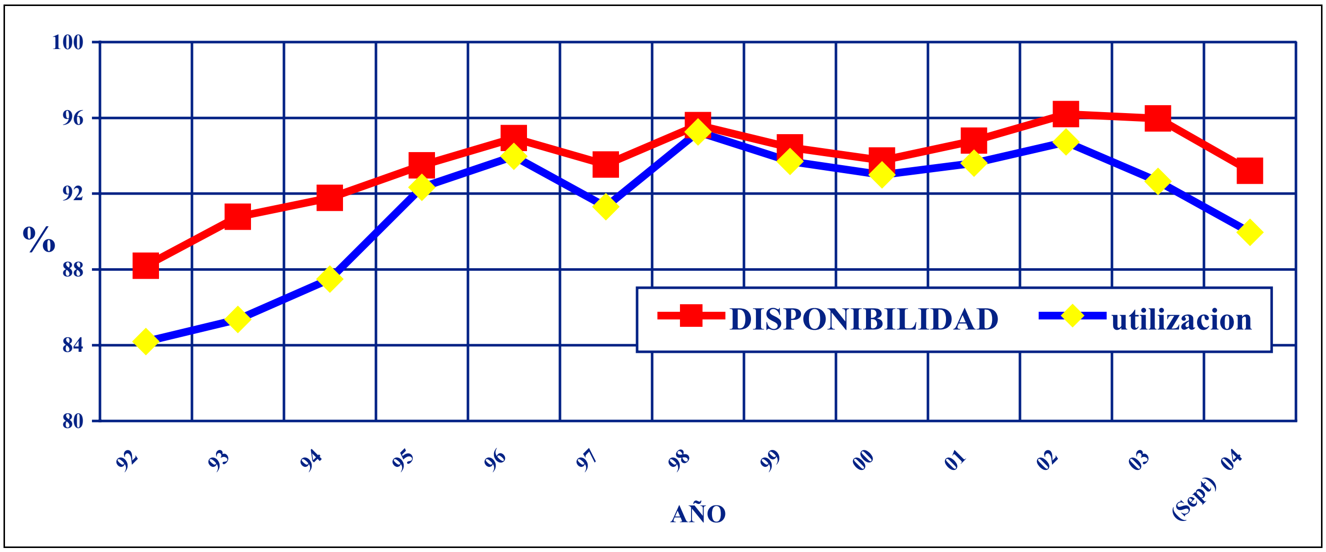
A la luz de los resultados obtenidos en el presente estudio, se hace imprescindible considerar en el diseño de pruebas piloto de molienda SAG, explorar el efecto de la variación del perfil granulométrico, además de las variables tradicionalmente estudiadas como son: velocidad critica del molino, abertura de tromell, numero de rock-port abiertos, configuración de circuitos, nivel de llenado de bolas, etc.

EXPERIENCIAS DE MANTENCIÓN

Disponibilidad planta SAG

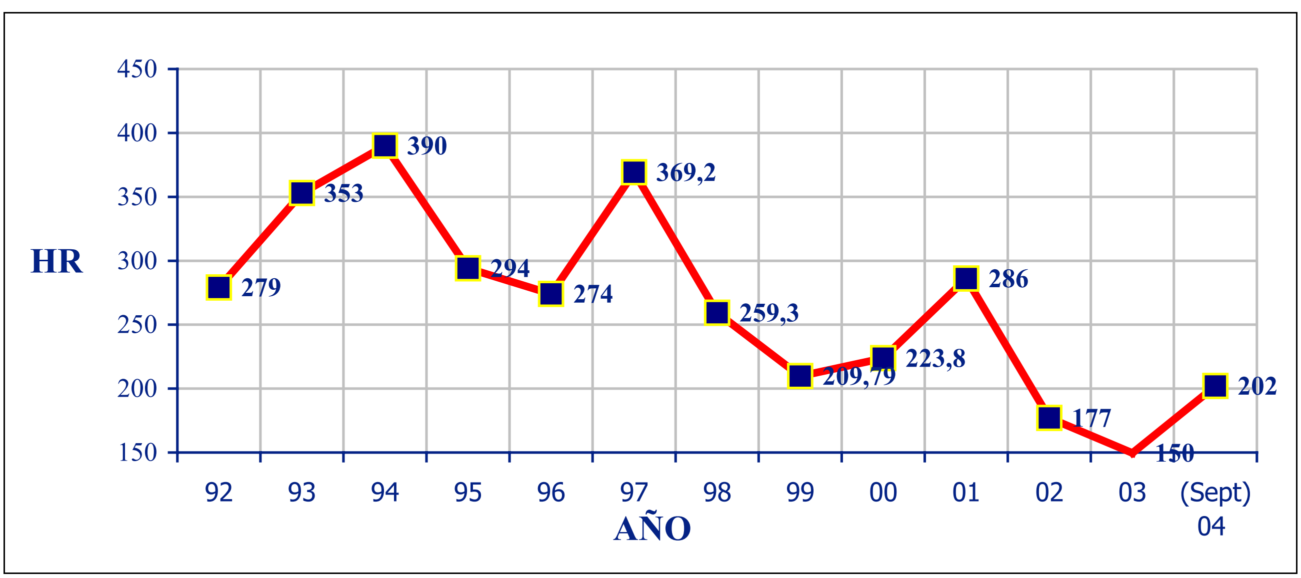
La disponibilidad de la planta SAG Teniente ha ido aumentando hasta alcanzar un 96.2 % el año 2002. La baja experimentada en el año 2004 se debe a la quebradura de lainas en el anillo nº 3 de la tapa de descarga producto de falla en la fabricación.

Debido a una buena gestión operativa, se ha logrado llevar la utilización a valores muy cercanos a la disponibilidad. La baja experimentada en los años 2003 se debe principalmente a interferencias con el proyecto ACB y en el año 2004 a la falta de mineral (debido a atrasos en el ACT) y por falta de agua en los meses de invierno por aluviones en bocatomas.



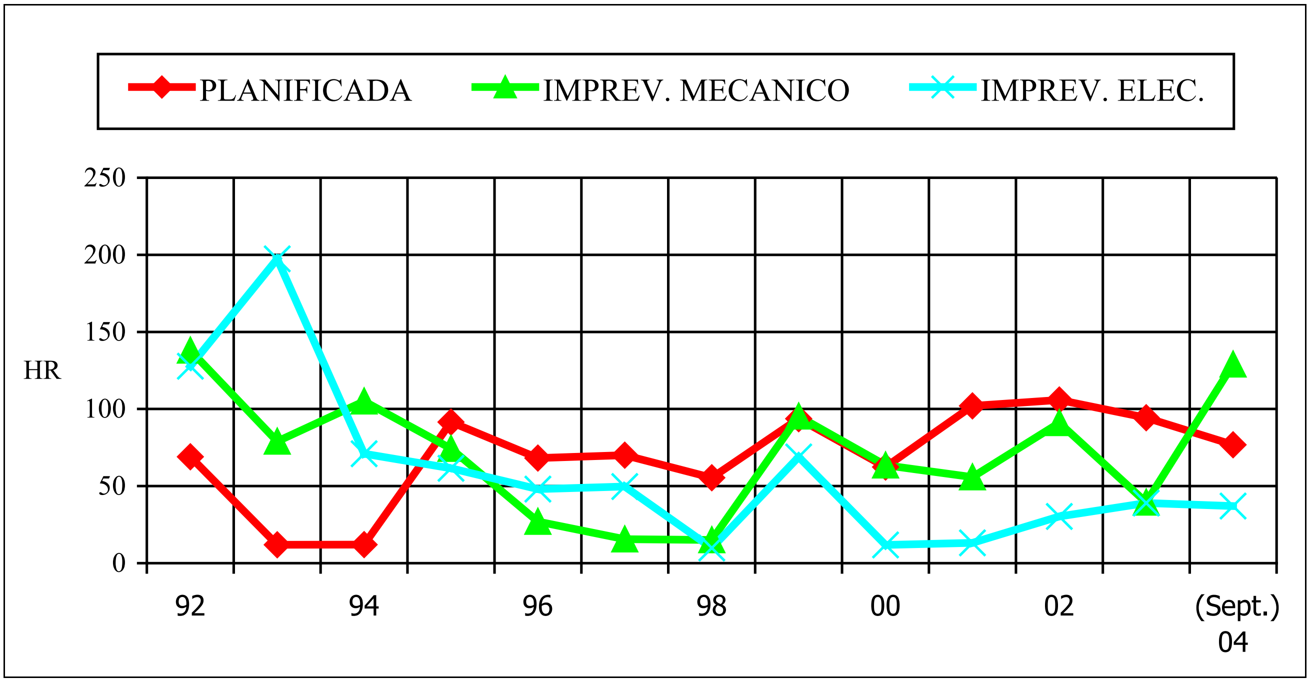
Mantención planificada para cambio de revestimientos

Salvo el aumento experimentado en el año 1997 por el problema de fabricación de los pulp filters, los tiempos ocupados en el cambio de revestimiento han ido bajando paulatinamente.



Mantenciones planta SAG

El aumento de las horas de mantención imprevista observado en el año 2004 se debió a una serie de detenciones provocadas por quiebre de lainas del anillo Nº 3 de la etapa de descarga por falla en la fabricación de éstas.

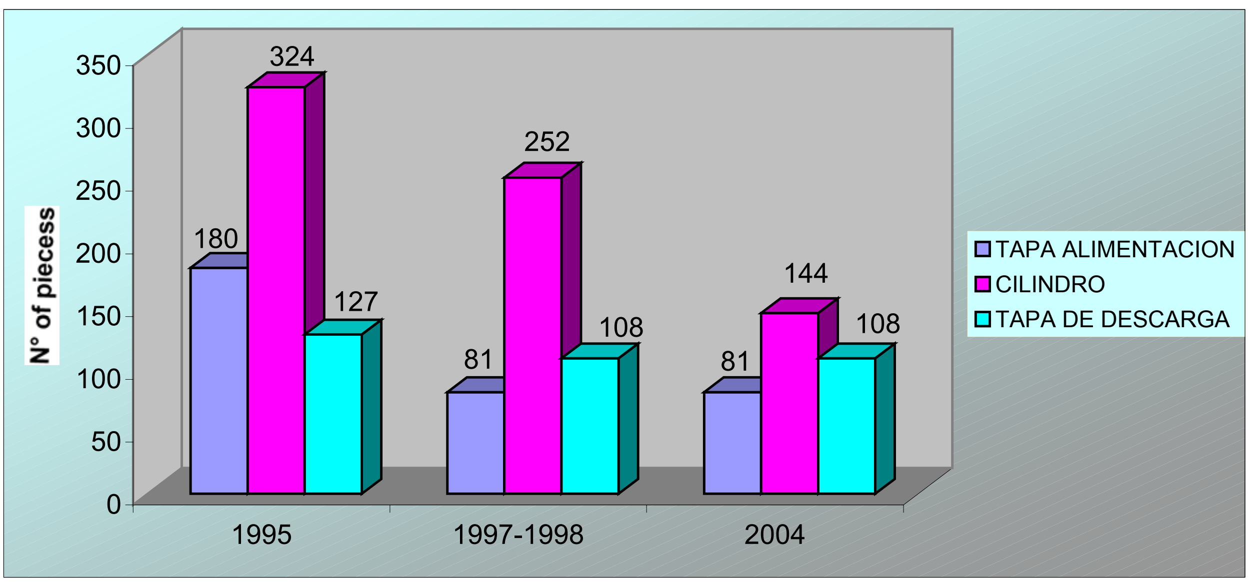


Razones de la mejora de la disponibilidad

- Por intervención en Molinos
  - Racionalización de revestimientos
    - Cambio de perfiles de desgaste
    - Cambio diseño anillo 1 tapa descarga acero a goma
    - Cambio diseño anillo 1 tapa alimentación, acero a goma
    - Eliminación de un anillo tapa alimentación
    - Eliminación de un anillo lifters tapa alimentación
    - Eliminación cono descarga
    - Eliminación de un anillo de lifters en el cilindro
    - Disminución de 18 a 9 lainas anillo 2 tapa descarga
    - Disminución de 18 a 9 pulp lifters anillo 2 descarga
    - Estandarización de pernos
    - Cambio de slot parrillas de descarga SAG
    - Eliminación de lifters en anillo Nº 1 en tapa alimentación y descarga
    - Eliminación de filas de lifters en cilindro de 72 a 36
    - Eliminación de un anillo de placas en el cilindro (de 3 a 2)
    - Aumento en un 20% red de evacuación pulp-lifters anillo 1
    - Se aumenta hasta 30 mm espesor goma de recubrimiento pulp- lifters

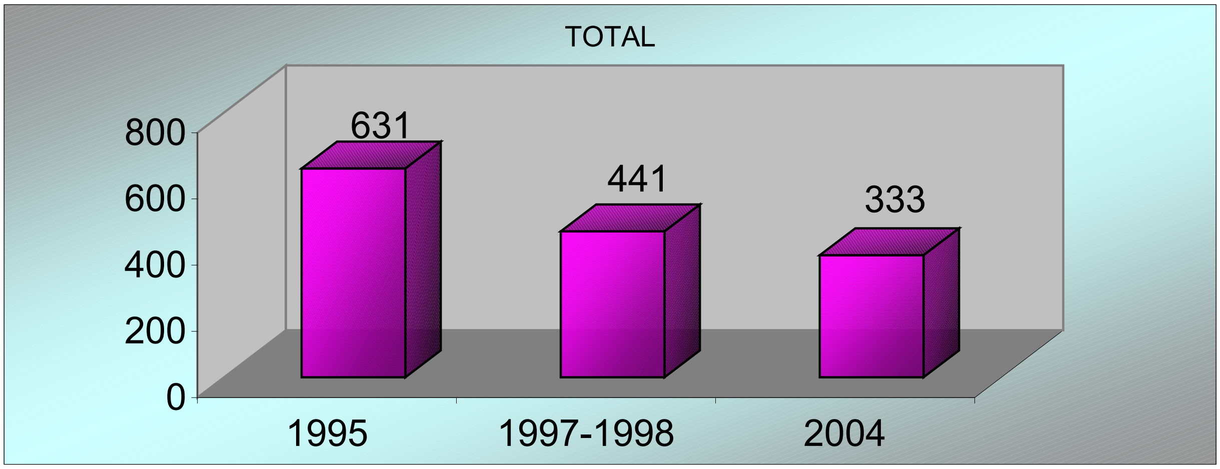
- Traspaso pulp lifters importados a nacionales
- Cambio diseño trommel
- Instalación monorriel alimentador lainas SAG
- Compra de simulador de lainas (estadio)
- Por intervención en Planta
    - Implementation de harnero stand by
    - Instalación de segundo chancador de pebles
    - Instalación de compuertas hidráulicas cambio harneros
    - Cambio válvulas pinch por cuchilla
    - Estandarización y modificación cañerías transporte pulpa
    - Cambio diseño harnero, bombas, chutes, correas, etc.
    - Estrategias de control de la planta
    - Comunicación expedita Operación - Mantención
    - Planificación detallada de detenciones planta
    - Cambio sistema resortes harnero
    - Estandarización de válvulas 20" y bifurcaciones

Racionalización revestimiento molino SAG



Disminución de elementos

Debido a las modificaciones que hemos realizado en lo referente al revestimiento, el Nº de piezas ha disminuido de 631 en el año 1998 a 441 en la actualidad. A futuro pensamos llegar a 33 unidades.



Planificación de la mantención

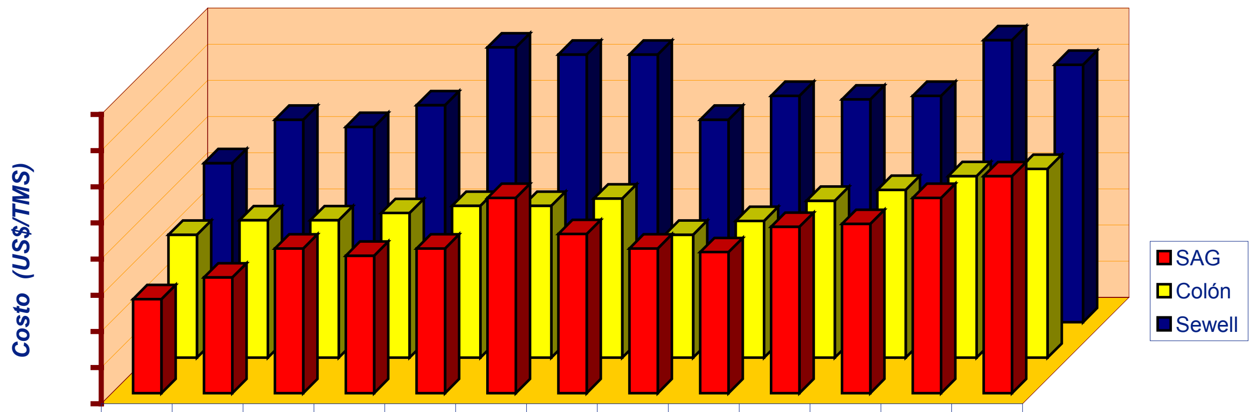
- Planificación en la planta
- Carta gantt antes de cada mantención
- Programas anuales de cambio de revestimientos
- Sistema de control de perdidas
- Control de equipos principales en planta
- Trabajos envergadura externalizados
- Utilización de contratos marcos
- Consignaciones y convenios de repuestos
- Archivo electrónico de planos
- Estandarización de repuestos
- Uso del sap

Planes de desarrollo

- Eliminar la mitad de las filas de los lifters del cilindro
- Eliminar un anillo de lainas de la tapa de descarga
- Modernización del control eléctrico del molino
- Prechancado
- Pebles en circuito abierto con el PDT
- Harnero doble deck
- Consignación de repuestos
- Desarrollo del personal
- Especificaciones comunes repuestos e insumos
- Establecer alianzas estratégicas con proveedores
- Planes futuros considerando impacto ambiental

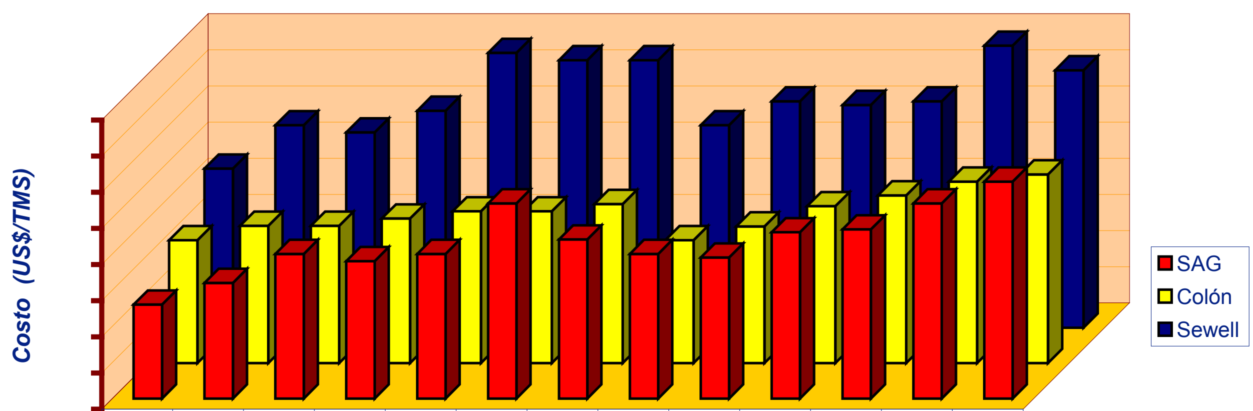
Resultados globales de la Gerencia por sistemas de reducción de tamaño
(Chancado Secundario- Terciario y Molienda)

Costos



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004 (Sep)
SAG	1,3	1,6	2,0	1,9	2,0	2,7	2,2	2,0	2,0	2,3	2,3	2,7	3,0
Colón	1,7	1,9	1,9	2,0	2,1	2,1	2,2	1,7	1,9	2,2	2,3	2,5	2,6
Sewell	2,2	2,8	2,7	3,0	3,8	3,7	3,7	2,8	3,1	3,1	3,1	3,9	3,6

Consumos de energía



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004 (Sep)
SAG	1,3	1,6	2,0	1,9	2,0	2,7	2,2	2,0	2,0	2,3	2,3	2,7	3,0
Colón	1,7	1,9	1,9	2,0	2,1	2,1	2,2	1,7	1,9	2,2	2,3	2,5	2,6
Sewell	2,2	2,8	2,7	3,0	3,8	3,7	3,7	2,8	3,1	3,1	3,1	3,9	3,6

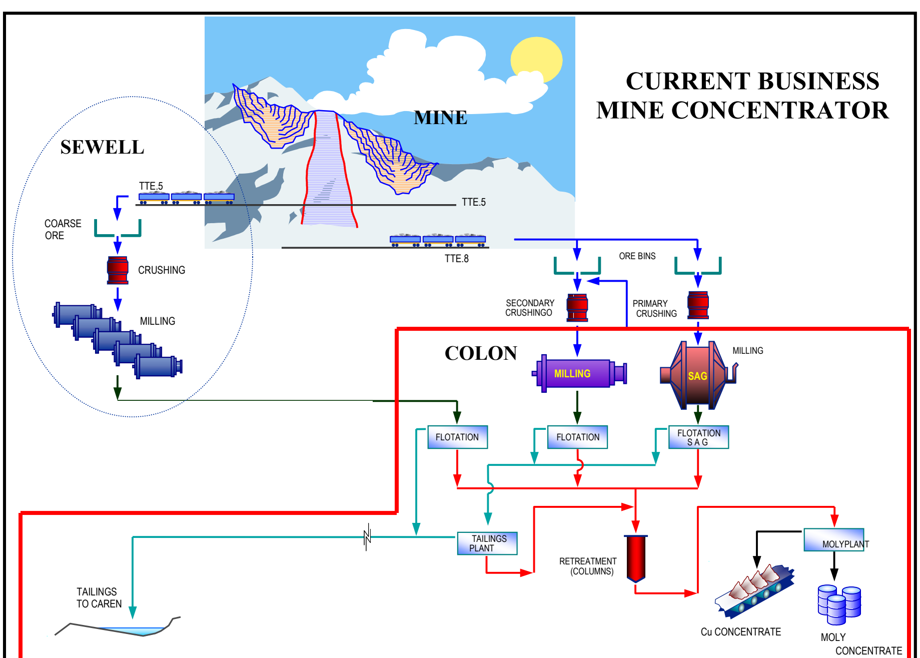
OPERATING AND MAINTENANCE TENIENTE SAG MILL Nº 1.

October 2004

PLANT MANAGEMENT

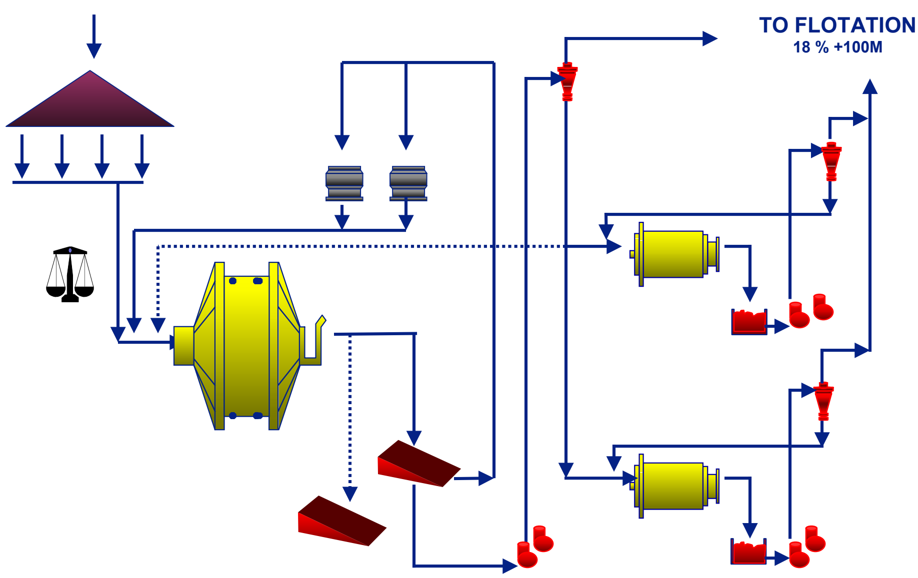
SAG UNIT


18 11 2003


CURRENT BUSINESS
MINE CONCENTRATOR
MINE
SEWELL
TTE.5
TTE.5
COARSE
ORE
CRUSHING
MILLING
TTE.8
ORE BINS
SECONDARY
CRUSHINGO
PRIMARY
CRUSHING
COLON
MILLING
SAG
MILLING
FLOTATION
FLOTATION
FLOTATION
S A G
TAILINGS
PLANT
RETREATMENT
(COLUMNS)
MOLYPLANT
TAILINGS
TO CAREN
Cu CONCENTRATE
MOLY
CONCENTRATE

TENIENTE GRINDING SAG PLANT.

FLOW CHART



OPERATING EXPERIENCES

SAG MODULE, PROCESING RATE

TP = P x U x 24 / E

where :

TP = **Processing rate (tmsd)**

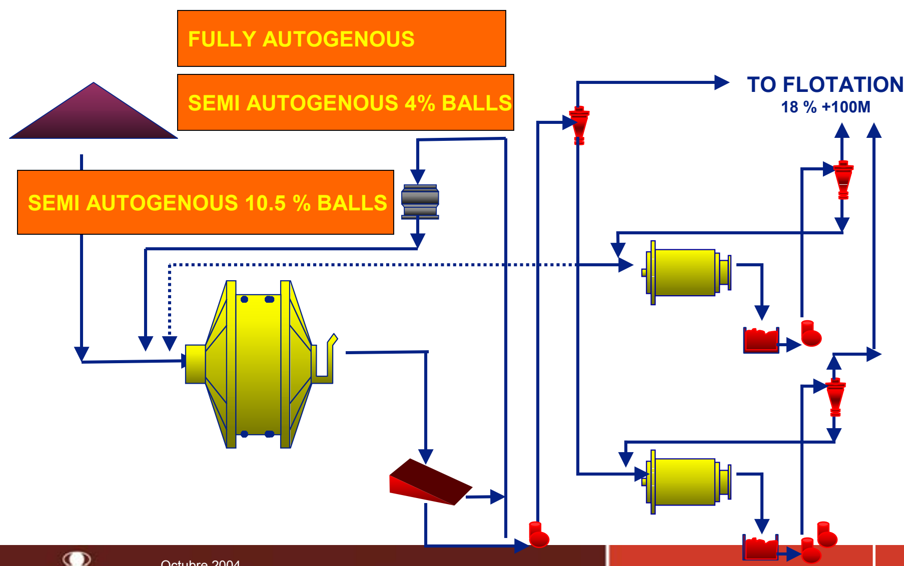
P = **Power Draw (Kw)**

U = **Utilization SAG mill (%/1)**

E = **Energy specific consumption (Kwh/tms)**

ALTERNATIVES EVALUATION

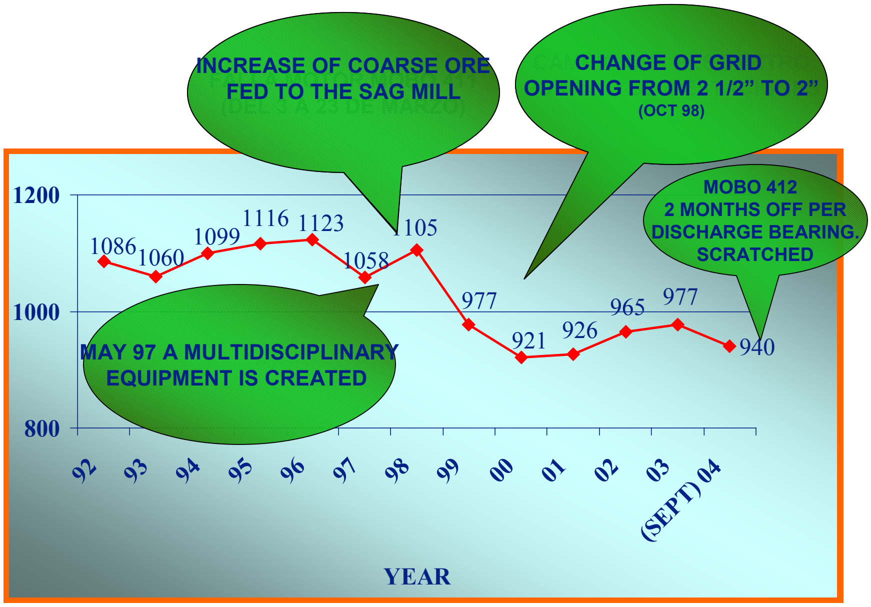
(AUGUST 15 TO DECEMBER 30, 91)



RESULTS

	POWER (KW)		KWH/TMS			
LEVEL	SAG M.	BALLS M.	SAG M.	BALLS M.	TMS/HR	F 80 SAG
FULL AUTOG.	7095	3810	19,0	10,3	381	81283
SEMI AUT. 4%	8474	4204	12,3	6,0	700	53065
SEMI AUT.10.5%	10621	4232	8,9	7,4	1193	87871
SEMI AUT.12,3%	10998		11,3	8,0	976	108540

RATE (TMS/HR)



SAG F-80 VARIATION

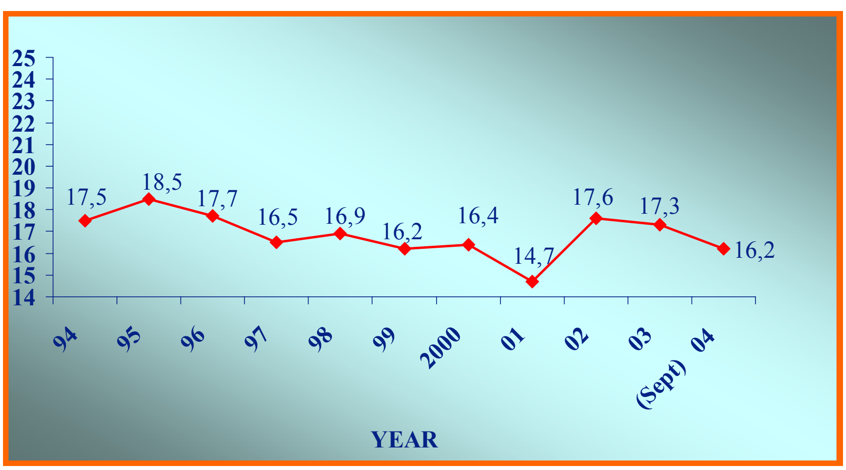
OPERATING PARAMETERS

% OF + 100 MESHES

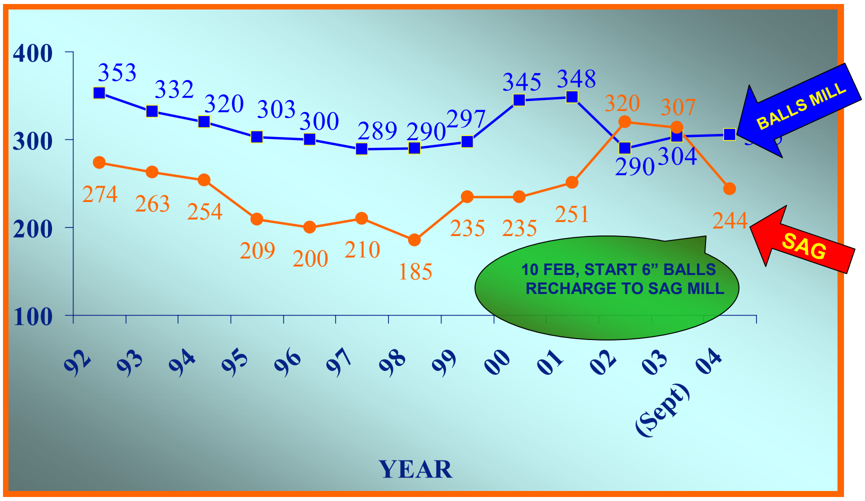
BALLS CONSUMPTION
- SAG MILL
- BALLS MILL

POWER CONSUMPTION

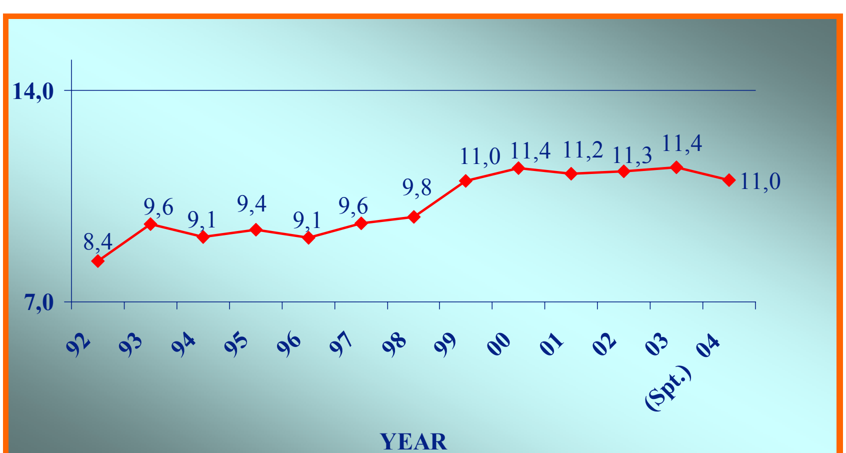
+ 100 MESHES (%)



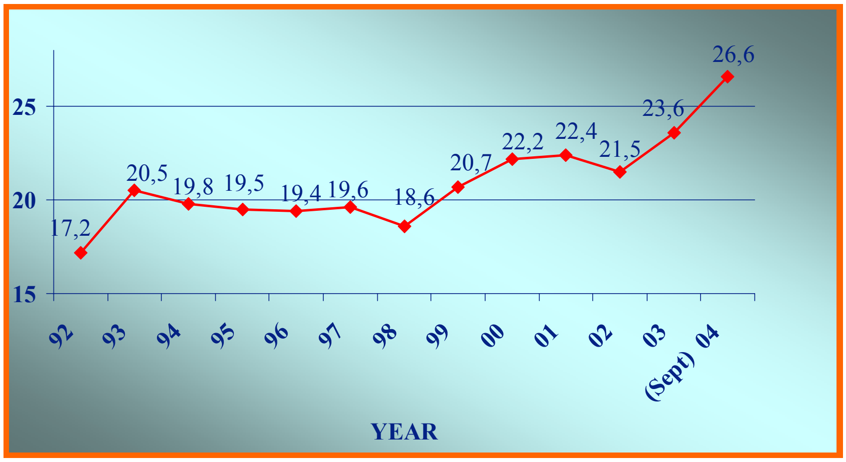
BALLS CONSUMPTION GR/TON



POWER CONSUMPTION (KWH/TMS)



PLANTA POWER CONSUMPTION (KWH/TMS)



Wi (kWh/Tcs)

OPERATION MANAGEMENT
MAIN INDICATORS

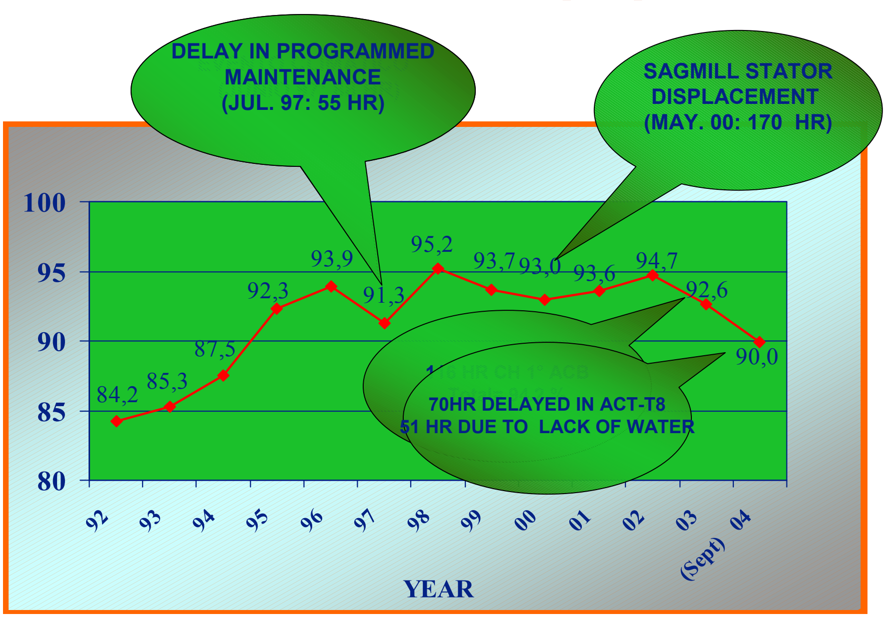
UTILIZATION PERCENTAGE

COSTS

ACCIDENTS FREQUENCY RATE

PRODUCTIVITY

UTILIZATION (%)



UTILIZACION IMPROVEMENT CAUSES

MODIFICATION OF TRANSFER CHUTES DUE TO NON SUITABLE DESIGN (Discharge area is increased)

MODIFICATION OF SAG FEEDING CHUTE (Transfer area is increased)

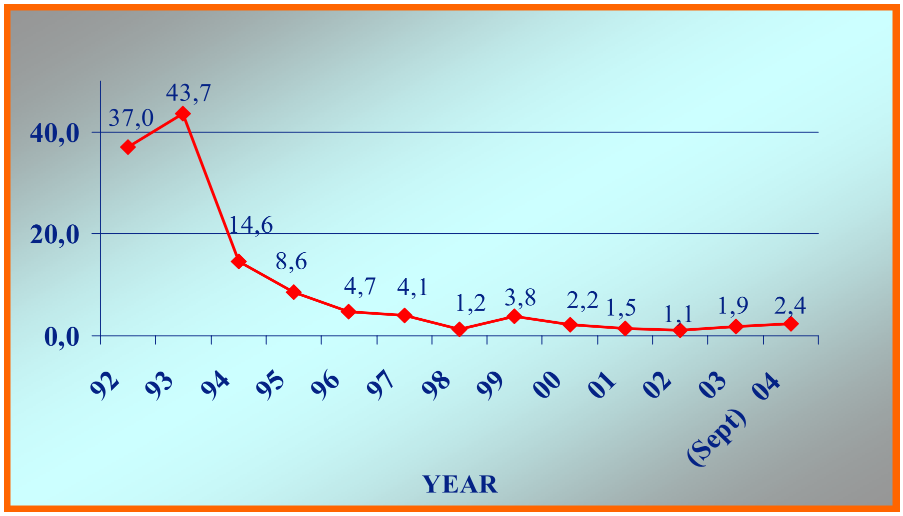
MODIFICATION OF TRANSFER BELTS DESIGN(Grater power motors and higher capacity belt conveyors)

DESIGN MODIFICATION OF EMERGENCY CABLE STOP SYSTEM

(Defenses over cable are installed, to avoid the stop action of falling stones)

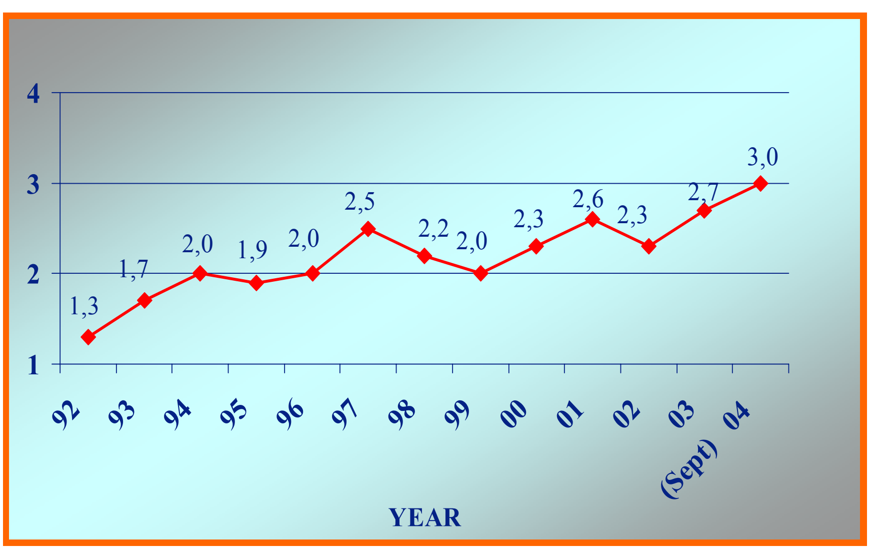
PLANT SHUT DOWN HOURS DUE TO TRANSFER CHUTES AND BELTS OBSTRUCTIONS

PLANT SHUT DOWN HOURS DUE TO SAFETY CABLES OPERATION

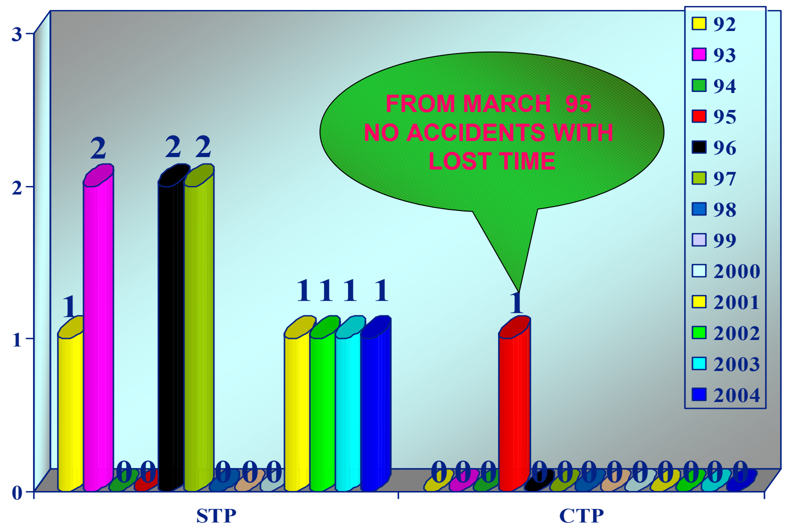


SAG PLANT COSTS

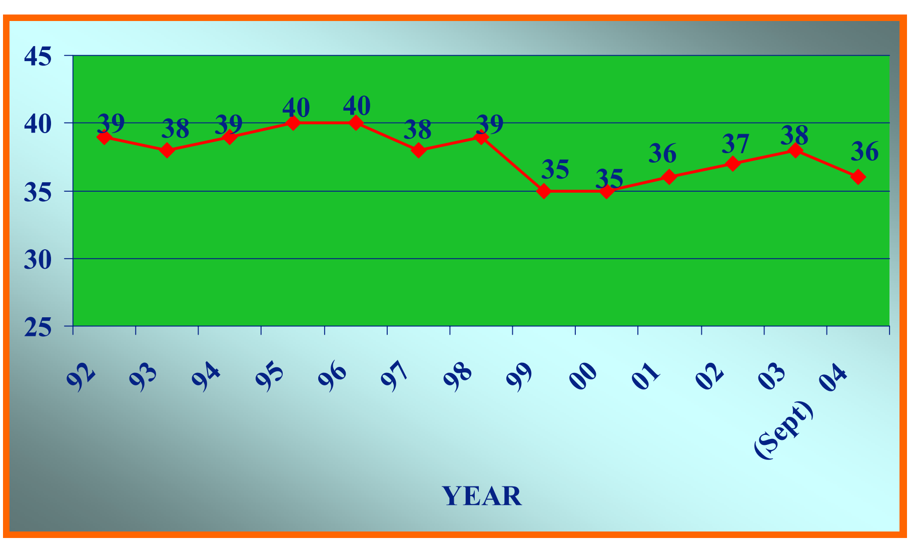
(US$/MTS MILLED)



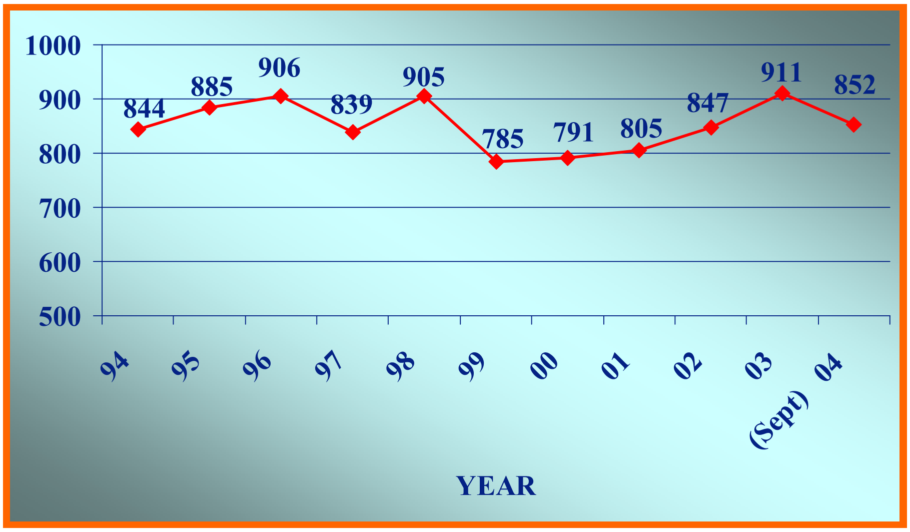
ACCIDENTS PER YEAR



PRODUCTIVITY
(MTSHR/H REGISTERED)



PRODUCTIVITY
(MTS DAY/H REGISTERED)



OPERATION STRATEGY

MAXIMUM TONNAGE TREATMENT

MILL OPERATION FILLING LEVEL (26 TO 30% FILLING)

MAXIMUM SPEED (10.3 RPM)

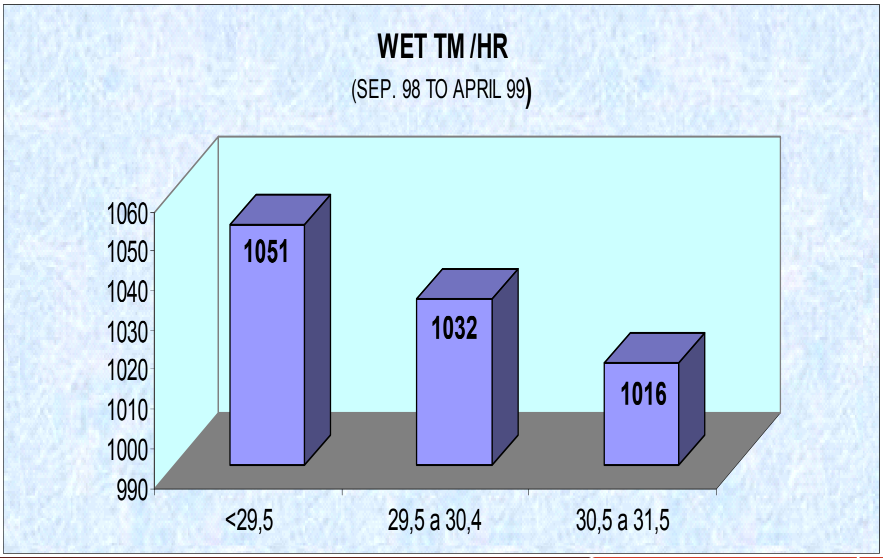
WITH FEED SOLIDS % AS LOW AS ALLOWED BY RECIRCULATION

USING THE “SUPERSAG” EXPERT CONTROL SYSTEM

IMPROVED FINAL PRODUCT

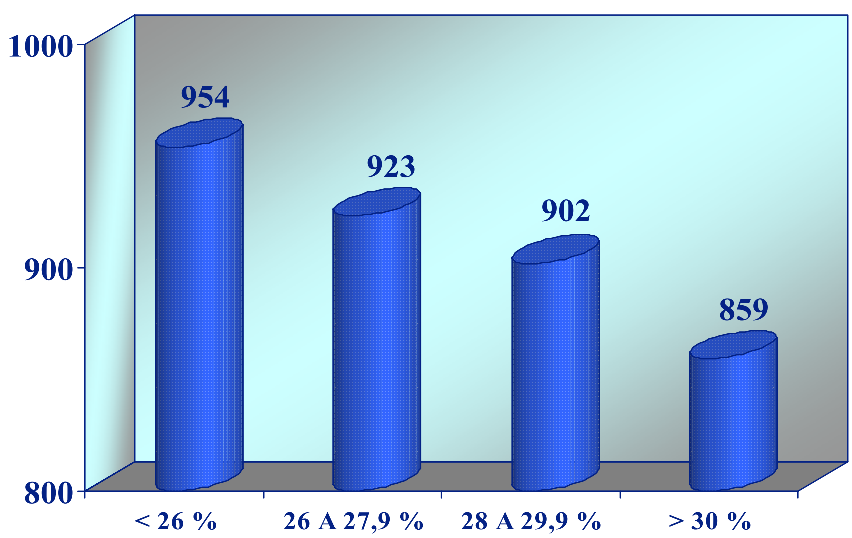
P 80 147 MICRONS

EFFICIENCY V/S FILLING LEVEL



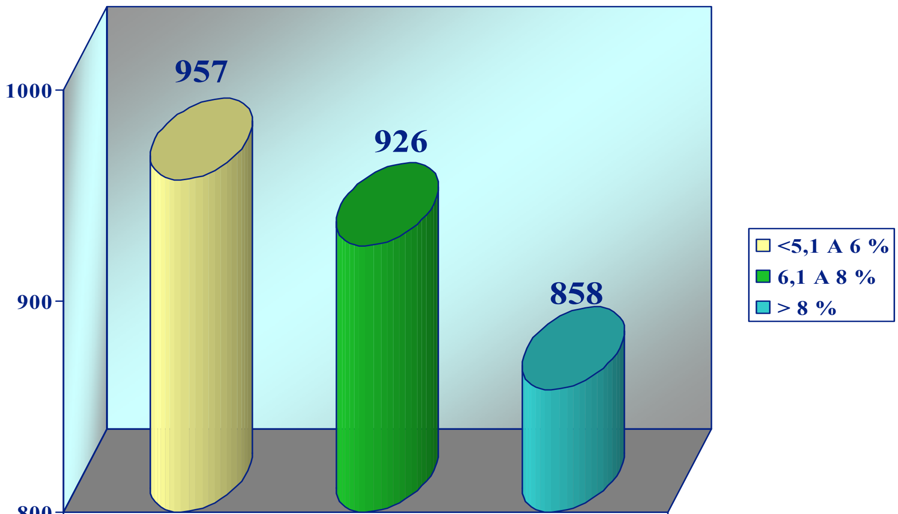
EFFICIENCY V/S FILLING LEVEL

(JANUARY TO OCTOBER 2000)



EFFICIENCY V/S COARSE %

(JANUARY TO OCTOBER 2000)



¿HOW TO REVERT A LOW EFFICIENCY SITUATION?

- **CHANGING THE BALL DIAMETER**

  RECHARGING 6" BALLS

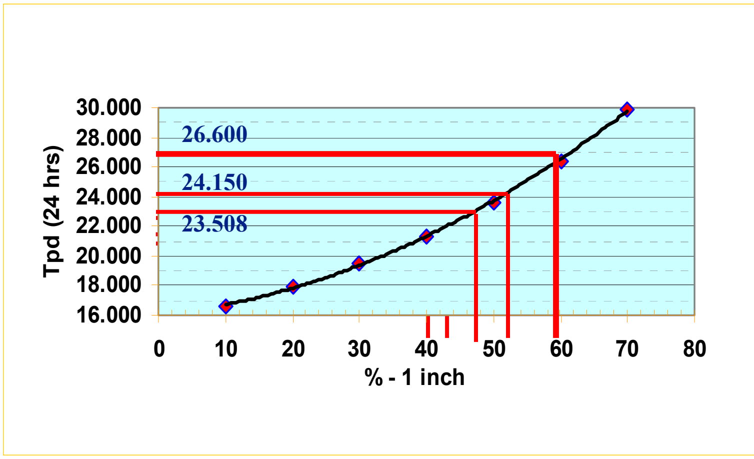
  IMPLEMENTATION DATES YEAR 2.004

- **FEED SIZE DISTRIBUTION MODIFICATION**

  PRE-CRUSHING PROCESS

  IMPLEMENTATION DATES YEAR 2.006

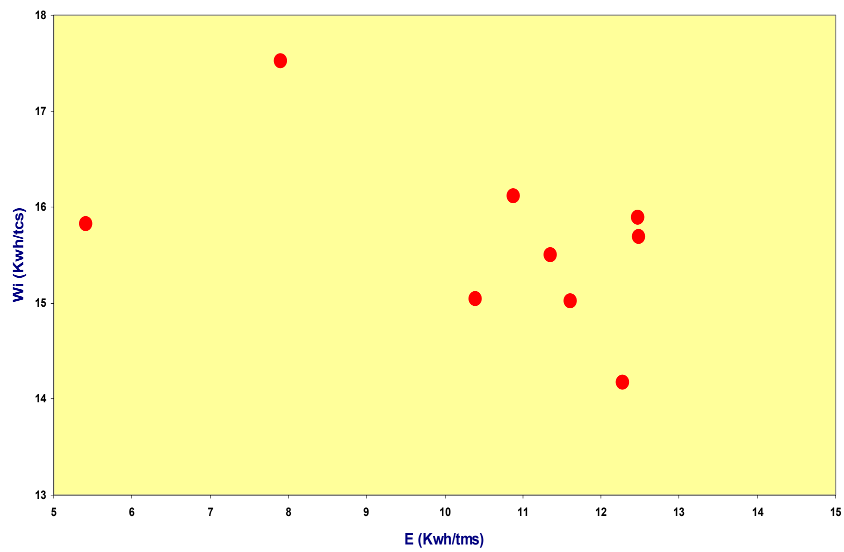
FINE % EFFECT ON SAG PLANT PROCESSING ANALYSIS



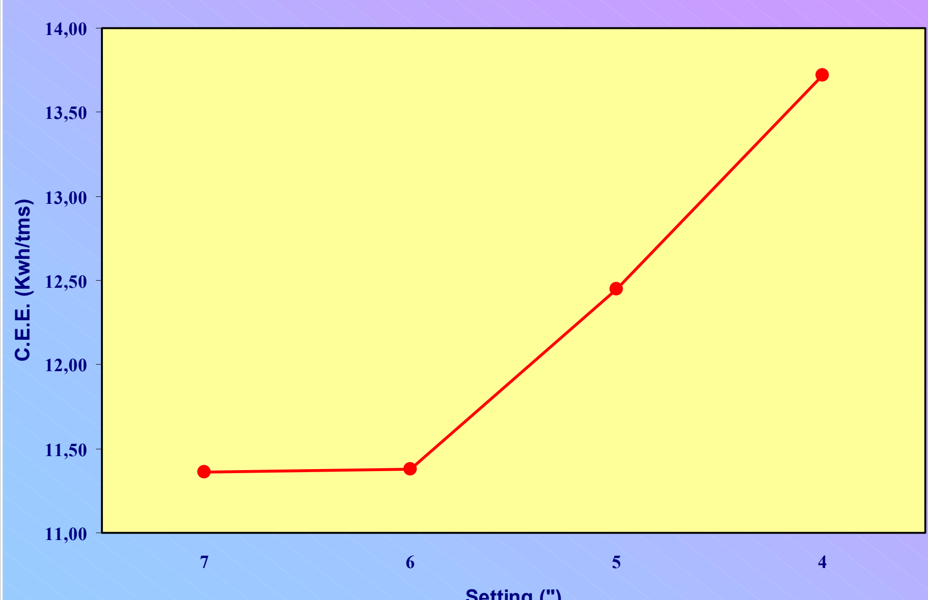
MINE SECTORS STUDIED IN SAG GRINDING PILOT TESTS

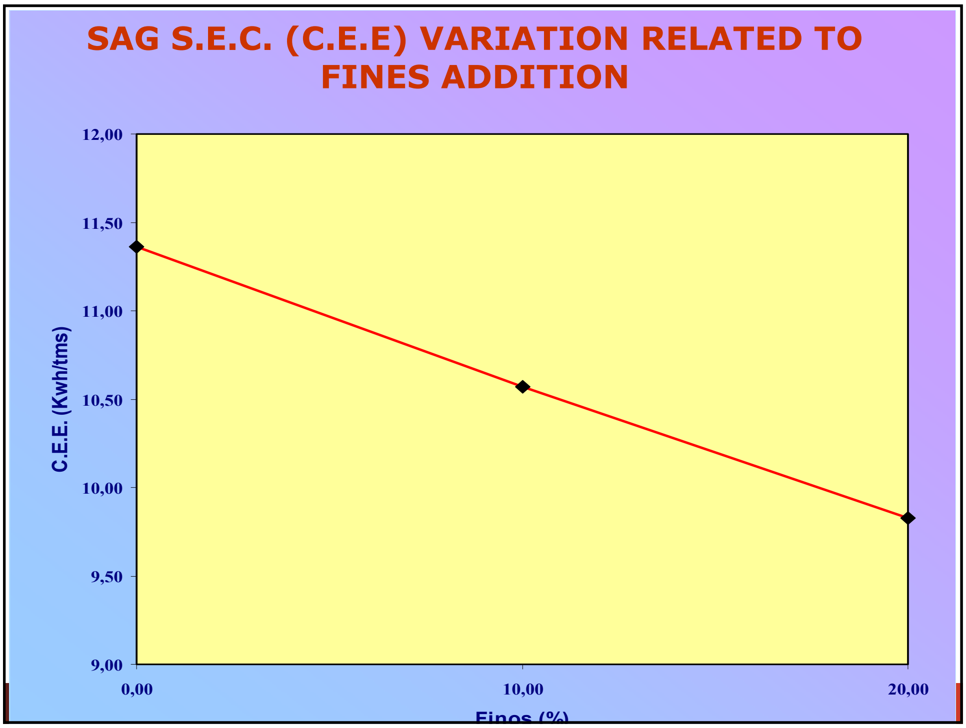
SECTOR	LITHOLOGY	C.E.E (KWH/TMS)
QUEBRADA TENIENTE	SECONDARTY ANDESITE	5,63
SUB-6	PRIMARY ANDESIT	12,97
ESMERALDA	PRIMARY ANDESITES-BREACHES	11,03
ISLA MARTILLO	PRIMARY DIORITE	12,50

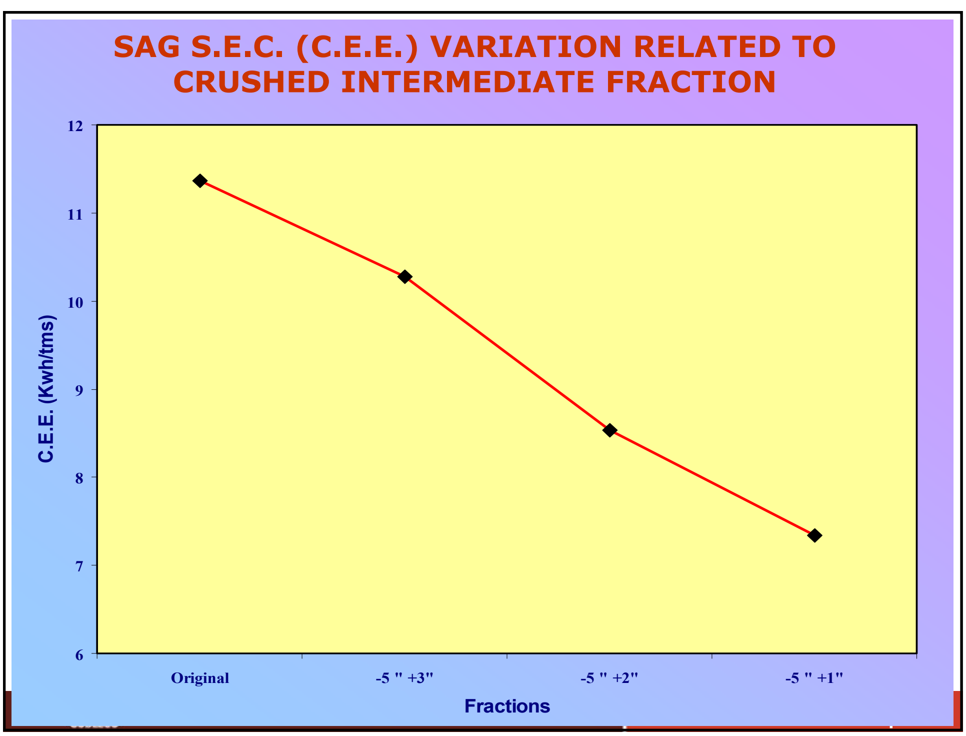
RELATION S.E.C. SAG V/S BOND BALL Wi

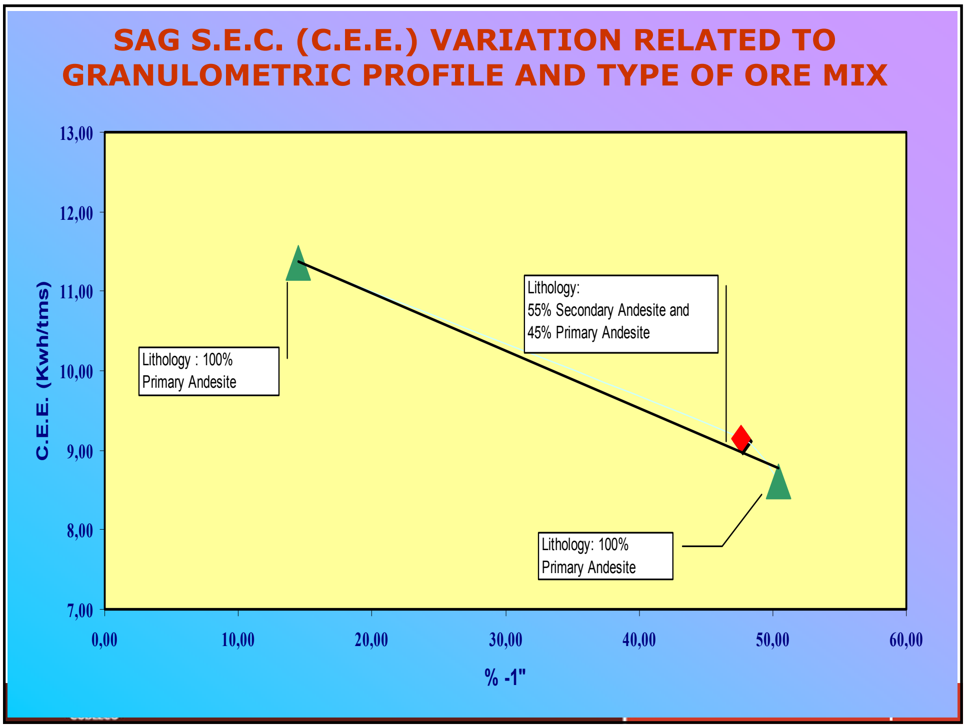


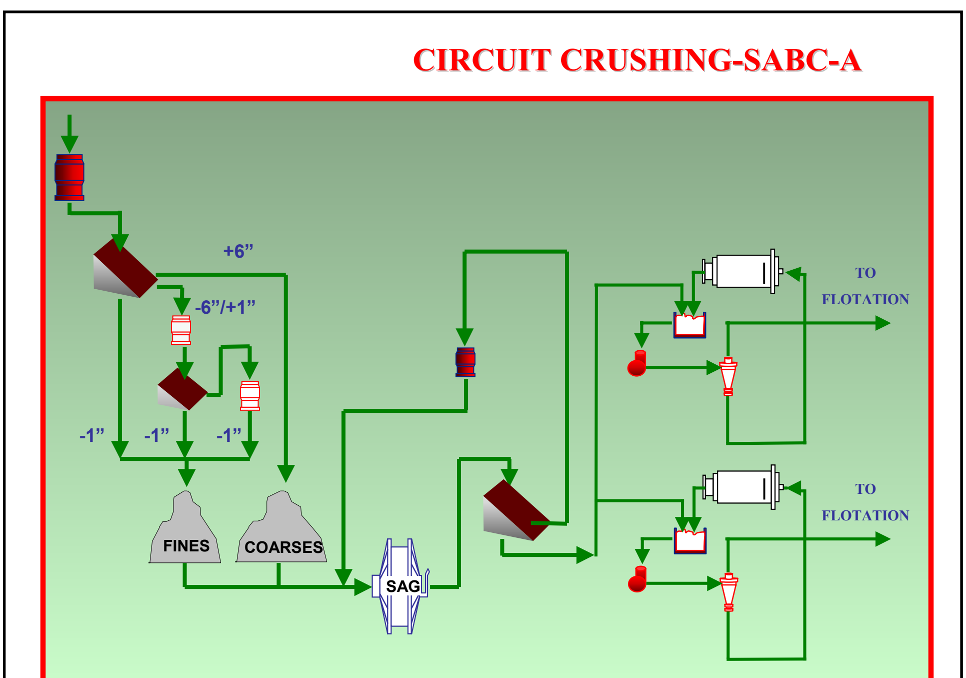
SAG S.E.C. (C.E.E) VARIATION RELATED TO PRIMARY CRUSHER SETTING



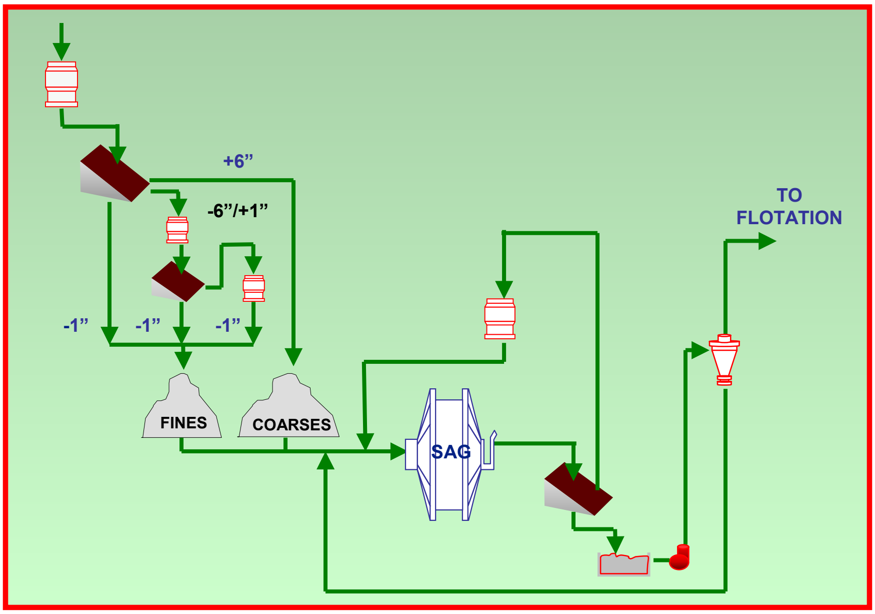

SAG S.E.C. (C.E.E) VARIATION RELATED TO FINES ADDITION
12,00
11,50
11,00
10,50
10,00
9,50
9,00
C.E.E. (Kwh/tms)
0,00
10,00
20,00
Finos (%)


SAG S.E.C. (C.E.E.) VARIATION RELATED TO CRUSHED INTERMEDIATE FRACTION
12
11
10
9
8
7
6
C.E.E. (Kwh/tms)
Original
-5 " +3"
-5 " +2"
-5 " +1"
Fractions

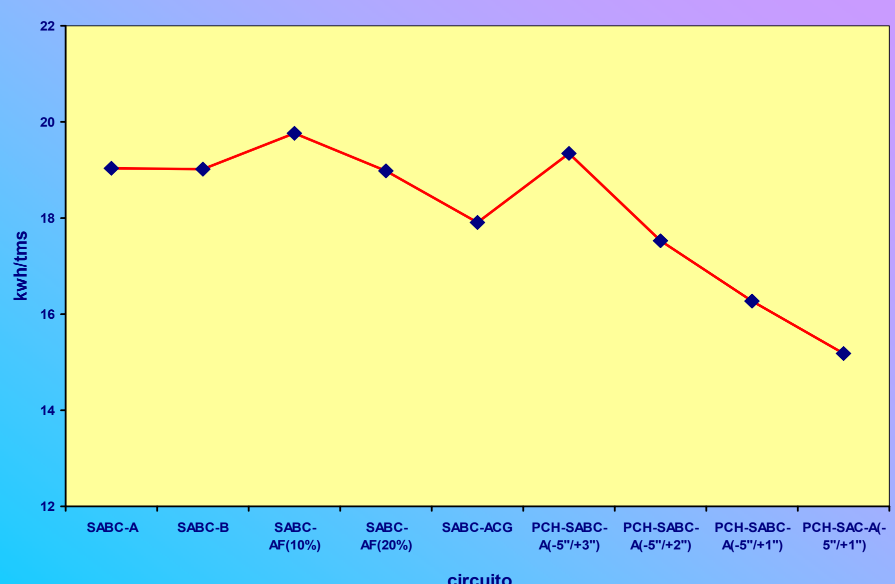

SAG S.E.C. (C.E.E.) VARIATION RELATED TO GRANULOMETRIC PROFILE AND TYPE OF ORE MIX
C.E.E. (Kwh/tms)
13,00
12,00
11,00
10,00
9,00
8,00
7,00
0,00
10,00
20,00
30,00
40,00
50,00
60,00
% -1"
Lithology : 100% Primary Andesite
Lithology: 55% Secondary Andesite and 45% Primary Andesite
Lithology: 100% Primary Andesite


CIRCUIT CRUSHING-SABC-A
+6”
-6”/+1”
-1”
-1”
-1”
FINES
COARSES
SAG
TO FLOTATION
TO FLOTATION

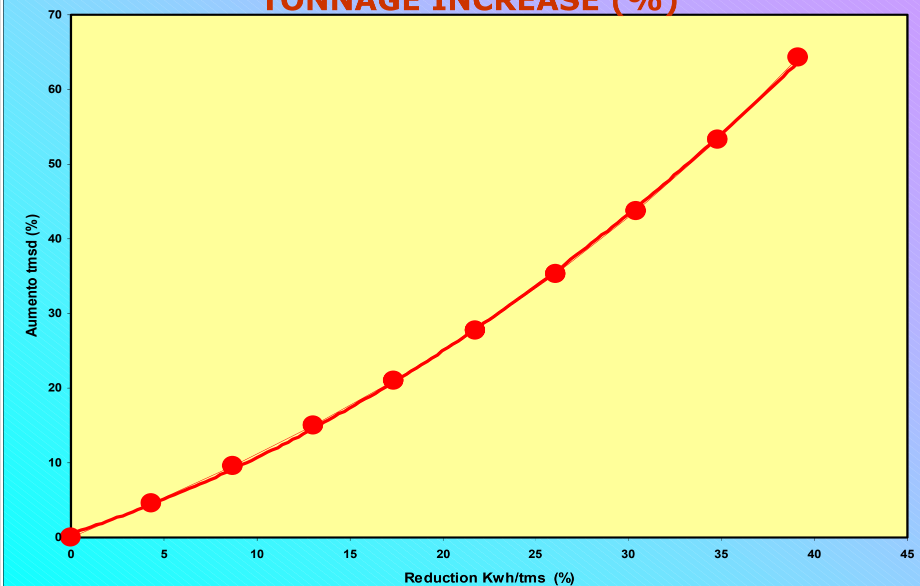
CIRCUIT CRUSHING-SAC-A



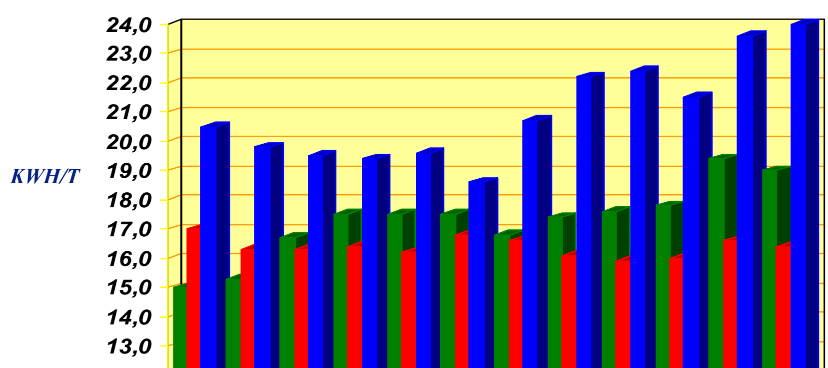
SPECIFIC POWER CONSUMPTION IN ALTERNATIVE CIRCUITS FOR A PRODUCT OF 20%+100M



DECREASE RATIO OF E (%) V/S TONNAGE INCREASE (%)

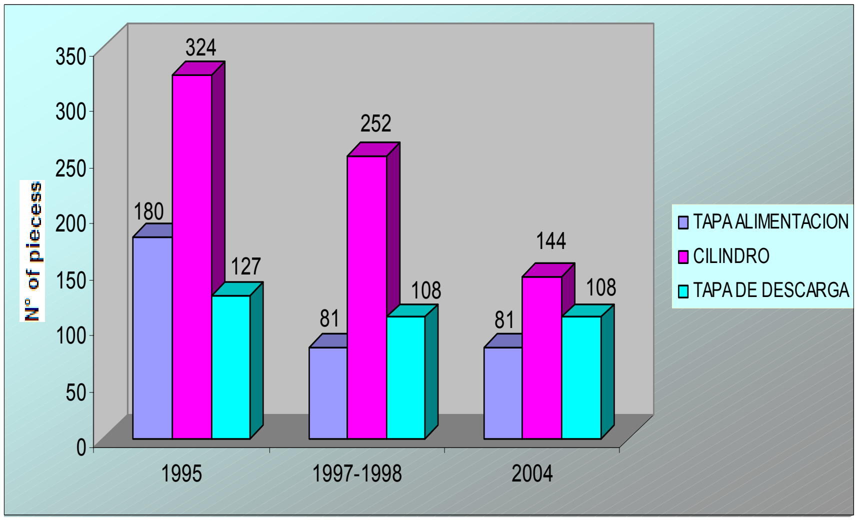


POWER CONSUMPTION MILLING AND CRUSHING

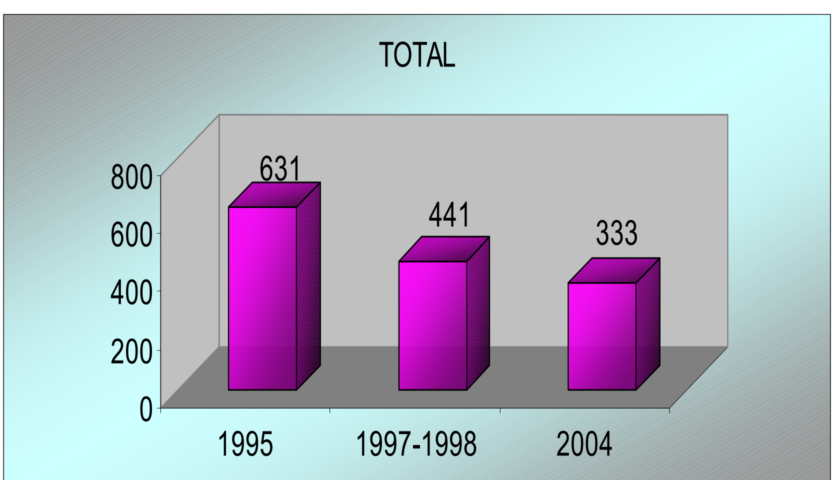


	93	94	95	96	97	98	99	00	01	02	03	04 Sep
Sewell	15	15,3	16,7	17,5	17,5	17,5	16,8	17,4	17,6	17,8	19,4	19,0
Colón	17	16,3	16,3	16,4	16,2	16,8	16,6	16,1	15,9	16	16,6	16,4
SAG	20,5	19,8	19,5	19,4	19,6	18,6	20,7	22,2	22,4	21,5	23,6	26,6

SAG MILL LININGS RATIONALIZATION



ELEMENTS QUANTITY REDUCTION



CONCLUSIONS

THE SAG MILL FEED SIZE DISTRIBUTION IS THE MOST IMPORTANT VARIABLE ON THE ENERGETIC AND METALLURGIC PROCESS EFFICIENCY.

THE PERCENTUAL INCREASE OF FINE MATERIAL (FRACTION -1") ON THE FEED SIZE DISTRIBUTION, CONSIDERABLY REDUCES THE SAG MILL SPECIFIC ENERGY CONSUMPTION, AND SIGNIFICANTLY INCREASING ITS PROCESSING RATE.

DEPENDING ON THE CRITERION USED TO INCREASE THE PRESENCE OF FINES IN THE SAG FEED SIZE DISTRIBUTION FOR A LITHOLOGIC MIX, IT IS POSSIBLE TO DECREASE THE SPECIFIC POWER CONSUMPTION BETWEEN 11% AND 35%.

FROM ALL THE CRITERIA ANALYZED FOR THE MODIFICATION OF THE ORIGINAL FEED SIZE DISTRIBUTION, THE MOST ATTRACTIVE IS THE ONE THAT CONSIDERS A PRE CRUSHING STAGE OF THE INTERMEDIATE FRACTION -6" / +1".

CONCLUSIONS

FOR LITHOLOGIC MIXES OF DIFFERENT SAG GRINDING COMPETENCIES, IT IS POSSIBLE TO EQUALIZE THE SPECIFIC ENERGY CONSUMPTIONS, AND CONSEQUENTLY THEIR PROCESSING RATES, WHEN PROCESSING IDENTICAL SAG FEED GRANULOMETRIC DISTRIBUTIONS.

IN THIS SPECIFC CASE, THE BOND BALL Wi, USUALLY USED IN THE SAG STAGE TO ESTABLISH GREATER OR LOWER HARDENESS OF THE PROCESSED ORES, NO MEANS ANY CORRELATION WITH DE SPECIFIC POWER CONSUMPTION IN THIS GRINDING STAGE. FOR THIS REASON ITS UTILIZACION MUST NOT BE CONSIDERED WITH DIMENSIONING PURPOSES AND CALCULATION OF PROCESSING RATES.

IN RELATION WITH THE RESULTS OBTAINED IN THE CURRENT STUDY, WHEN DESIGNING THE SAG MILLING PILOT TESTS, IT IS IMPERATIVE TO CONSIDER THE REVISION OF THE EFFECT OF THE GRANULOMETRIC PROFILE VARIATION, BESIDES THE TRADITIONALLY STUDIED VARIABLES AS THEY ARE: CRITICAL SPEED OF THE MILL, TROMEL OPENING, NUMBER OF ROCK-PORTS OPEN, CIRCUTS CONFIGURATION, BALLS FILLING LEVEL, ETC.

SUMMARY

- THE CHANCES FOR OPTIMIZING THE USE OF THE POTENCIES INSTALLED AND, THEREFORE THE TONNAGES PROCESSED ARE:
  - IN THE EVENT THAT CONVENTIONAL AND SAG MILLING CIRCUITS EXISTS AT A PLANT , IF LACK OF ORE OCCURS, THE SAG PLANTS PROCESS MUST BE MAXIMIZED AS PRIORITY, BY STOPPING, IF NECESSARY, PROCESSING STEPS IN CONVENTIONAL CIRCUITS.
  - SPECIFIC POWER CONSUMPTION OF THE ORE MIX CAN BE VARIED BY CHANGING THE FEEDING GRANULOMETRY TO THE PLANTS, EITHER ADDING FINES OR BY PRE-CRUSHING THE COARSE MATERIAL LESS COMPETENT WITH THE SAG MILLING.
  - OPTIMIZING THE UTILIZACION OF THE PLANT. BY IMPROVING THE MATERIALS QUALITY, ADVANCED DESIGN OF PARTS AND PIECES AND BY REDUCING THE NUMBER OF LINING PIECES, LIFTERS AND PULP LIFTERS, SO AS TO MINIMIZE THE MAINTENANCE HOURS.
  - OPTIMUM OPERATION PARAMETERS MUST BE DETERMINED, SUCH AS FILLING LEVEL, BALLS LEVEL, MILL SPEED, PERCENTAJES OF SOLIDS, ETC., WICH MUST BE INCORPORATED TO EXPERT SYSTEMS.

TP (tmsd) = P (Kw) x U (%/1) x 24 / E (Kw/tms)

END OF PRESENTATION

EFFECTIVE ENERGY UTILIZAYION ON JAPANESE COPPER SMELTERS

AKADA AKIHIKO
SUMITOMO METAL MINING Co. Ltd., Japan

1. Transition of Copper Production in Japan

Figure I shows production and consumption of copper in Japan during the last 5 decades (1). In the 1950's the both production and consumption were still 200,000 tonnes or less. At that time, the blast furnaces, the reverberatory furnaces and the electric furnaces with a small capacity, that were mainly located nearby the copper mines inland, were used for copper smelting. In the 1960's to 1970's the smelters increased their production to balance the rapid increase of domestic demand in the use of the imported copper concentrate because the price of domestic concentrate, that was exploited from the deeper face and processed from the lower grade ore than before, became much more expensive than the concentrate from abroad.

In 1965 the coastal smelter and refinery complex was built by Onahama Smelting and Refining Co. Ltd. to gain an advantage over treatment of the imported concentrate. This smelter was equipped with two reverberatory furnaces that were the one of the largest reverberatory furnace in the world at that time and its original capacity was 72,000 tonnes of copper/year. And then, from 1967 to 1973, the rush of constructing the coastal smelter and refinery complexes that adopted the Outokumpu flash furnaces as smelting furnace and the shut down of the conventional furnaces occurred in Japan. And then, commercial operation of Mitsubishi's continuous furnace started in 1973.

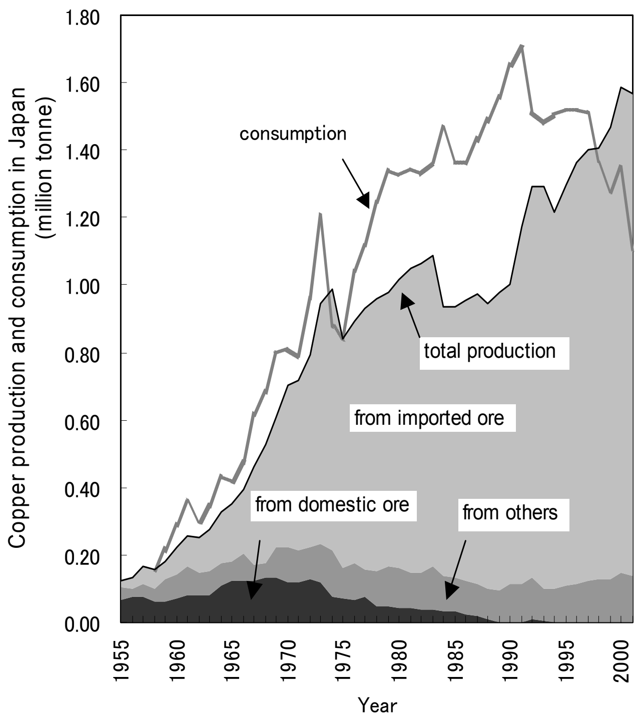


Figure I - Copper Production and Consumption in Japan

On the other hand, in 1970's the energy crises shook the world twice. In Japan, the oil price and the electricity price soared 10-folds and 4-folds, respectively. In order to break through these tougher conditions, Japanese Copper industry tried to reduce the energy cost and to increase production, and survived successfully. Table I shows the copper production of 6 smelters in Japan in 2002.

Table I - Copper Smelters of Japan (2)

COMPANY NAME	Sumitomo Metal Mining Co. Ltd.	Nippon Mining and Metals Co. Ltd.	Onahama Smelting and Refining Co. Ltd	Hibi Kyodo Smelting Co. Ltd	Dowa Mining Co. Ltd	Mitsubishi Materials Corp.
PLANT NAME	Toyo	Saganoseki	Onahama	Tamano Smelter	Kosaka	Naoshima
Annual Production	260,000	472,650	221,000	283,660	65,000	222,000
Type of Smelting Furnace	Flash	Flash	reverberatory	Flash with electrodes	Flash	MMC Continuous
Number of units	1	1	2	1	1	1

2. World Trend in the Copper Industry

2.1. Production and Demand in the World

As can be seen from the forecast of world copper production shown in Figure II, copper production will increase by 1.5 million tonnes during the period from 2003 to 2005 (3). As production from the SX-EW process will not increase, smelter and refinery production are expected to increase.

Figure III shows the predicted world copper demand. The 2002 copper demand of about 15 million tonnes will increase 21 million tonnes by 2010 (4). Nearly half of this 6 million tonnes increase is anticipated due to growth in the Asia/Oceania region.

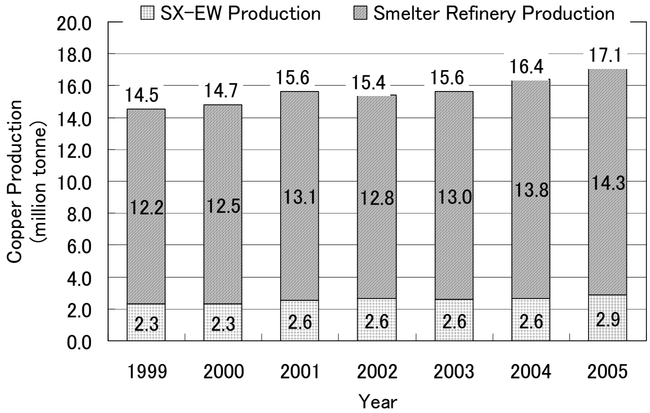


Figure II - Forecast of World Copper Production

2.2. World Trend in Copper Smelters

Table II compares the energy requirements for seven smelting processes, including the energy equivalents of materials consumed by each process (5). Although there is no data for Teniente and Isasmelt because this assessment was done in 1980, the energy requirement for these two processes is estimated as almost the same as the one for Mitsubishi furnace. In addition, It is said that there are no difference in the energy requirements between for the flash smelting and for the bath smelting nowadays.

Types of smelting furnaces operating around the world are the Outokumpu flash furnace, reverberatory furnace, Teniente Converter, Isasmelt, Mitsubishi furnace, INCO flash furnace, Noranda reactor and the shaft furnace. Figure IV shows world copper production classified by smelting process. Outokumpu flash furnaces produce about half of the total copper production in the world, and are thus the main stream of the copper smelting processes (3).

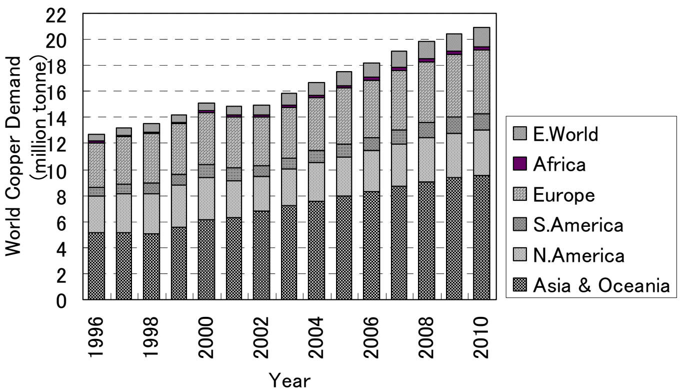


Figure III - Predicted World Copper Demand

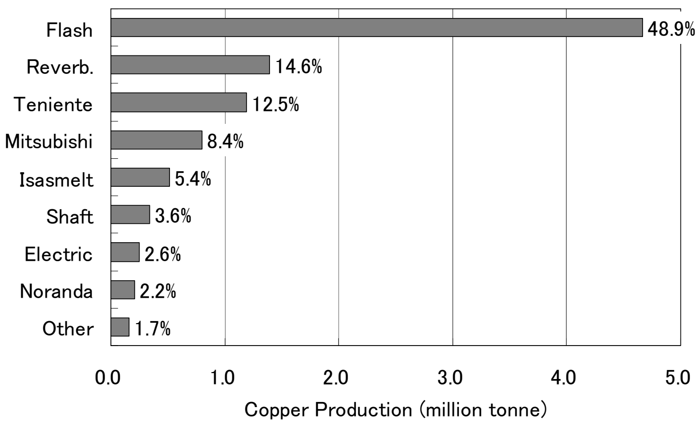


Figure IV - World Copper Production Classified by Smelting Process

Table II - Energy Requirements for Pyrometallurgical Process

	Reverberatory wet charge	Reverberatory dry charge	Electric furnace	INCO flash	Outokumpu flash	Noranda reactor	Mitsubishi reactor
Materials handling	0.77	0.77		0.77	0.60	0.83	0.70
Dry or roast		0.70	2.82	1.96	1.30	0.84	1.36
Smelting							
Fuel	26.39	15.30			0.84	3.92	6.82
Electricity	0.68	0.68	20.08	0.05		1.33	1.67
Surplus steam	-10.55	-4.59			-3.62	-1.92	-8.44
Converting							
Electricity	1.72	1.33	3.08	0.99	0.68	0.39	1.50
Fuel	0.57	0.34	3.78			0.09	0.26
Slag Cleaning					1.57	1.38	1.42
Gas handling							
Hot gas	4.25	2.99	0.82	0.62	0.44	0.73	0.91
Cold gas	0.26	0.42	2.33	0.33	0.22		0.34
Fugitive emissions	3.77	3.77		3.77	3.77	3.77	0.94
Acid plant	2.39	4.08	5.00	3.37	4.07	3.27	4.30
Water	0.11	0.11		0.11	0.11		0.11
Electrorefining	6.14	6.14	5.38	6.14	6.14	6.14	6.14
Materials:							
Miscellaneous					0.04	0.69	0.66
Oxygen				3.72	3.21	3.34	1.36
Electrodes			0.91				0.17
Fluxes	0.04	0.03	0.13	0.02	0.01	0.02	0.06
Water	0.08	0.08		0.08	0.08		0.08
Anode furnace	0.50	0.50	0.54	0.50	0.50	0.50	0.50
Total	37.12	32.63	44.86	22.43	19.96	25.33	20.86

3. Energy Utilization on Japanese Copper Smelters

In 1996, *Nippon Keidanren*, one of the three major economic organization of Japan, decided upon the independence action plan from the viewpoint of the both energy conservation and prevention of CO_2 emission prior to the Kyoto Protocol. The target of this action plan for the non-ferrous metal industry is the reduction of unit energy consumption by 12% in year 2020 compared with 1990. Table III shows the progress until 2001 and predicted ones (6). Although the information below is disclosed as one category for four kind of non-ferrous metals, it is clear that the copper smelters in Japan keep progress in reducing unit energy consumption successfully as copper production takes about 70% of non-ferrous metal production in Japan.

Table III - Energy Consumption of Non-ferrous Metal Industry in Japan

	Fiscal Year 1990	1998	1999	2000	2001	2005(predicted)	2010(predicted)
Cu,Zn,Pb and Ni production(1000 tonne	2,005	2,153	2,266	2,383	2,320	2,543	2,778
compared with 1990		7%	13%	19%	16%	27%	39%
Energy consumption (TJ)	54.6	53.9	54.6	54.0	53.1	56.5	66.8
compared with 1990		-1%	0%	-1%	-3%	3%	22%
Unit energy consumption (GJ/tonne)	27.2	25.0	24.1	22.7	22.9	22.2	24.0
compared with 1990		-8%	-12%	-17%	-16%	-18%	-12%

The measures of effective energy utilization that have been adopted in the copper smelters in Japan for the last five years are itemized below. There are two main trends for effective energy utilization. One is energy saving and the other is utilizing exhaust energy and spent materials.

1) Energy Saving

- Employment of high efficiency motors
- Reduction of free air infiltration
- Employment of power factor corrected
  a. Oxygen plant b. Power receiving end
- Increasing of blower efficiency
- Increasing of pump efficiency
- Control of damper openness
- Employment of low pressure drop gas line
  a. Catalyst b. Duct arrangement
- Maintenance of oil burner
- Decreasing of resistance in electrolysis circuit
- Less idling operation
  a. Pump b. Coal mill c. Fan d. Furnace
- Employment of lower temperature operation

2) Utilization of exhaust energy and spent materials

- Increasing of heat recovering efficiency
  a. Employment of high heat conductivity material for condenser tube
  b. Employment of boiler instead of SO_3 cooler
  c. Periodic maintenance of condenser tube
- Automobile Shredder Residue for fuel
- Spent Tire for fuel
- Spent Oil for fuel
- Employment of steam dryer using exhaust steam

4. Examples of Energy Utilization at Toyo Smelter

4.1. The Outline of Toyo Smelter and its Expansion Project

The Sumitomo Toyo Smelter commenced its operation in 1971 with a smelting capacity of 850 tpd (tonnes per day) of copper concentrate. The present capacity has reached almost 2,700 tpd of copper concentrate and the projected capacity will reach 3,950 tpd.

The flow sheet of the Toyo Smelter is shown in Figure V and historic data recording the amounts of copper production and projected production at the Toyo Smelter are shown in Figure VI.

The Toyo smelter is carrying out an expansion project to increase its annual electrolytic copper production capacity from 270,000 tpa to 450,000 tpa by 2007 at the latest. The completion of the expansion project will be done the next year under the following policy guidelines:

A. Reduce production costs by increasing smelter capacity.
B. Save on capital costs by utilizing existing capacity.
C. Minimize operation risks resulting from expansion.
D. Strengthen environmental management.

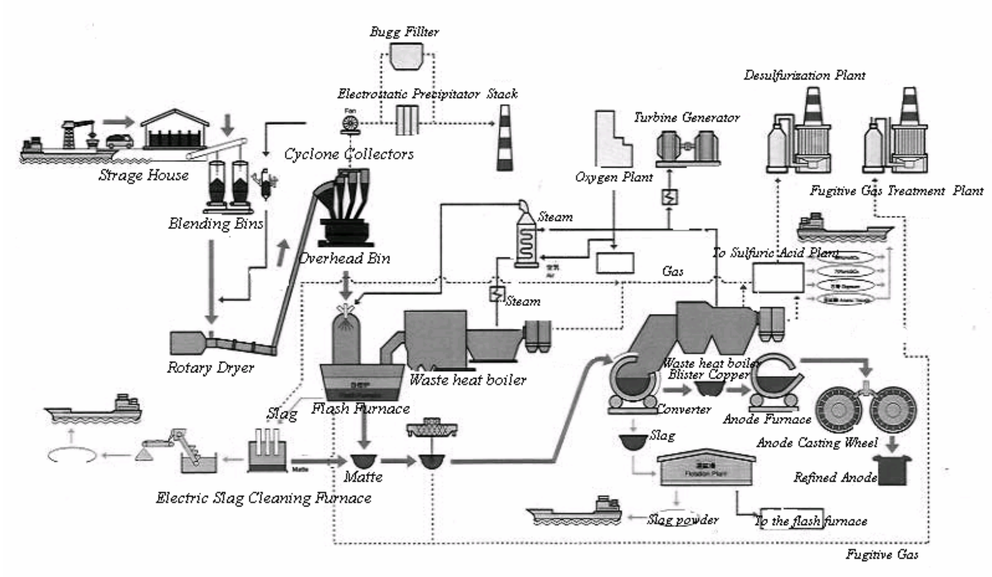


Figure V - Schematic Flow Sheet of the Toyo Smelter

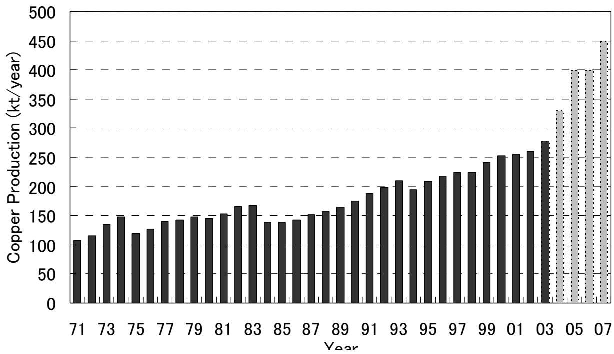


Figure VI - Projected Copper Production

4.2. Fuel Reduction in the Flash Furnace

The Toyo flash furnace was originally equipped four concentrate burners and its dust generation ratio had been around 9% since commencement. When oxygen enrichment to the flash furnace was introduced in 1982 in order to increase the production and to decrease the fuel consumption, dust generation ratio jumped up to 12-14% and fuel consumption increased to compensate the heat for dust decomposition.

In order to reduce dust generation, the Toyo smelter set about developing a

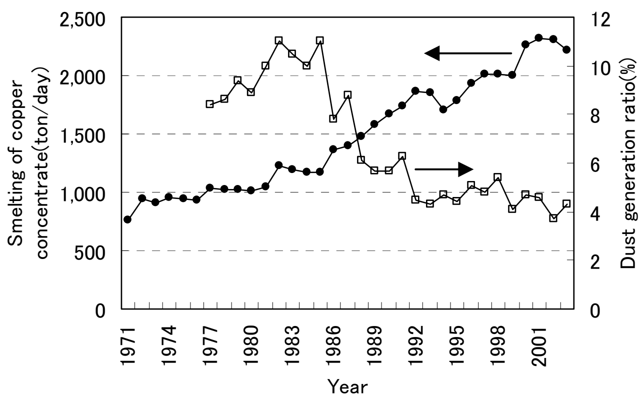


Figure VII - Smelting Rate of Concentrate and Dust Generation Ratio better performance concentrate burner which is still on progress even now. Our strategy for the development of a better performance concentrate burner was worked out based on the two-particles model obtained by an extensive research work of the Sumitomo Metal Mining Niihama Research Laboratory.

The concentrate burner was changed to the single type in 1996 and now the Toyo flash furnace equips the original single concentrate burner called the Sumitomo type concentrate burner.

Table IV shows the heat balance of the flash furnace. Compared to 2003 with 1985, heat input by fossil fuel in 2003 is reduced by 43% of 1985's, or unit heat input by fossil fuel per tonne of concentrate is reduced by 21.5%. In 2007 at the copper production rate of 450,000 tpa, unit heat input by fossil fuel per tonne of concentrate is expected to be reduced by only 3% of 1985's.

Table IV – Heat Balance of Flash Furnace

	Year 1985		2003		2007(plan)	
OPERATING CONDITION						
concentrate charge (ton/hour)	44.5		90		164.6	
dust generation ratio(%)	11.8		5.1		4.0	
O_2 enrichment in Reaction Air	32.1		49.5		72.1	
matte grade	56.0		63.5		65.0	
HEAT INPUT and PRODUCTION (GJ/hour)	(GJ/hour)	(%)				
heat of matte and SO_2 production	80.0	51	172.9	84	382.5	99
heat for decomposition of dust	-24.1	-15	-22.0	-11	-32.8	-9
sensible heat of ore	2.5	2	5.1	2	10.1	3
sensible heat of reaction air	17.1	11	15.0	7	8.7	2
oil and pulverized coal	81.1	52	35.3	17	17.1	4
heat input total	156.7	100	206.4	100	385.5	100
HEAT OUTPUT(GJ/hour)						
sensible heat of matte and slag	45.9	29	103.2	50	209.5	54
sensible heat of gas	73.1	47	65.4	32	117.4	30
sensible heat of dust	7.5	5	7.4	4	15.9	4
heat losses	24.7	16	25.0	12	33.1	9
others	5.5	3	5.3	3	9.7	3
heat output total	156.7	100	206.4	100	385.6	100

4.3. Electric Power Reduction in the Acid Plant

Figure VIII shows the flow of the acid plant at the present. The upper part in this figure is the new gas cleaning system, the middle is the old converting and absorbing line, and the bottom is the newly added converting and absorbing line as a part of the expansion project.

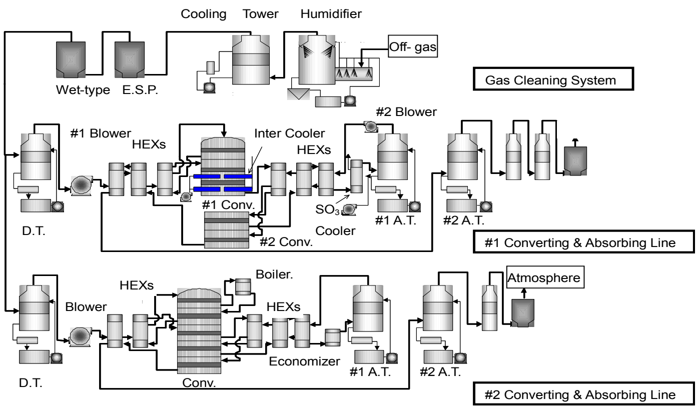


Figure VIII - Schematic Flow Sheet of the Acid Plant

Figure IX shows the changes of the index of electric power consumption per tonne of sulfuric acid produced as compared to the figure in 1985 of 100.

There are two drastic falls of electric power consumption, one was done during 1985 and 1990, and the other has being done for the past four years.

Although the original capacity of the sulfuric acid plant that was consist of the demolished gas cleaning system replaced by the new gas cleaning system drawn in Figure VIII and the old converting and absorbing line was only 850 tpd of sulfuric acid and/or 167 kNm3/h of off gas treated, the capacity of this system was increased to 2,300 tpd and/or 175 kNm3 in accordance with the increase of the smelting capacity by the improvements below.

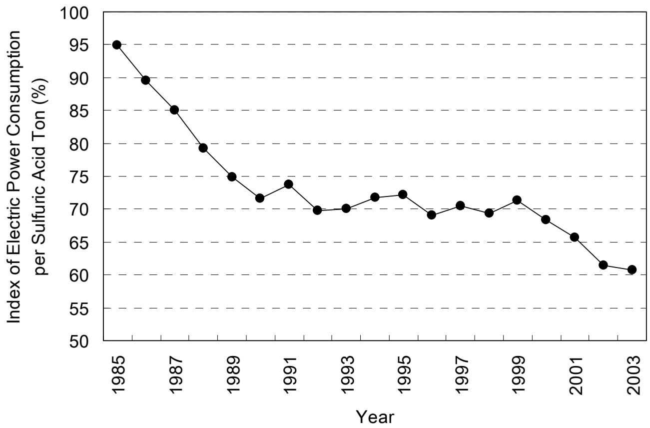


Figure IX – Electric Power Consumption in the Acid Plant

- ✓ Increase absorbing efficiency of No.1 absorber.
  Decrease the inside acid temperature and the outlet acid concentration of the absorber.

- ✓ Increase oxidation rate of converter.
  Increase O_2/ SO_2 ratio of the process gas.
  Increase catalyst temperature in the converter.

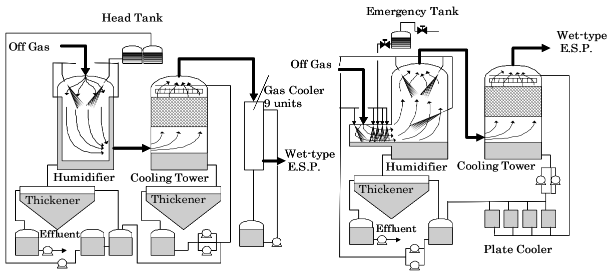
As the increase of the treated off gas volume is very small, the electric power consumption for SO_2 blower that is the biggest power consuming equipment almost does not change. On the other hand, the acid production increased almost 2.7 times, so the unit electric power consumption decreased drastically. Moreover, four measures of improvement in order to save the electric power were done shown in table V. As a result, the almost 30% of electric power reduction was achieved during this period

Table V – Measures for Electric Power Saving

Measures	Enforcement matter	Reduction of electricity MWH/y	Enforcement period
1. Scaling up of SO_2 blower inlet damper	For the purpose of decreasing the specific regular pressure drop at damper 1)No.1 SO_2 blower φ1.16m → 1.60m 2)No.2 SO_2 blower φ1.35m → 2.00m	780	1988
2. SO_2 blower power saving operation	For the purpose of automatic draft control on gas pressure fluctuation at the inlet of acid plant which is mainly attributed to CF operation, the damper opening of the SO_2 blower inlet was improved from 60% to 100% by developing a pressure fluctuation monitoring with online process computer and feed forward system.	1180	1988
3. Gas cooler bypass ducting installation	Though shell & tube type gas cooler is used to control temperature of inlet gas at the drying tower, a bypass duct(φ 2.5m) was installed at the gas cooler, since surplus on gas cooling capacity resulted from the elevation of the SO2 strength. Its operation is done by the optimum opening bypass damper visualized on the picture of a process computer.	410	1987
3. Pressure drop decrease at the converting system	1)Renewal of catalyst to a ring catalyst(Ring catalyst occupies 60% of the whole one) 2)A bypass line modification of A to C heat exchanger.	2,300	1989 to 1992
	Total	4,670	

The reduction of electric power consumption for the last four years was mainly achieved by the implementation of the new gas cleaning system, new converting and absorbing line with high performances.

Figure X shows the old gas cleaning system and the new gas cleaning system. The difference of the pressure loss between the old and new gas cleaning system is shown in this Figure.



	Humidifier	Cooling Tower	Gas Cooler	Wet type E.S.P.	total
New System	306	420	-	1,390	2,116
Old System	480	510	549	1,882	3,421
differnce	-174	-90	-549	-492	-1,305

Figure X - Old Gas Cleaning System(left), New System(right), and Pressure Losses(kPa as unit)

In addition, the new converting and absorbing system has several features below:

- SO_2 blower with the current source Inverter can follow the rapid increase and decrease of off-gas volume
- Vanadium pentoxide catalyst with the ring-shape that has lower pressure loss
- High efficiency acid distributors and mist eliminators in the absorption tower
- High efficiency desulfurization tower for flue gas
- DCS control system
- etc.

Figure XI shows the comparison of the consumption of the electric power of the old and new line. Unit power consumption for the blower on new converting and absorbing line is smaller than the one for the old line by about 25%. When the both line are operated at the same gas volume, total unit power consumption for SO2 blowers is decreased by 13%.

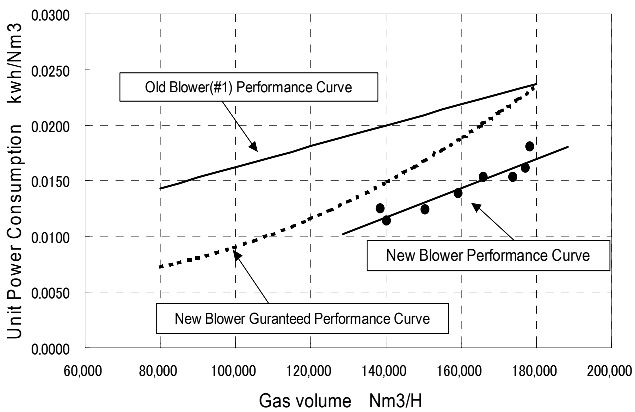


Figure XI - Unit Power Consumption of SO_2 Blowers

Furthermore, various efforts to save the electric power were executed during this period:

- Suspension of No.1 SO_3 cooler fan; 2,010 MWH/Y saving
- Suspension of booster pump for cooling water; 1,120 MWH/Y saving
- Optimization of fugitive gas fan operation; 2,500 MWH/Y saving
- etc.

4.4. Recovery and Utilization of Exhausted Energy and Reinforcement of Cogeneration System

On completion of the expansion project, the improvements for recovery and utilization of exhausted energy and cogeneration system are executed below:

- Installation of a boiler to converter in acid plant

  As the conversion of SO_2 to SO_3 is an exothermic oxidation reaction, there is considerable excess heat generated in the converter. In the old line, this excess heat, 6.7GJ/hour, is removed from the process gas to atmosphere by use of intercooler and SO_3 cooler. In the new acid line, an economizer instead of SO_3 cooler and a boiler instead of intercooler were installed. This boiler system generates steam of 12 T/hour and this steam is send to the powerhouse to generate the electricity.

- Installation of a rotary steam dryer

  The existing equipment for drying raw material is a flash dryer. In order to correspond to the amount of raw material needed for the increase of flash furnace capacity, a rotary steam dryer was added. As this dryer uses steam generated in the plant, there is no need of oil and/or coal consumed. As a result, energy consumption for drying 240 t/hour raw material by two dryers is expected to be reduced by 26% compared with energy consumption for drying 115 t/hour by the existing dryer.

- Installation of a new turbine generator

  At the production rate of 450,000 tpa, steam generated at the plant will increase to 90 t/hour compared to 68 t/hour at the production rate of 270,000 tpa. As the rated output of the existing turbine generator is 8,700 kW, excess steam of 36 t/hour will be dumped without generation. In order to avoid the waste of this steam, a new generator, the rated output 10,200 kW, was installed. By the use of two turbine generators, 10,000 kW at norm. and 18,000 kW at a peak condition will be generated at the production rate of 450,000 tpa. Figure XII shows the cogeneration system at the Toyo Smelter.

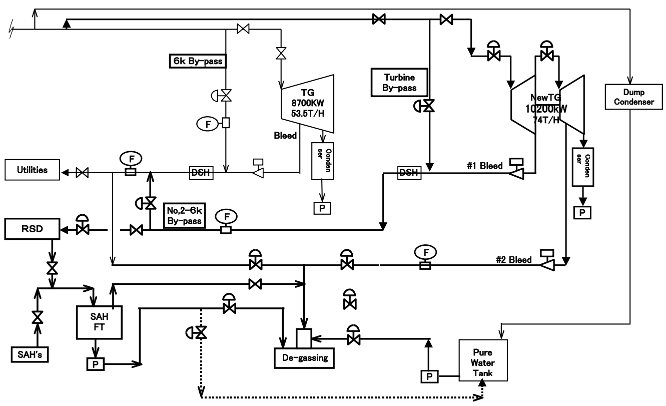


Figure XII - Cogeneration System

4.5. Overall Energy Consumption at Toyo Smelter and Refinery

Figure XIII shows the Index of energy consumption rate per tonne of treated concentrate as compared to the figure in 1985 of 100. Hence, the energy means the total energy consumed at the entire Toyo Smelter and Refinery including the tank house. The unit energy consumption was reduced by 40% or more for the last two decades. And it is expected that the

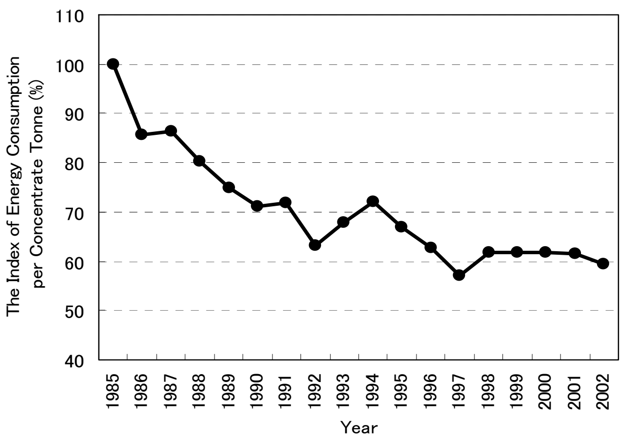


Figure XIII – Energy Consumption rate at Toyo further energy reduction should be done in accordance with the increase of the copper production.

SUMMARY

Copper production in Japan was 1.54 Million ton in 2003, that is the 3rd in the world subsequently to Chile and China. In order to reduce the production cost and to maintain the competitiveness in the world copper business, copper smelters of Japan have been fully using the measures of the both energy saving and utilization of exhaust energy and spent materials.

As an example, the measure at the Toyo Smelter was described. The Toyo Smelter and Refinery is carrying out an expansion project to increase copper production capacity by 1.7 times in order to meet future copper demand growth in the Asia region now. The unit energy consumption at the Toyo Smelter was reduced by 40% or more for the last two decades and further reduction is expected after the completion of its expansion project.

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Effective Energy Utilization on Japanese Copper Smelters

Oct. 21 2004
Akihiko Akada

SUMITOMO METAL MINING CO., LTD.

Position of the Japanese Copper Smelters

Comperison of the World Copper Smelters, 2001
(from Mineria Chilena, May, 2003)

	Japan	Chile	W.Europe	China	India	Average
Operating ratio (%)	92	90	93	86	92	83
Cu recovery (%)	98	97	98	97	97	97
SO2 recovery (%)	99	89	99	83	83	84
Productivity (tonne/100 personnel)	97	32	89	15	16	20
Labor cost, unit (US$/h)	31.9	10.6	20.7	1.5	0.8	13.1
Electricity price (¢ /kWh)	6.1	3.2	3.7	4.3	6.7	3.9
Production rate of the world (%)	13	13	9	8	3	100

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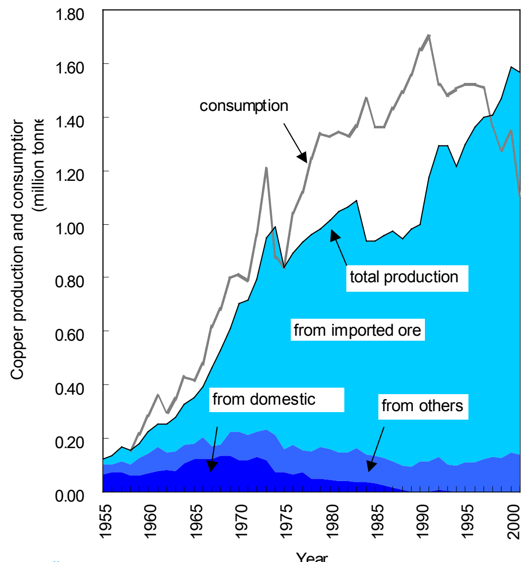
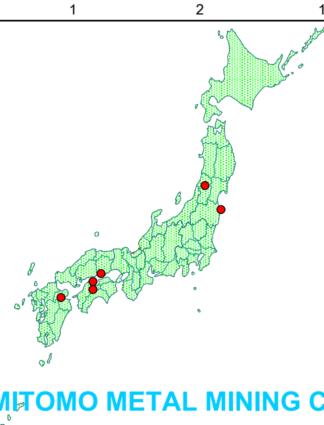
Historical Copper Production and Consumption in Japan



SUMITOMO METAL MINING CO., LTD.

Existing Six Copper Smelters in Japan

Company Name	Sumitomo Metal Mining Co. Ltd.	Nippon Mining and Metals Co. Ltd.	Onahama Smelting and Refining Co. Ltd	Hibi Kyodo Smelting Co. Ltd	Dowa Mining Co. Ltd	Mitsubishi Materials Corp.
Plant Name	Toyo	Saganoseki	Onahama	Tamano Smelter	Kosaka	Naoshima
Annual Production	260,000	472,650	221,000	283,660	65,000	222,000
Type of Smelting Furnace	Flash	Flash	Reverberatory	Flash with electrodes	Flash	MMC Continuous
Number of units	1	1	2	1	1	1



SUMITOMO METAL MINING CO., LTD.

Measures of effective Energy Utilization

1) Energy Saving

Employment of high efficiency motors
Reduction of infiltration air
Employment of power factor corrected
a. Oxygen plant b. Power receiving end
Increasing of blower efficiency
Increasing of pump efficiency
Control of damper openness
Employment of low pressure drop gas line
a. Catalyst b. Duct arrangement
Maintenance of oil burner
Decreasing of resistance in electrolysis circuit
Less idling operation
a. Pump b. Coal mill c. Fan d. Furnace
Employment of lower temperature operation

2) Utilization of exhaust energy and spent materials

Increasing of heat recovering efficiency
a. Employment of high heat conductivity material for condenser tube
b. Employment of boiler instead of SO_3 cooler
c. Periodic maintenance of condenser tube
Automobile Shredder Residue for fuel
Spent Tire for fuel
Spent Oil for fuel
Employment of steam dryer using exhaust steam

Action Plan of Energy Conservation

	Fiscal Year 1990	1998	1999	2000	2001	2005(predicted)	2010(predicted)
Cu,Zn,Pb and Ni production(1000 tonne	2,005	2,153	2,266	2,383	2,320	2,543	2,778
compared with 1990		7%	13%	19%	16%	27%	39%
Energy consumption (TJ)	54.6	53.9	54.6	54.0	53.1	56.5	66.8
compared with 1990		-1%	0%	-1%	-3%	3%	22%
Unit energy consumption (GJ/tonne)	27.2	25.0	24.1	22.7	22.9	22.2	24.0
compared with 1990		-8%	-12%	-17%	-16%	-18%	-12%

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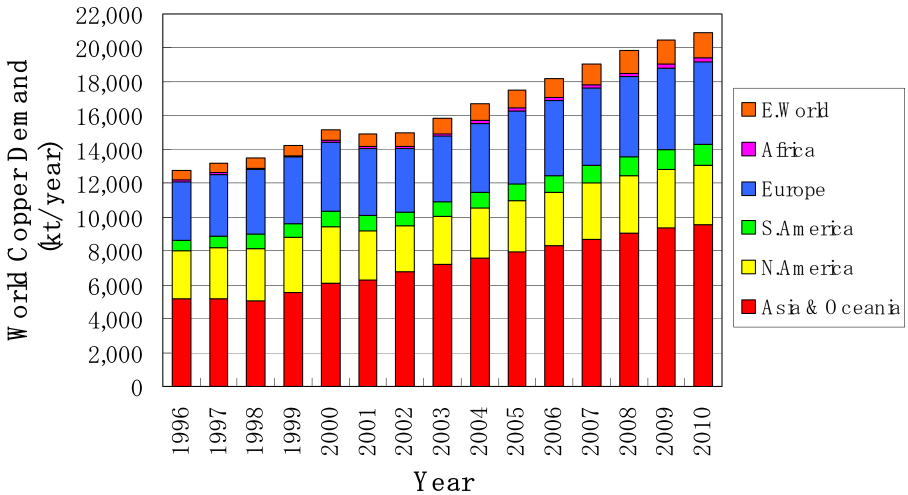
Predicted World Copper Demand

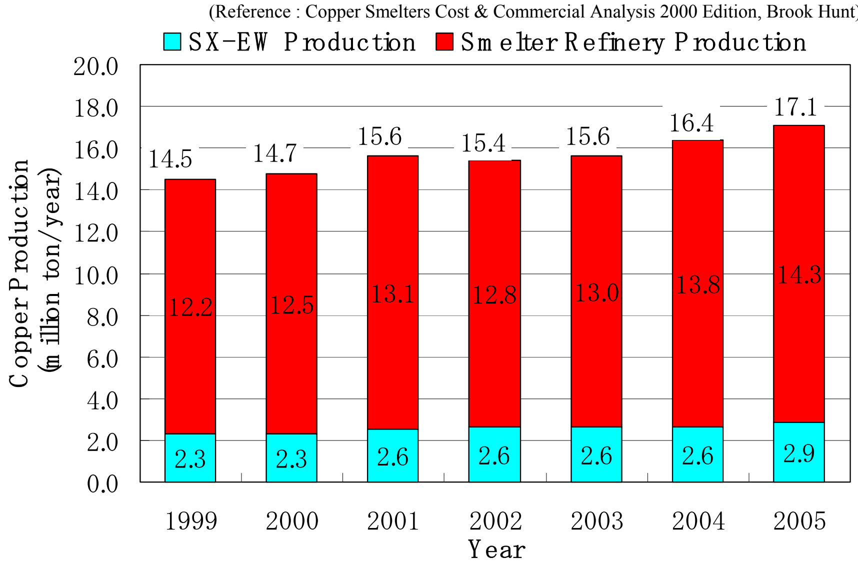
(Reference : Copper Metal Service, Brook Hunt, 2003)



SUMITOMO METAL MINING CO., LTD.

Prospects for World Copper Production

(Reference : Copper Smelters Cost & Commercial Analysis 2000 Edition, Brook Hunt)



SUMITOMO METAL MINING CO., LTD.

Energy Requirement of Various Processes

Energy Requirement of Pyrometallurgical Processes(GJ/ton)

	Reverberatory wet charge	Reverberatory dry charge	Electric furnace	INCO flash	Outokumpu flash	Noranda reactor	Mitsubishi reactor
Materials handling	0.77	0.77		0.77	0.60	0.83	0.70
Dry or roast		0.70	2.82	1.96	1.30	0.84	1.36
Smelting							
Fuel	26.39	15.30			0.84	3.92	6.82
Electricity	0.68	0.68	20.08	0.05		1.33	1.67
Surplus steam	-10.55	-4.59			-3.62	-1.92	-8.44
Converting							
Electricity	1.72	1.33	3.08	0.99	0.68	0.39	1.50
Fuel	0.57	0.34	3.78			0.09	0.26
Slag Cleaning					1.57	1.38	1.42
Gas handling							
Hot gas	4.25	2.99	0.82	0.62	0.44	0.73	0.91
Cold gas	0.26	0.42	2.33	0.33	0.22		0.34
Fugitive emissions	3.77	3.77		3.77	3.77	3.77	0.94
Acid plant	2.39	4.08	5.00	3.37	4.07	3.27	4.30
Water	0.11	0.11		0.11	0.11		0.11
Electrorefining	6.14	6.14	5.38	6.14	6.14	6.14	6.14
Materials:							
Miscellaneous					0.04	0.69	0.66
Oxygen				3.72	3.21	3.34	1.36
Electrodes			0.91				0.17
Fluxes	0.04	0.03	0.13	0.02	0.01	0.02	0.06
Water	0.08	0.08		0.08	0.08		0.08
Anode furnace	0.50	0.50	0.54	0.50	0.50	0.50	0.50
Total	37.12	32.63	44.86	22.43	19.96	25.33	20.86

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Features of Smelting Processes (1) Flash

Furnace Type	Productivity $T/m^2 \cdot D$	Furnace Charge	Matte Grade %	Characteristics
1.Flash smelting				
Outokumpu	8～11	dry conc.	55 - 65	environment-friendly process high flexibility for operation high potentiality for expansion high dust generation
Inco	12	dry conc.	45	pure oxygen smelting autogenous operation low dust generation restriction on MG (low MG)

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Features of Smelting Processes (2) Bath

Furnace Type	Productivity $T/m^2 \cdot D$	Furnace Charge	Matte Grade %	Characteristics
2.Bath smelting				
Noranda	15	green conc.	65 - 75	high flexibility for row materials high MG (white metal) short brick life of tuyere
Mitsubishi	21	dry conc.	55 - 70	continuous process short brick life high energy cost due to pressurized air
Teniente	12	green conc.	70 - 75	high flexibility for row materials short brick life of tuyere
Oxy-Fuel reverb.	5	green conc.	40 - 45	low MG and productivity
Vanyukov	80	green conc.	45 - 70	form smelting high productivity low dust generation
Isa smelt	65	conc. pellet	55	compact furnace using a submerge low dust generation due to conc. pellet short brick life

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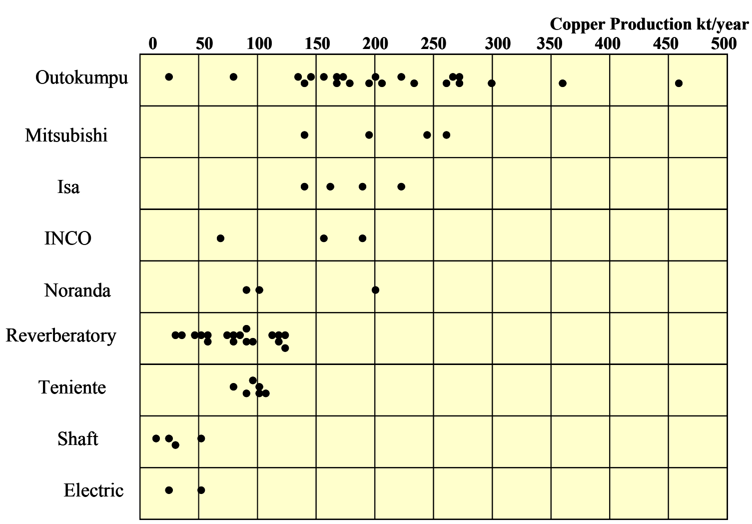
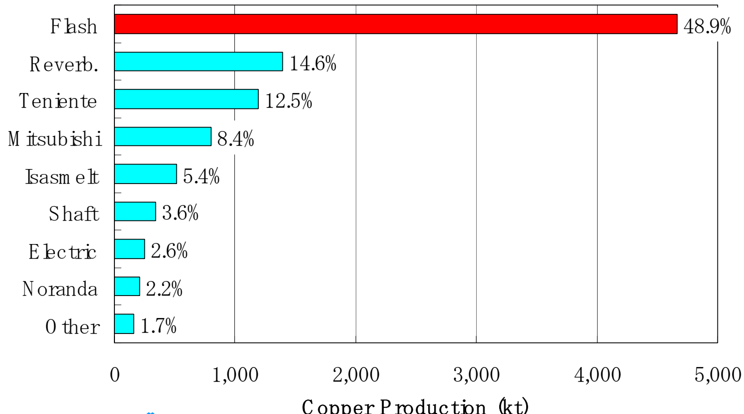
Productivity of individual smelting furnace



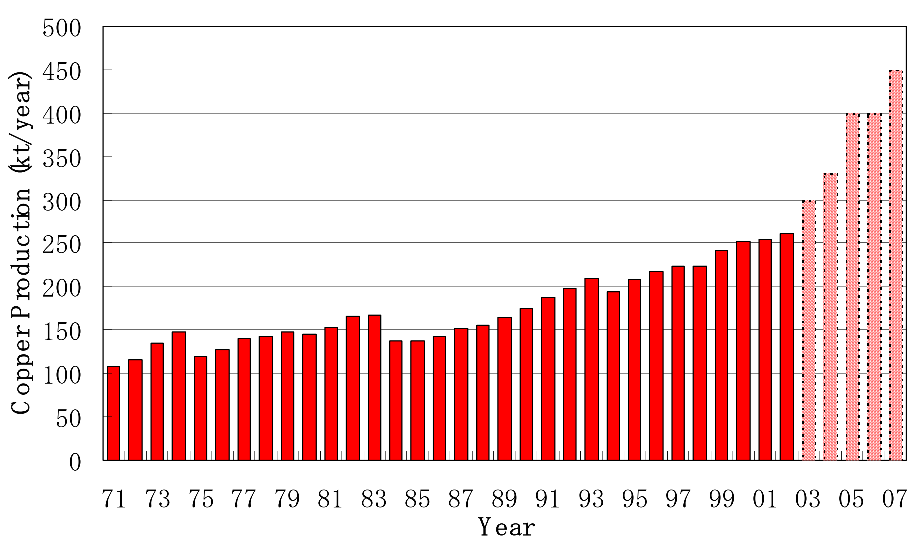
World Smelting Furnaces

(Reference : Copper Smelters Cost & Commercial Analysis 2000 Edition, Brook Hunt)

	O/K FF	Reverb.	Teniente	Isa	Mitsubishi	INCO FF	Noranda	Shaft	**Sum**
Asia and Oceania	13	2	0	5	3	0	2	1	**26**
S. America	3	6	8	0	0	0	0	0	**17**
Europe	5	1	0	0	0	0	0	2	**8**
N. America	2	3	1	1	1	4	1	1	**14**
Sum	**23**	**12**	**9**	**6**	**4**	**4**	**3**	**4**	**65**



Planed Copper Production of Toyo Smelter



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Expansion Policy of the Toyo Smelter

A. Reduce production costs by increasing smelter capacity
B. Save on capital costs by utilizing existing facilities
C. Minimize operation risks resulting from expansion
D. ~~Strengthen environmental management~~

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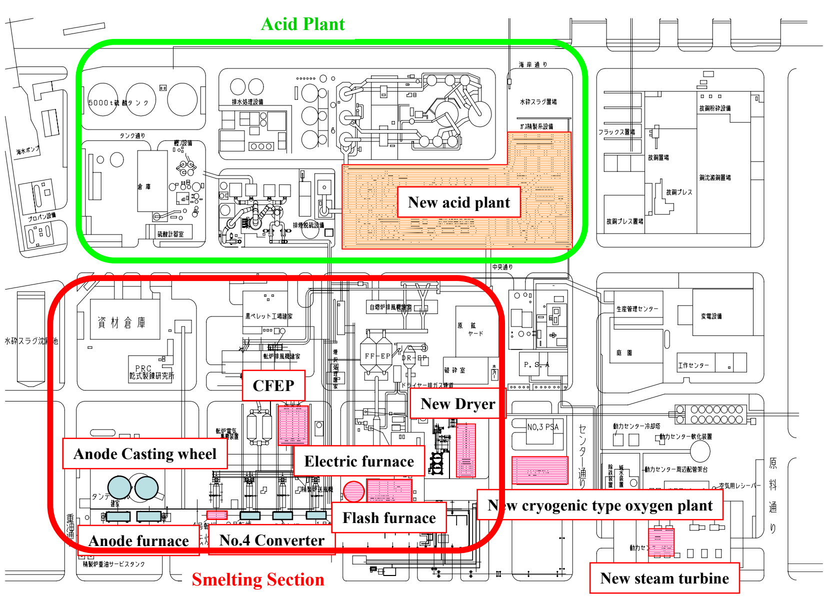
Layout of the Smelting Area



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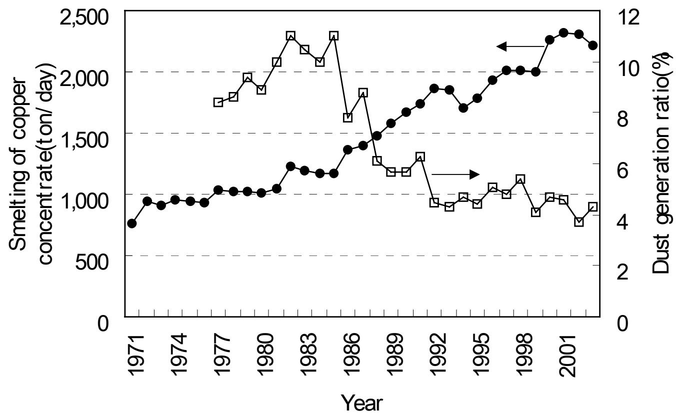
Dust Generation Ratio in Toyo Flash Furnace



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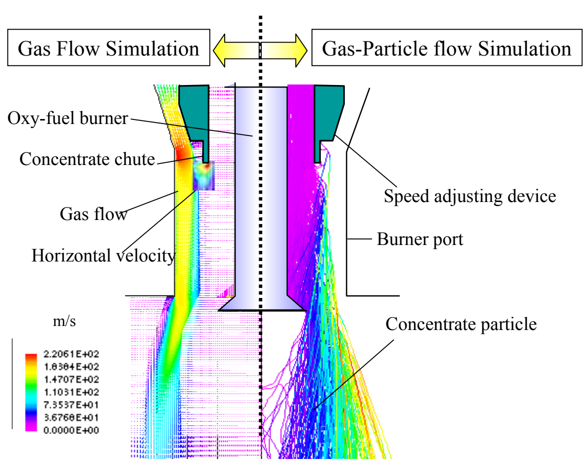
Example of gas and gas-particle simulation model Concentrate Burner



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Fuel Reduction in Sumitomo Flash Furnace

	Year 1985		2003		2007(plan)	
OPERATING CONDITION						
concentrate charge (ton/hour)	44.5		90		164.6	
dust generation ratio(%)	11.8		5.1		4.0	
O_2 enrichment in Reaction Air	32.1		49.5		72.1	
matte grade	56.0		63.5		65.0	
HEAT INPUT and PRODUCTION (GJ/hour)	(GJ/hour)	(%)				
heat of matte and SO_2 production	80.0	51	172.9	84	382.5	99
heat for decomposition of dust	-24.1	-15	-22.0	-11	-32.8	-9
sensible heat of ore	2.5	2	5.1	2	10.1	3
sensible heat of reaction air	17.1	11	15.0	7	8.7	2
oil and pulverized coal	81.1	52	35.3	17	17.1	4
heat input total	156.7	100	206.4	100	385.5	100
HEAT OUTPUT(GJ/hour)						
sensible heat of matte and slag	45.9	29	103.2	50	209.5	54
sensible heat of gas	73.1	47	65.4	32	117.4	30
sensible heat of dust	7.5	5	7.4	4	15.9	4
heat losses	24.7	16	25.0	12	33.1	9
others	5.5	3	5.3	3	9.7	3
heat output total	156.7	100	206.4	100	385.6	100

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Installation of Rotary Steam Dryer

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Reduction of Fuel and ＳＯx Emission at 450 KT/Y

	unit	Present	450,000T/Y
Feed rate of rotary dryer	W T/H	120	80
Feed rate of rotary steam dryer	W T/H	–	160
Fossil fuel of dryer (Crude petroleum conversion)	L/H	2049 →	1698
SO2 volume	Nm3/H	13.5	10
Exhaust gas volume	Nm3/H	99000	99000
SOx density by fossil fuel	ppm	137	101

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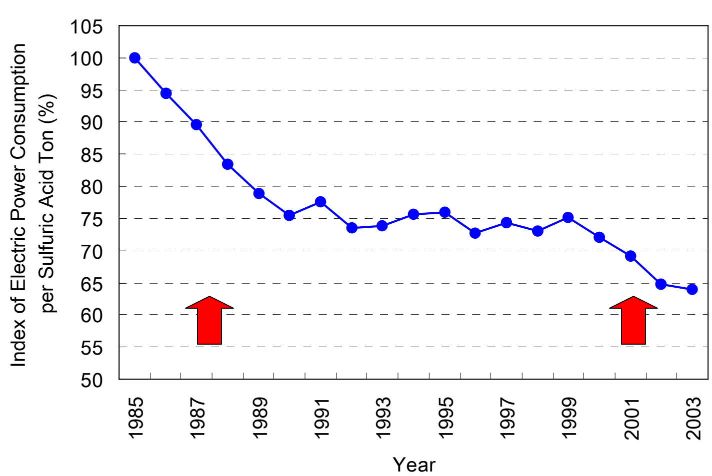
Trend of Unit Energy Consumption at Acid Plant



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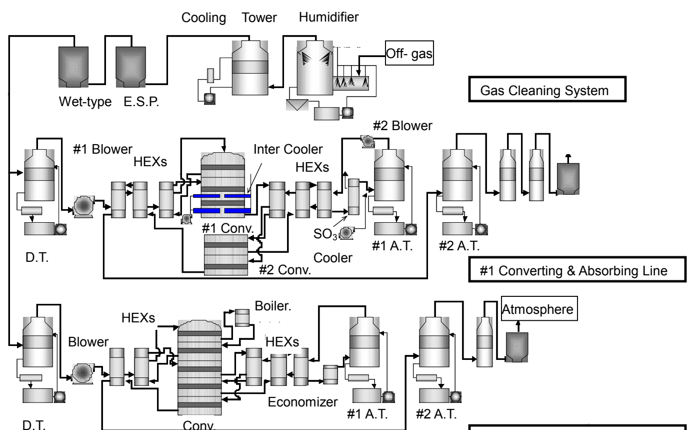
Schematic Flow of Acid Plant



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Various Measures for Energy Saving at Acid Plant

Measures	Enforcement matter	Reduction of electricity MWH/y	Enforcement period
1. Scaling up of SO_2 blower inlet damper	For the purpose of decreasing the specific regular pressure drop at damper 1)No.1 SO_2 blower φ1.16m → 1.60m 2)No.2 SO_2 blower φ1.35m → 2.00m	780	1988
2. SO_2 blower power saving operation	For the purpose of automatic draft control on gas pressure fluctuation at the inlet of acid plant which is mainly attributed to CF operation, the damper opening of the SO_2 blower inlet was improved from 60% to 100% by developing a pressure fluctuation monitoring with online process computer and feed forward system.	1180	1988
3. Gas cooler bypass ducting installation	Though shell & tube type gas cooler is used to control temperature of inlet gas at the drying tower, a bypass duct(φ 2.5m) was installed at the gas cooler, since surplus on gas cooling capacity resulted from the elevation of the SO2 strength. Its operation is done by the optimum opening bypass damper visualized on the picture of a process computer.	410	1987
3. Pressure drop decrease at the converting system	1)Renewal of catalyst to a ring catalyst(Ring catalyst occupies 60% of the whole one) 2)A bypass line modification of A to C heat exchanger.	2,300	1989 to 1992
	Total	4,670	

About 7% of total electric consumption at Acid Plant

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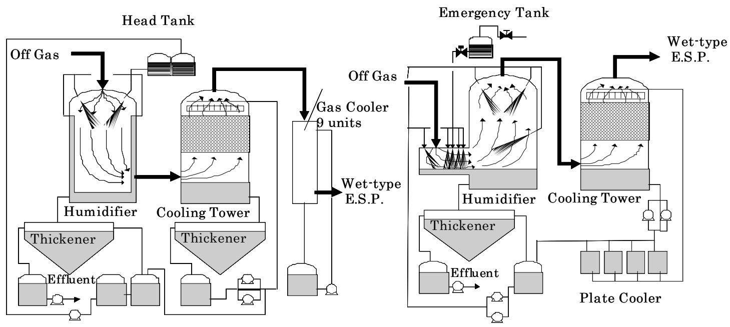
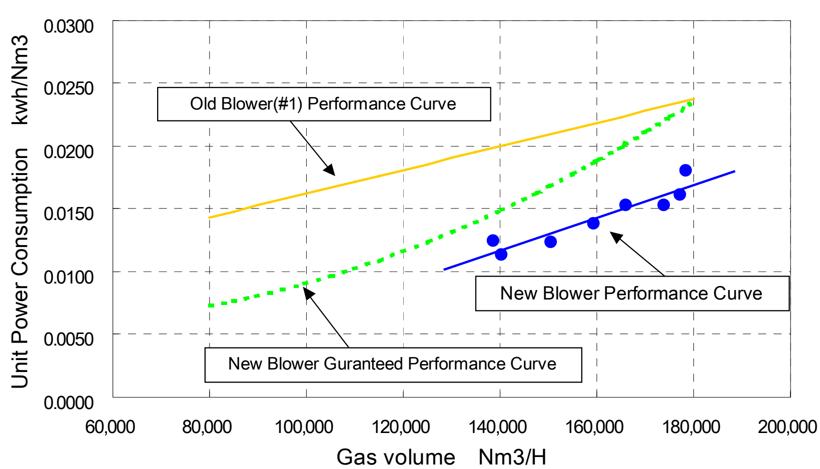
Gas Cleaning System



	Humidifier	Cooling Tower	Gas Cooler	Wet type E.S.P.	total
New System	306	420	-	1,390	2,116
Old System	480	510	549	1,882	3,421
differnce	-174	-90	-549	-492	-1,305

Unit: kPa

Unit Power Consumption of SO2 Blower



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Introduction of Converter Boiler – (1)

Old line

New line

Inter Cooler Fan : 210kW

Converter Boiler

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Introduction of Converter Boiler –(2)

Old line

New line

SO3 Cooler Fan : 160+290 kW

Economizer

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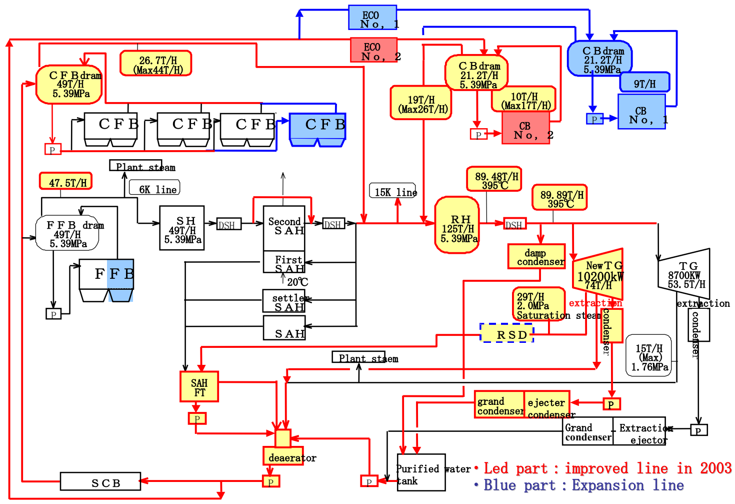
Boiler Turbine Flow sheet



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Boiler & Turbine Generator

No. 1 Steam Turbine

(8,700kW)

No. 2 Steam Turbine

(10,200kW)

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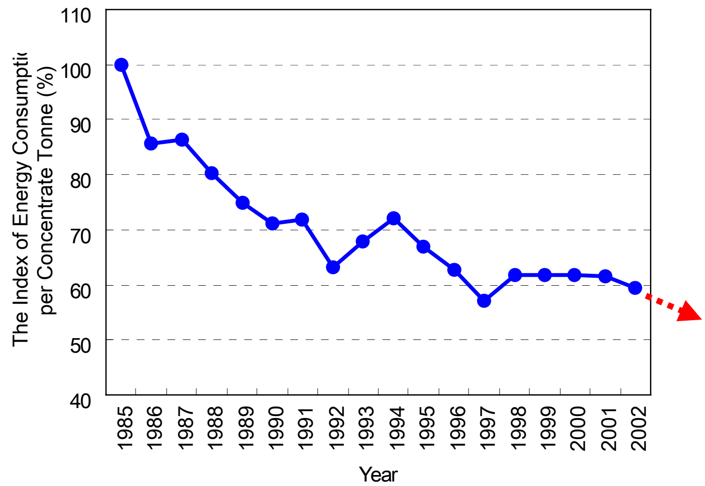
Trend of Unit Energy Consumption at Toyo Smelter



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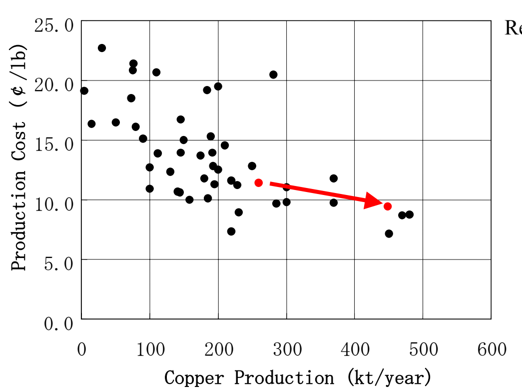
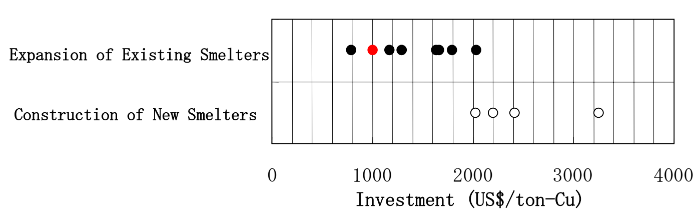
Copper production vs Production Costs

Ref : Brook Hunt 2000





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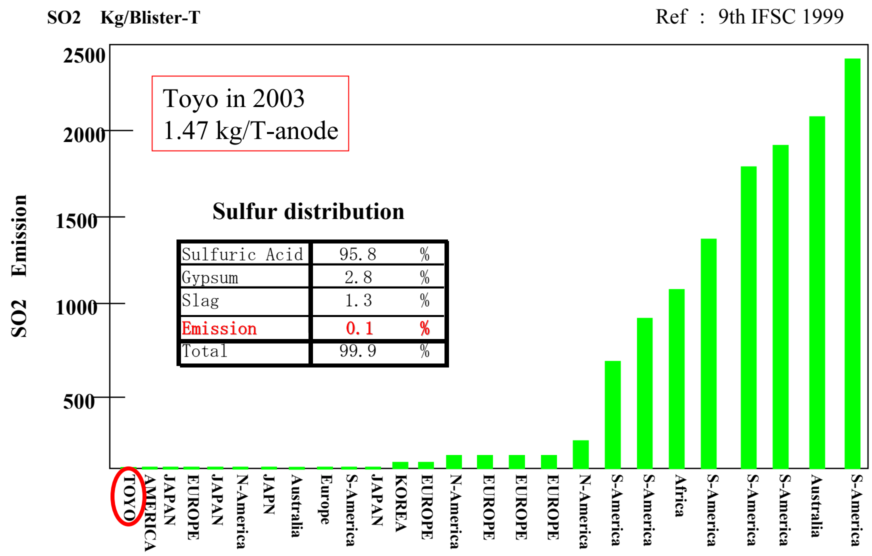
SO2 Emissions per Ton of Anode



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Sources of Copper of Japan

Sources of Copper Imports by Mine Configuration

	1970	1975	1980	1985	1990	1995	2000	2001
Independently Developed Mines	40.8	51.3	45.8	40.2	54.4	198.8	557	551.9
Percentage	10.9%	7.4%	5.70%	4.80%	5.80%	18.50%	41.30%	42.90%
Financed Mines	103	345.5	297.9	275.3	312	342.2	446.9	395.8
Percentage	27.5%	49.9%	37.00%	32.60%	33.50%	31.80%	33.20%	30.80%
Other Mines	230.1	295.4	461	530.1	564	534.2	344	337.3
Percentage	61.5%	42.7%	57.30%	62.70%	60.60%	49.70%	25.50%	26.20%
Total	373.9	692.2	804.7	845.6	930.4	1075.2	1347.9	1285

(Unit: equivalent 1000 tonne of Cu)

Note:

Independently Developed Mines: mines in which a company has been involved from the exploration stages and in which the company has invested; imports procured from mines where there is capital participation and the procuring company is involved in capital participation.

Financed Mines: mines where there has been both financing and capital participation by companies but where the procuring company is not involved in financing or investment.

Other Mines: other than those described above

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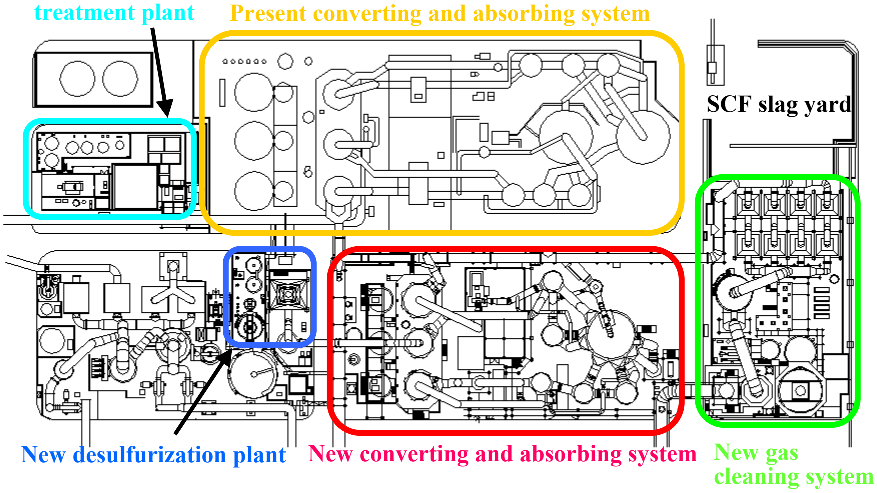
Layout of New Acid Plant



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Ranking of Copper Production in the world

Ref : Brook Hunt 2000

Rank	Smelter	Country	Copper production (t/year)
1	Chuquicamata	Chili	480,000
2	LG Nikko	Korea	452,000
	Toyo after expansion	Japan	450,000
3	Saganoseki	Japan	450,000
4	Caletones	Chili	378,000
5	Norddeutche Affinerie	Germany	370,000
6	Guixi	China	340,000
7	Atlantic Copper	Spain	300,000
8	Souther	Peru	290,000
9	La Caridad	Mexico	285,000
10	Kennecot	U.S.A	265,000
11	Toyo	Japan	260,000
12	Naosh	Japan	235,000
13	Onahama	Japan	228,000
14	Tamano	Japan	225,000
15	Mount Isa	Australia	210,000

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Acid Plant Capacity

	#1 (Present Plant)	#2 (New Plant)	Total
Gas Cleaning System			
Inlet Gas Volume (Nm^3/hr)	(165,000)	275,000	275,000
Converter and Absorber			
Inlet SO2 Density (vol %)	13	13	-
SO2 Volume (Nm^3/hr)	22,750	22,100	44,850
Sulfuric Acid Production Capacity(tons/day)	2,000	2,000	4,000

Converter

Old line

New line

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De-Sulfurization Tower

Old line

New line

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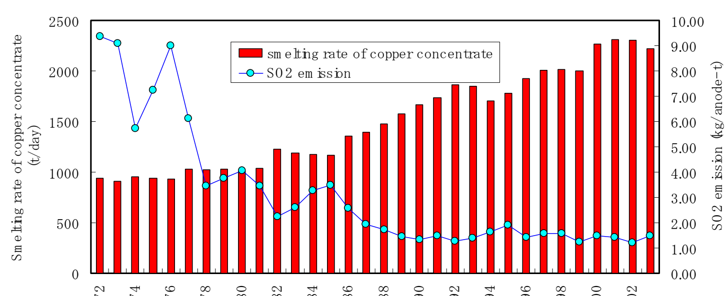
SO2 emission and smelting rate of copper concentrate



Sulfur distribution

Sulfuric Acid	95.8	%
Gypsum	2.8	%
Slag	1.3	%
Emission	0.1	%
Total	99.9	%

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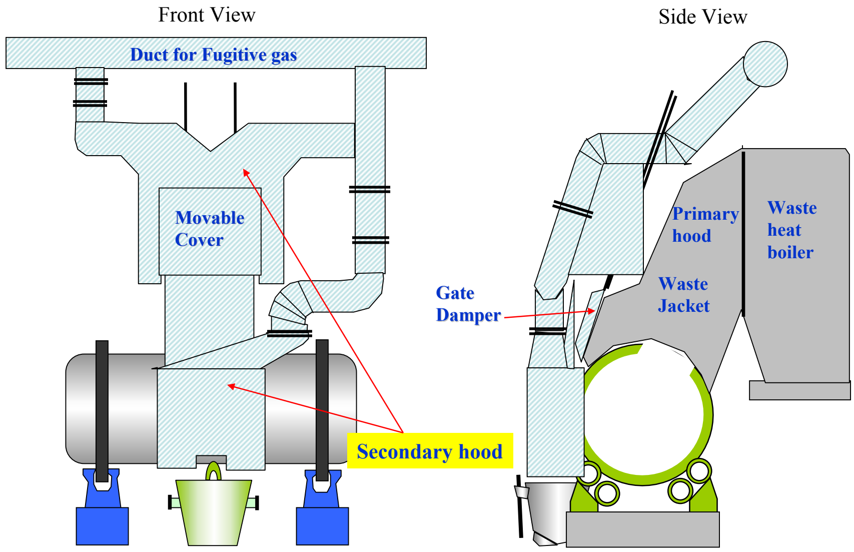
Fugitive gas collecting system



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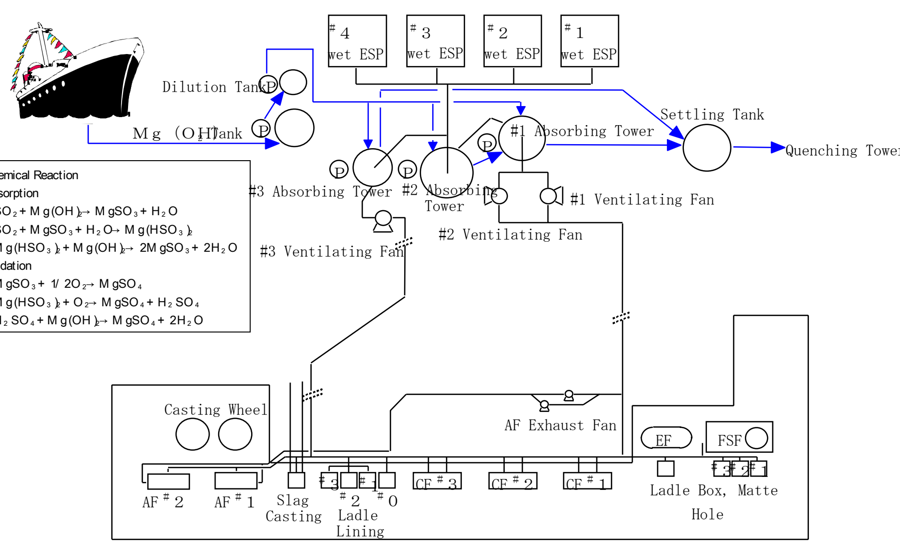
Fugitive Gas Collecting System



Chemical Reaction

Absorption

$SO_2 + Mg(OH)_2 \rightarrow MgSO_3 + H_2O$

$SO_2 + MgSO_3 + H_2O \rightarrow Mg(HSO_3)_2$

$Mg(HSO_3)_2 + Mg(OH)_2 \rightarrow 2MgSO_3 + 2H_2O$

Oxidation

$MgSO_3 + 1/2O_2 \rightarrow MgSO_4$

$Mg(HSO_3)_2 + O_2 \rightarrow MgSO_4 + H_2SO_4$

$H_2SO_4 + Mg(OH)_2 \rightarrow MgSO_4 + 2H_2O$

SUMITOMO METAL MINING CO., LTD.

Expansion Schedule

	2002	2003	2004	2005	2006	2007
Capacity of copper production (KT/Y)	270	300	330	400	400	450
Dryer		Install New Dryer				
Flash Furnace		Rebuild		Renew Waste Heat Boiler		
Slag Cleaning Furnace		Rebuild				
Converter		2hot-2blowing		3hot-2blowing (No.4CF)		
Anode Furnace				Enlarge Furnace		
Oxygen Plant		Install New Cryogenic Type				
Steam turbine		Install No.2 Steam Turbine				
Acid Plant		Construct New Acid Plant				
Tank house			←	150KT ISA process Start	→	
Precious Metal Plant			Start Au production →			

SUMITOMO METAL MINING CO., LTD.

REMARKS ON THE EXECUTION OF AN ENERGY EFFICIENCY PROGRAMME IN MEXICO MINERA AUTLAN'S MOLANGO MINING UNIT

NORBERTO I. ZAVALA-ARNAUD
Mining Director, Compañía Minera Autlán, S.A. de C.V.

Summary

Efficient use of energy is simply vital for any country since its significant social and economic impact. Protecting non-renewable resources and reducing pollution in both, industrial production processes and energy use, are paramount issues for mankind. However, we should admit that there is another reason for which energy efficiency is critical: the growing cost of energy in the world.

Minera Autlán is the leading manganese ore and ferroalloy producer in Mexico and utilises pyro-metallurgical processes, which make the company a very important natural gas and electricity consumer. These energy sources are relevant cost inputs for manganese and ferroalloys.

Therefore, Minera Autlán is fully committed to getting energy efficiency, especially in the last years. The company is permanently working on identifying potential ways to improving energy efficiency, developing and executing projects in this regard and following up the results. This strategy implies a virtuous circle, which leads us to gradually reduce the energy consumption in our production process. As in any optimisation process, the marginal advantages obtained will indicate the scope and limits of our search.

1. Foreword

Minera Autlán was established in 1953 in a town called Autlán, located in the State of Jalisco, Mexico to exploit a manganese ore deposit. At that time, the type of the ore exploited allowed the company to use a relatively simply industrial process to market the ores. Later on, Minera Autlán began to explore a new manganese ore deposit in the Molango Manganiferous District, located in the State of Hidalgo. This place includes one of the most important manganese ore deposits in the world. Notwithstanding, the physical and chemical characteristics of the new ore required Minera Autlán to develop another technological process.

Then, Minera Autlán commissioned a nodulisation kiln in 1968. This is a horizontal rotary kiln (diameter: 5 m., length: 114 m.), which is used to calcine the natural ores in order to improve their physical and chemical properties. The new ore obtained is called manganese nodules, which are employed as the main raw material to producing ferroalloys in electric furnaces.

Nowadays, most of the manganese nodule output is used for ferroalloy production at Minera Autlán's plants. Our final products, the manganese ferroalloys, are used as essential raw material for steel production in both Mexico and abroad.

My paper today is focused on the several efforts carried out by the Autlán's Molango Mining Unit to improving energy efficiency in our industrial processes. I will comment especially about our achievements of the last years.

As the audience will see in the course of my presentation, the main achievements take place over the last seven years. Such steady and important attainments should have rendered significant fruits on our costs posted in US dollars, however the unexpected highs recorded by world energy prices in the last years have somewhat offset our savings in energy consumption. Our work and effort to improve energy efficiency is currently critical, because we are committed to finding new efficiency opportunities to balance the high energy prices. We are sure that the path followed by Minera

*Compañía Minera Autlán, S.A. de C.V. – Dirección de Minería

Autlán is the right one, since our main competitors are also facing similar pressures caused by energy prices, and our company is successfully working in this regard.

Minera Autlán has primarily worked on two specific targets:

1. Lessening of natural gas consumption per tonne of finished product from the rotary kiln (MCAL/t)
2. Lessening of electricity consumption per tonne of finished product (KWH/t).

As for electricity, I should mention that the Molango Mining Unit has always been self sufficient, since it owns an electricity generating plant. This plant includes five generators (total capacity of 10.75 MW). Our Worthington engines can use natural gas or diesel as fuel. Usually we use natural gas as the main fuel, and use diesel only in specific cases.

It is noteworthy that the most important savings achieved by Minera Autlán in Molango are those related to the thermal efficiency of our rotary kiln process, since the kiln consumes more than 85% of total energy used in this mining unit. However, we also have reduced the electricity consumption of the plant and mine. Thus, the electricity generating plant currently works with only two generators.

So, even though some efforts were focussed on thermal efficiency and others on electric efficiency, all of them imply energy savings. Such savings are directly related to less natural gas consumption in both, the rotary kiln and the electricity generating plant.

2. Development

2.1 Background

Minera Autlán produces manganese nodules (as manganese oxides) from manganese carbonates. The company uses a rotary kiln for this purpose and the main fuel is natural gas, which is at the same time, one of the most important cost inputs for manganese nodules. As everybody knows, world natural gas prices have gradually increased over the last years and therefore; this is now a critical factor when producing manganese nodules.

Since the commissioning of the rotary kiln in 1968, the company has permanently looked for improving opportunities to get the most out of its efforts on thermal efficiency.

On the other hand, our production process requires the use of high energy consuming equipment, such as the rotary kiln, extractor fans, cooling fans, crushers, compressors, etc. But, we have made decisions to reduce the energy consumptions in this regard too.

I will firstly address the measures we have carried out to reduce the natural gas consumption of the rotary kiln, and later on, I will discuss about our efforts to lessen our electricity consumption.

2.2 Lessening of natural gas consumption at the rotary kiln

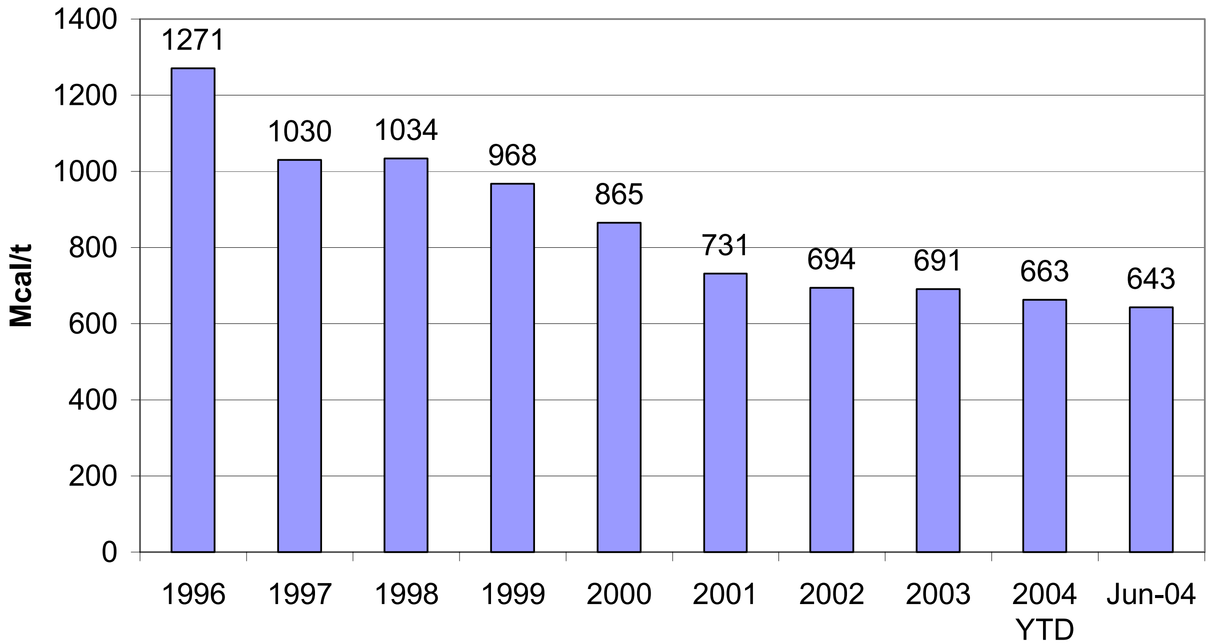
Graph I shows a histogram concerning our natural gas consumption posted in Mcal/t. As it can be seen, we have achieved significant consumption reductions. We could accomplish this goal by working in the most important improving opportunities:

<u>Improving Opportunities</u>

As in most of pyro-metallurgical processes, part of the heat related to the nodulisation of manganese ore, is lost by different ways:

- Throughout conduction, radiation and convection in the kiln structure.
- Through the gases and dust sucked by the shaft fan.
- As sensible heat from manganese nodules.
- Through the re-process of out of size specification manganese nodules.

Graph I: Historical Natural Gas Consumption per Metric Tonne of Output



Moreover, there are other phenomena that take place inside the kiln and that impact on the use of heat:

- Non-standard distribution of heat inside the kiln (because of the suck from the shaft)
- Inefficiency over the heat transmission to the particles feed to the kiln:
    - Due to the size of the particle.
    - Due to the low gas percentage in contact with the ore loading.
- Combustion inefficiency.

<u>Measures applied</u>

Over the time, we have applied several measures to eliminate the inefficiency causes discussed above. I will describe below each cause as well as their effects on the process:

Installation of concrete removers inside the furnace

In order to improve the contact between gases and ores, we set up special devices that we call “refractory concrete removers”. These are a kind of small walls and are used to remove or turn over the ore loading as soon as it goes through them. Without these removers, part of the load would remain on the top in contact with gases, while the other part would be in the bottom of the kiln taking advantage of the heat from the refractory concrete. Therefore, other part of the load would be in the middle of the both loads mentioned above and the disadvantage would be a minor temperature. I would like to explain clearly the importance of the concrete removers, using a simply analogy. Please imagine the preparation of a cake; if it is cooked poorly the surface of the cake will be toasted but inside you will find an uncooked cake.

Our concrete removers avoid that the different loading layers remain inert. By contrast, using our removers, the material is mixed and the heat transmission is homogenised throughout all their particles.

Set up of metallic lifters inside the kiln

Taking into account the positive experience in the use of the removers and looking for increasing the contact between the heat derived from the gases and our ores, the company installed three series of 70 metallic lifters in different stages. This measure has been the most important one, since the marginal benefits achieved. We attribute the lifters 50% of the savings we have accomplished since 1972 to date. The lifters we use lift the loading and pour it over the top of the kiln, taking advantage of the heat from gases. Otherwise, this contact would be impossible. Additionally, other improvements we have developed in the course of the years, have allowed us to improve the energy efficiency by 6.51%.

Increase of combustion air temperature

As I have discussed above, a great part of the heat provided to the process is lost in the production of manganese nodules. These nodules get out from the kiln at more than 1,000° C.

Manganese nodules are cooled through a special reciprocating cooler made of four fans. Then, there is a heat interchange between nodules (hot) and air (cold). So, we get nodules at lower temperature with stabilised chemical and metallurgical properties, and on the other hand, hot air at 600-800° C.

This air is used for combustion. The old system only allowed carrying the air to the burners at 180° C. By using our new system installed in 2000, we have air for combustion at 400° C. This system consists of a high-temperature resistance fan and a technically isolated duct system. We should recall that, in the cement production processes, air is used directly from the cooler to the kiln through the same shaft suck. This allows taking advantage of the maximum temperature of air.

However, we cannot do the same in our process because the contact of the cold air with the just made nodules causes an adverse re-oxidation, impacting negatively on the quality of our product. But, we continue to find the way to carry the air to our burners keeping its highest temperature. Meanwhile, the heat recovery we have achieved using our method has contributed with a reduction of 10.66% of total.

Reduction of re-circulation of nodule fines

We call “nodule fines” to the manganese nodules sized less than ¼”. Our ferroalloy plants do not consume this product because it causes operation problems. Therefore, most of this product is re-processed in the kiln, although a minor part is marketed. In order to resize the nodule, we require providing almost 50% of the heat necessary for transforming crude ore into manganese nodules, which is well beyond our aspirations.

By lessening the size of our nodule fines, which are re-processed in the kiln, we got that we re-circulate now 45% of what we re-circulated in the past (7 tonne/hr vs 16 tonne/hr). The company was able to accomplish this goal by testing several kinds of mesh in the screening system of nodules. However, we should admit that the increasing production of -4”+1” vs -1/2” +1/4” nodules played a crucial role in our success. These size improvements are primarily due to better process controls, experience and scientific development.

2.3 Lessening of electric energy consumption

Minera Autlán, as most of other mining companies in the world is a high-electricity consumer. The Molango Mining Unit has always been self sufficient in electricity because it has its own electricity generating plant since the establishment of Molango. As I discussed above, the plant includes five generators (total capacity of 10.75 MW). Our Worthington engines can use natural gas or diesel as fuel. Since 1999, when the Molango’s demand was 5 MW, the company began to implement specific measures to lessen the electricity consumption related to both, the industrial plant and the other areas of Molango. However, the most significant measures were focused on the Treatment Plant, where the unit electricity consumption decreased notably.

Specific Measures

We found that the fans used in the plant represented one of the most important improving opportunities to reduce our electricity consumption.

On the other hand, by looking for lessening natural gas consumption, we also found that we could reduce electricity consumption, replacing certain equipment that allowed us to get both objectives. I will explain each one of our measures.

Table I shows a summary of the results we achieved when applied the three concrete actions in our equipment.

Table I

Equipment	Power (HP)	% Savings	Saved Power (HP)	Measures
VX-2	300	100	300	Hot Air Fan (HAF)
VDQS	150	100	150	Hot Air Fan (HAF)
VDQI	150	100	150	Hot Air Fan (HAF)
VAR	250	80	200	Drive
VE-3	125	30	38	Drive
VE-4	100	70	70	Drive
VTIH	1,000	10	100	Seal
Compressor	250	80	200	Use of a smaller compressor
Total Savings			***1,208***	

Drives

As in most pyro-metallurgical plants, we extensively use induced draft fans (radial and axial flux centrifugal fans). We are aware that these kinds of equipment (related to hydraulic turbo-machines and centrifugal pumps) operate with very specific features. The first one is that the flux is directly proportional with the rotation speed. The second one is that pressure changes with the square of speed. Most importantly, the third one is that power changes with the cube of speed. Usually, the flux of this kind of equipment is regulated through floodgates powered by electromechanical, pneumatic or hydraulic devices. Although this is a simple and cheap way to make such regulation (at least for its initial investment), it may be very expensive in the long run in some cases. This operation cost is especially expensive when the fans work with their floodgates partially closed. In these cases, the energy consumption is great and economically unproductive. We carried out an analysis in order to detect the best fans according to their investment return. So, we began to install drives (solid state speed variators) for each one of the fans. The table above shows the fans where the drives were installed, as well as the result we got.

Hot Air Fan Installation (HAF)

We installed a high-temperature and abrasion resistance fan as part of our plan to reduce the gas consumption. The design of this new fan allowed us to replace four fans. Three of such four fans were used for the combustion air at the burners. The other fan worked as an extractor at the nodule cooler. So, our savings consisted of three fans, which are no longer used and that are exhibited in the table 1 as HAF. This is the most significant actions and represents 50% of the savings achieved by the plant.

Compressed Air Use

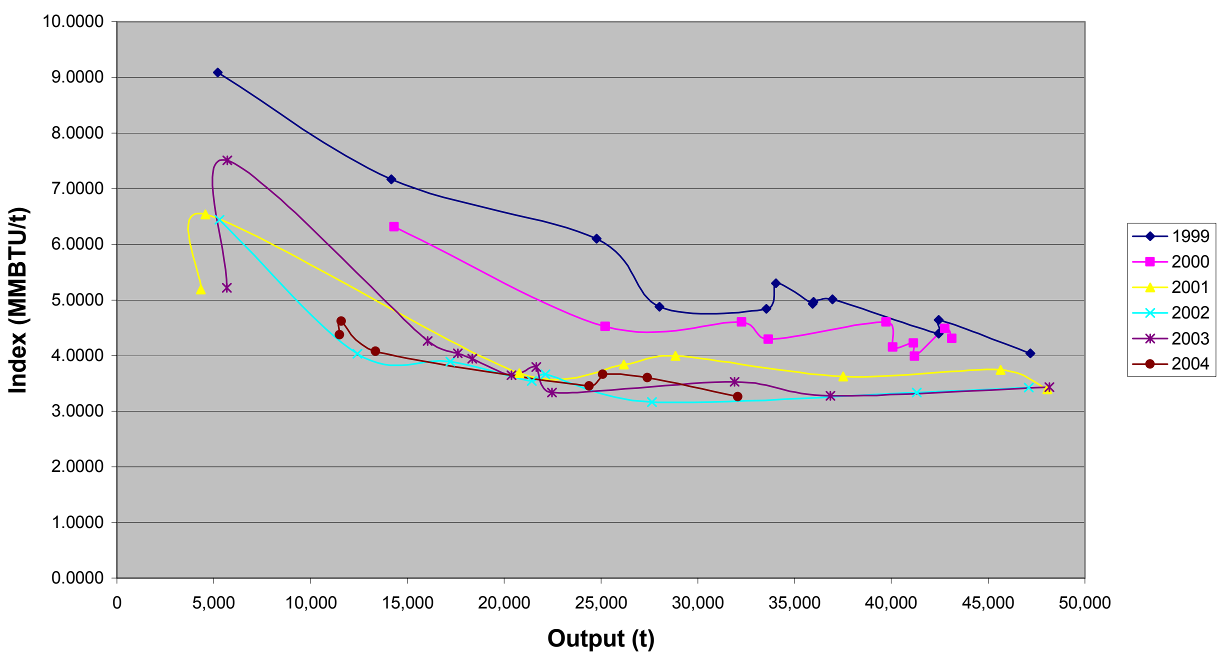
The plant worked with a compressed air system provided by a reciprocating compressor of pistons (250 HP). Taking into account the current operation conditions of the plant, we concluded that we could use just a compressor of 50 HP, by modifying slightly certain equipments. The 250 HP compressor is now only used in special situations, as when major kiln repairs are needed, because we require more flux.

3. Conclusion

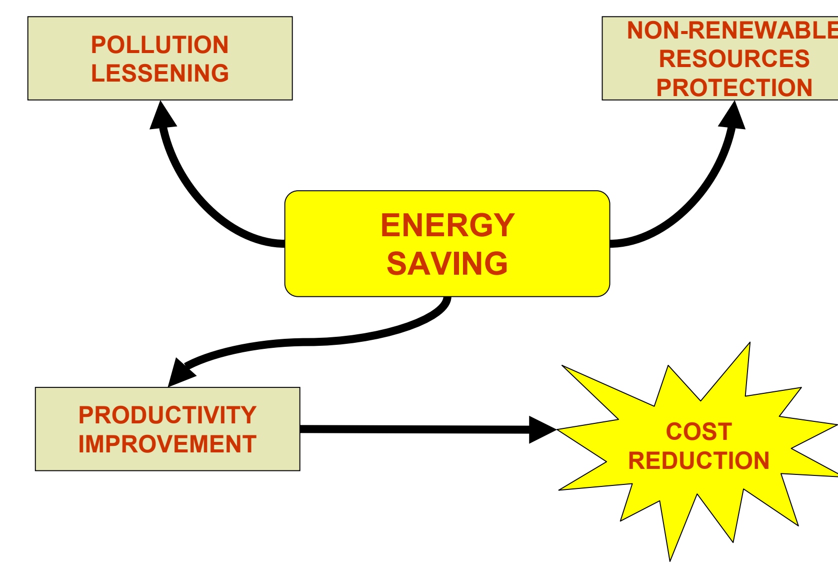
All the measures we have taken have significantly contributed to reduce considerably our energy consumption. Graph II shows the improvement of the Global Energy Index concerning the Molango Mining Unit.

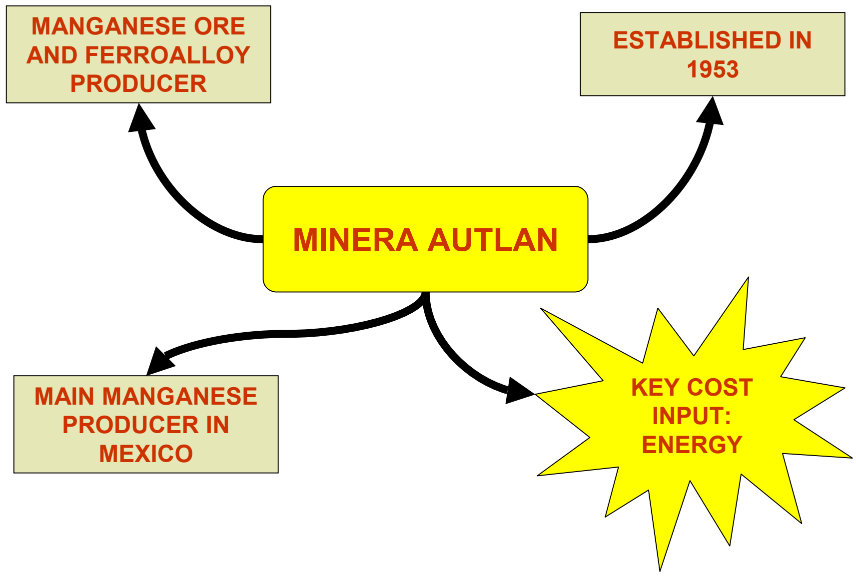
The results we have achieved prompt us to continue to find more ways to increase our energy efficiency. Notwithstanding we require technology investments to continue to progress in this regard in the light of the results of the last two years. Since we are self sufficient in electricity, we do not have access to the support given by local authorities to make more investments in energy affairs. However, we expect some changes in this regard soon so that there is a positive impact on the industry.

Graph II: Global Energy Index

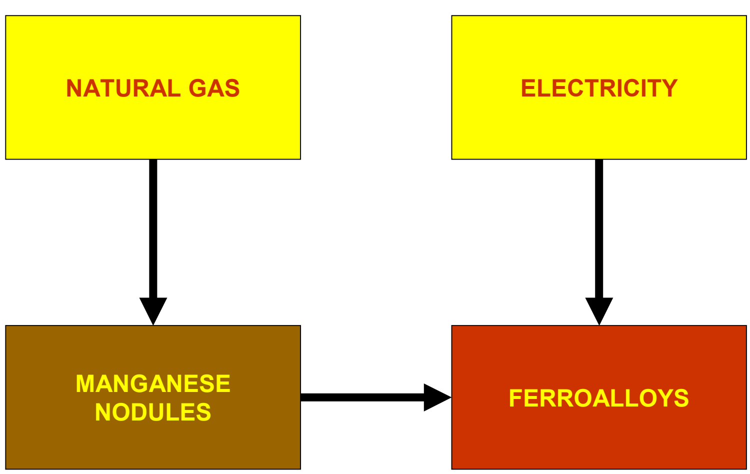


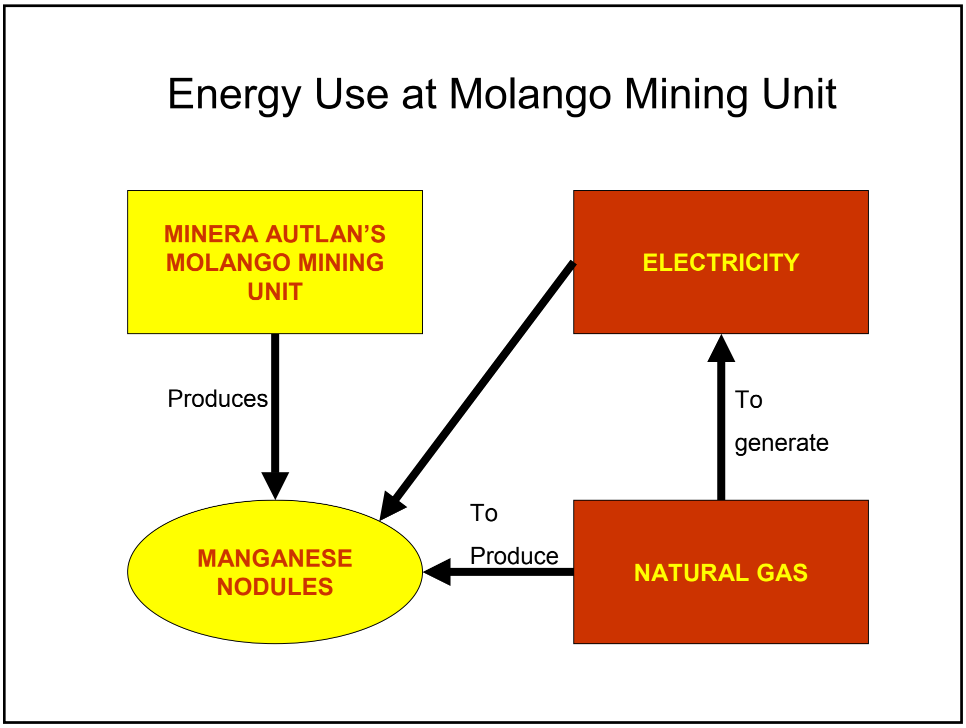

REMARKS ON THE EXECUTION OF AN ENERGY EFFICIENCY PROGRAMME IN MEXICO
MINERA AUTLAN´S MOLANGO MINING UNIT

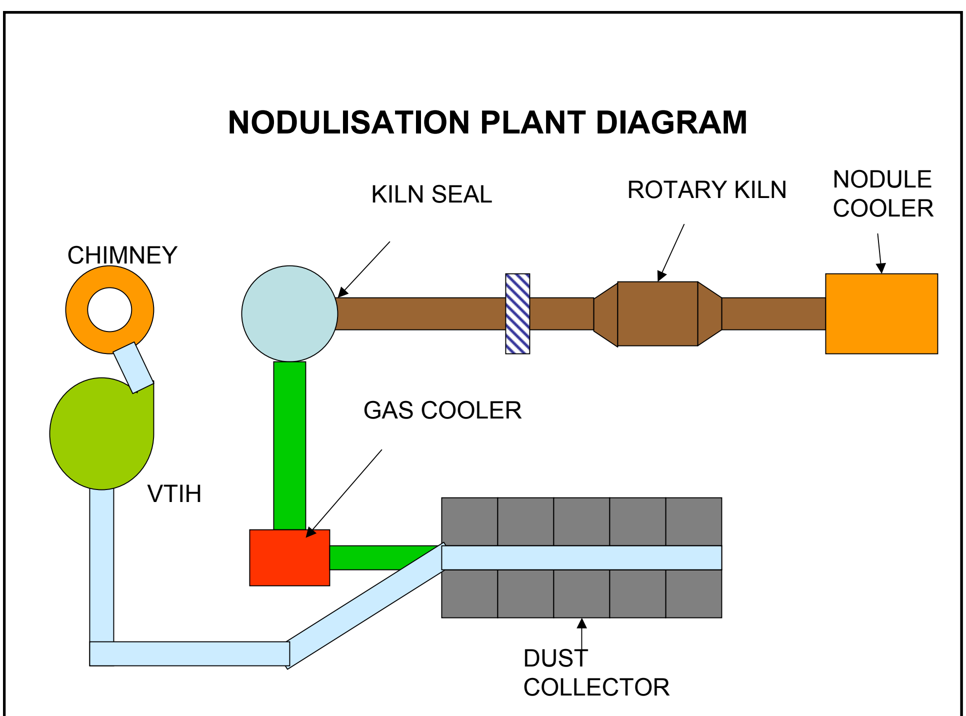

POLLUTION LESSENING
NON-RENEWABLE RESOURCES PROTECTION
ENERGY SAVING
PRODUCTIVITY IMPROVEMENT
COST REDUCTION



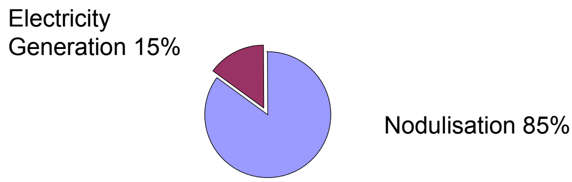
Minera Autlán's Main Raw Materials and Products

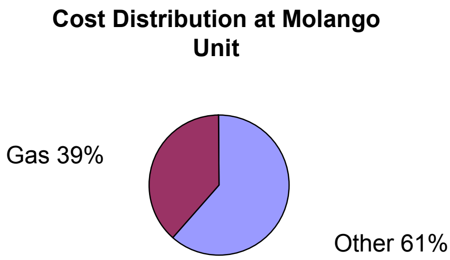


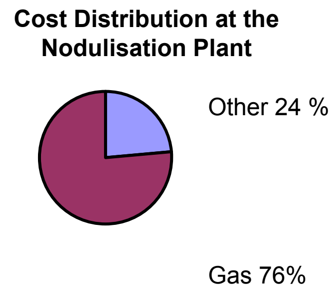

Energy Use at Molango Mining Unit
MINERA AUTLAN'S MOLANGO MINING UNIT
ELECTRICITY
Produces
To generate
To Produce
MANGANESE NODULES
NATURAL GAS


NODULISATION PLANT DIAGRAM
KILN SEAL
ROTARY KILN
NODULE COOLER
CHIMNEY
GAS COOLER
VTIH
DUST COLLECTOR

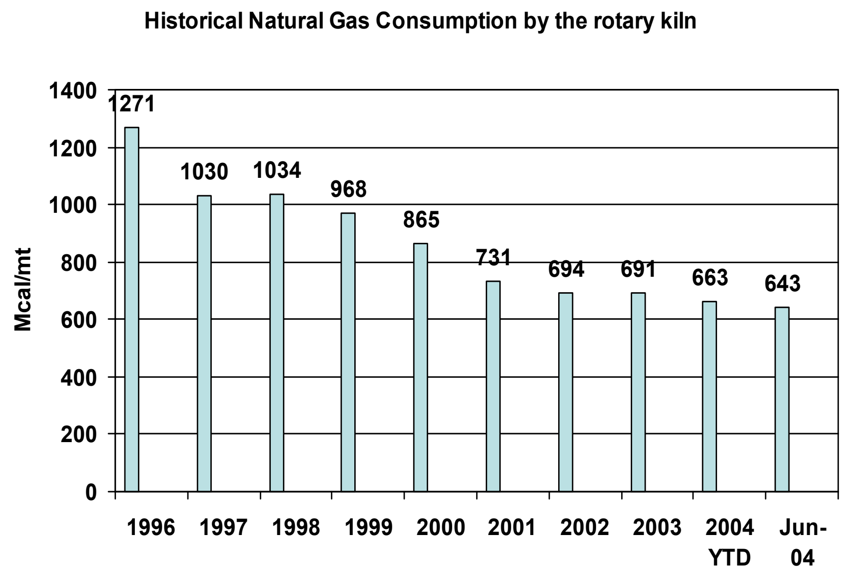
Natural Gas Use at Molango







The current conditions have prompted us to look for savings in our thermal and electric energy consumption in a permanent way

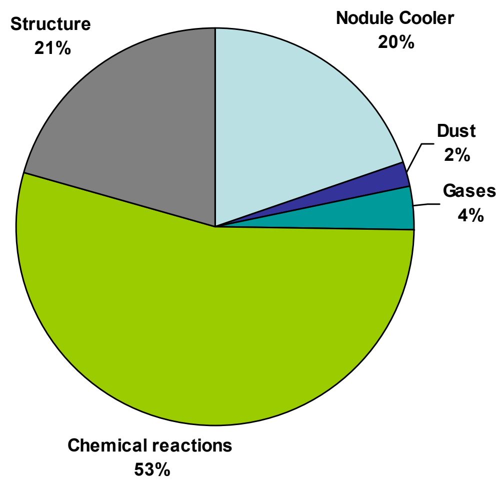


Improving Opportunities

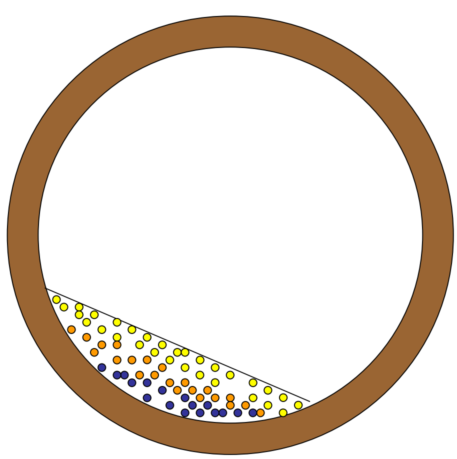
As in most of pyro-metallurgical processes, part of the heat related to the nodulization of manganese ore, is lost by different ways:

•Throughout conduction, radiation and convection in the kiln structure.
•Through the gases and dust sucked by the shaft fan.
•As actual heat from manganese nodules.

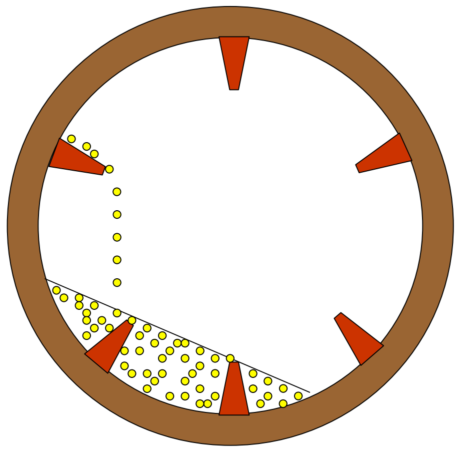
Rotary Kiln Thermal Balance



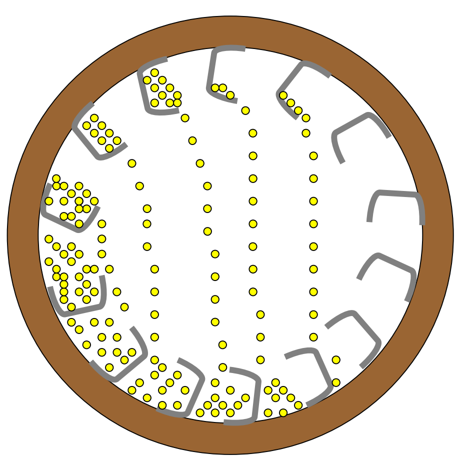
1.- Installation of Concrete Removers inside the Rotary Kiln



Installation of Concrete Removers inside the Rotary Kiln

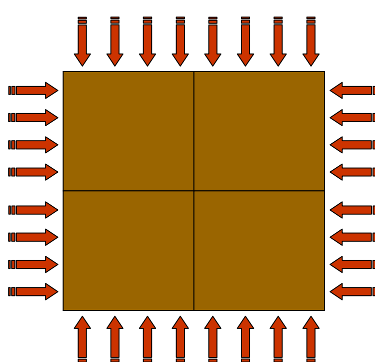


2.- Installation of Metallic Lifters inside the kiln

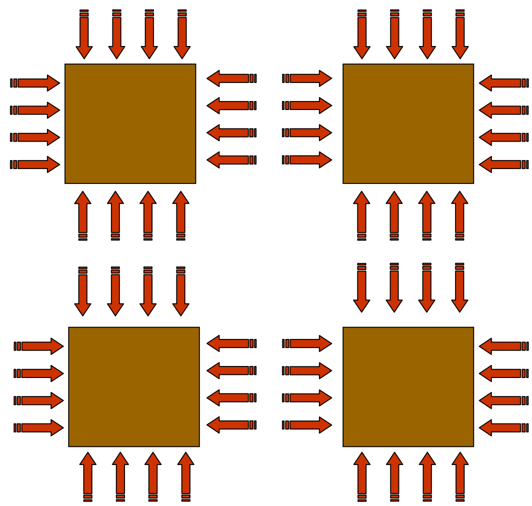


3.- Reduction of the size of the ore feeded to the kiln

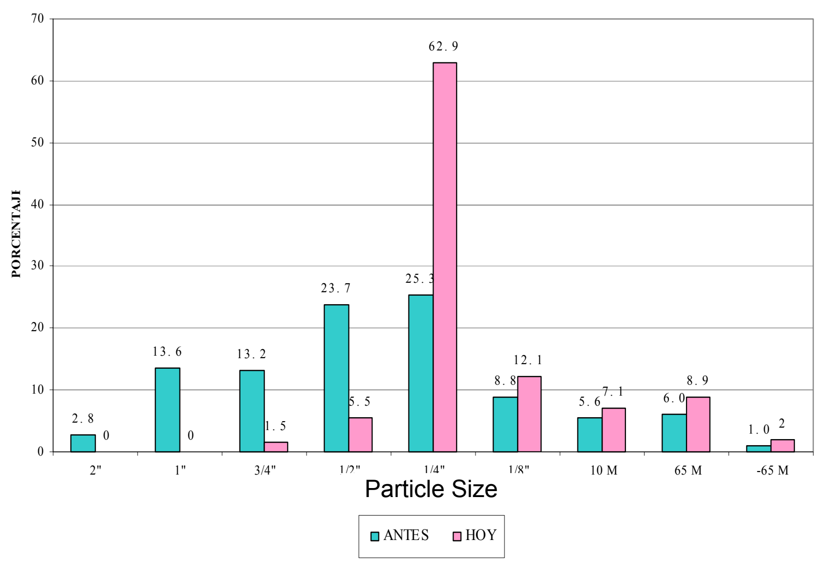
Heat transfer in a large particle (ie. 32 thermal units / surface unit)



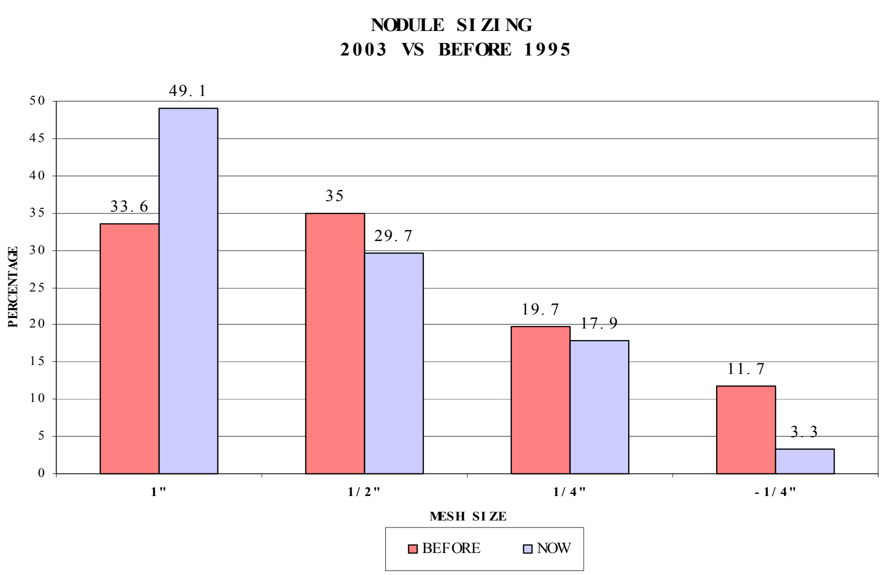
Heat transfer in a small particle (ie. 64 thermal units / surface unit)



Feed Sizing to the kiln 2003 vs Before 1995

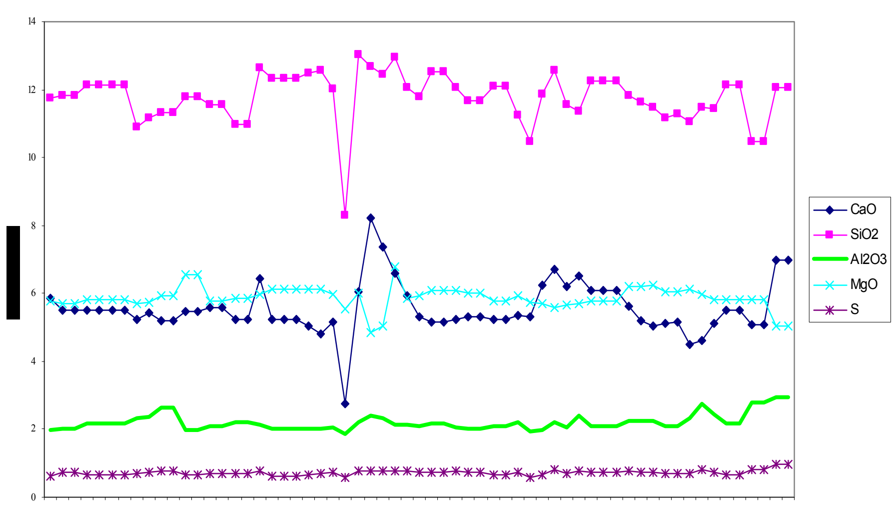


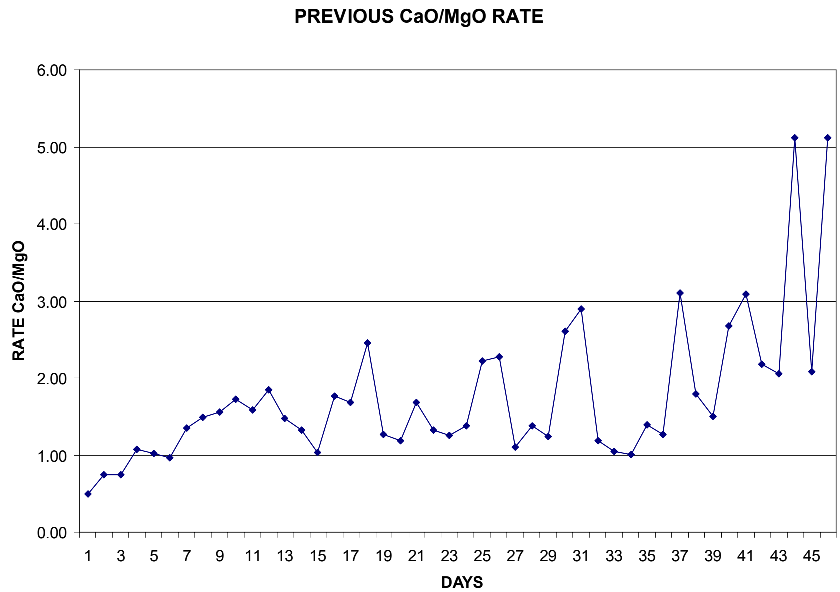
Nodule sizing has also improved. This has allowed us to reduce the re-circulation of manganese nodule fines
inside the kiln, as can be seen in the next slide



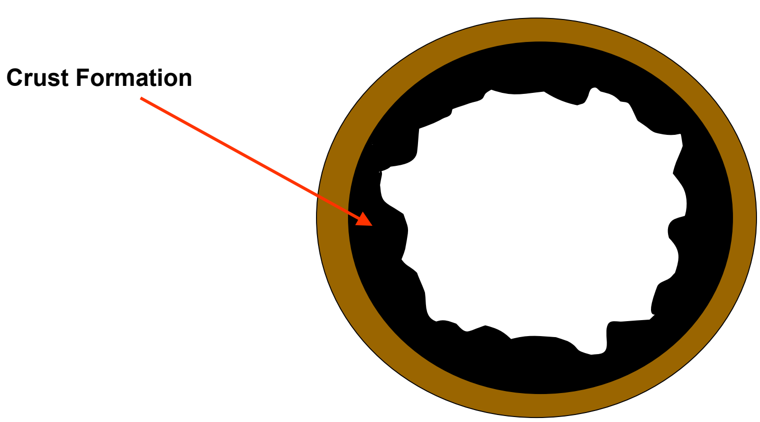
4.- We have also worked to get more stability in the chemical composition of the ore

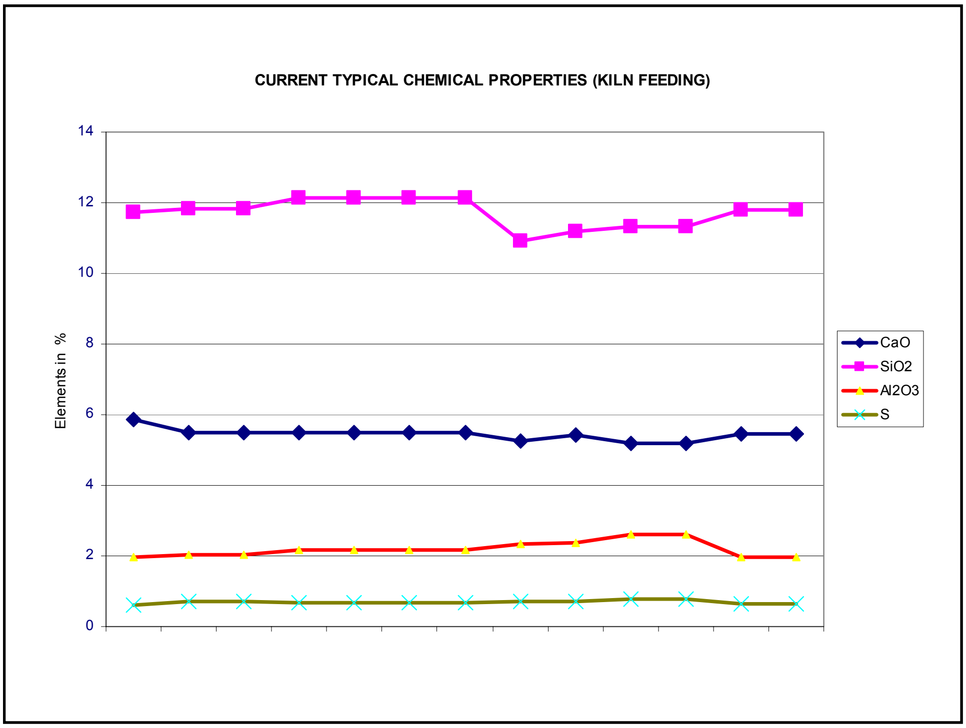
PREVIOUS TYPICAL CHEMICAL PROPERTIES (KILN FEEDING)



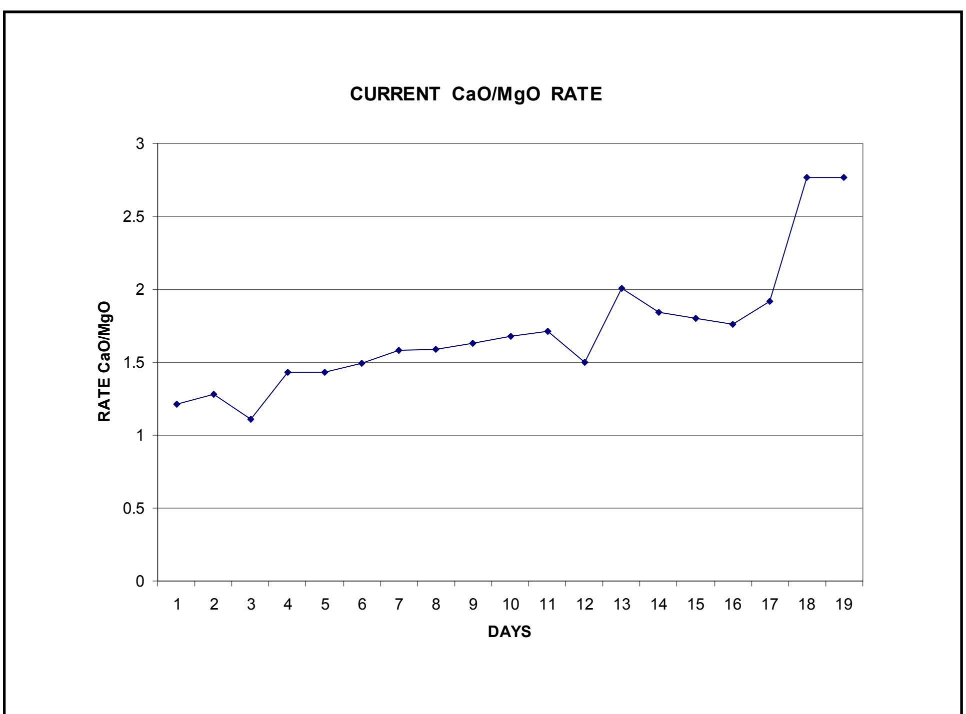


Crust formation inside the kiln because of a lack of chemical control





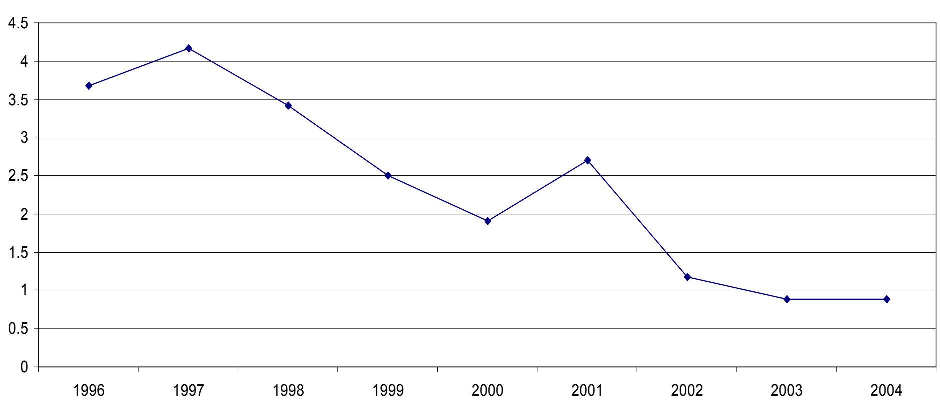
CURRENT TYPICAL CHEMICAL PROPERTIES (KILN FEEDING)
Elements in %
14
12
10
8
6
4
2
0
CaO
SiO2
Al2O3
S



CURRENT CaO/MgO RATE
RATE CaO/MgO
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
DAYS

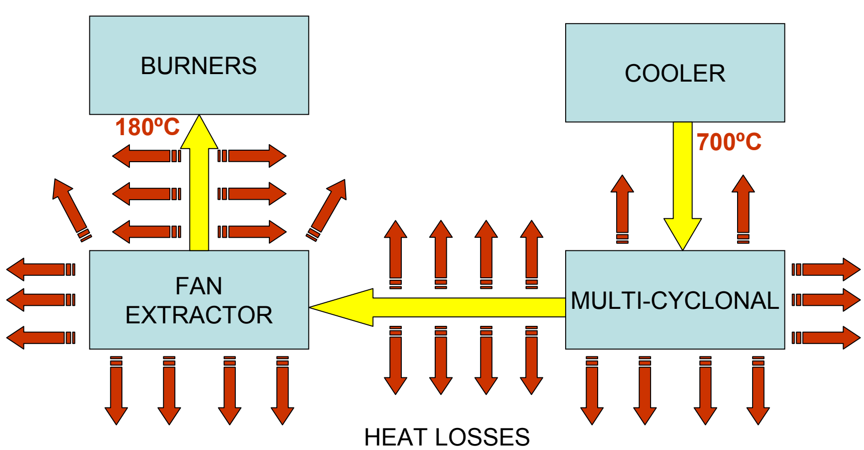
Thanks to the measures taken, crust formation has reduced, efficiency has increased and gas consumption has decreased

Annual lost hours Crust Formation

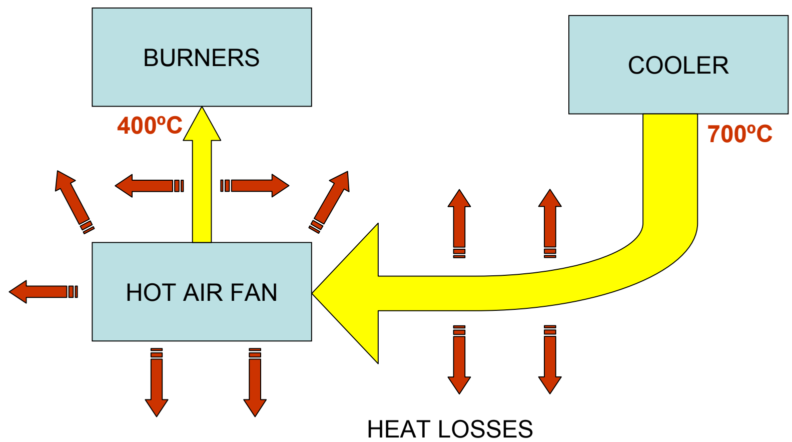


5.- Increase of combustion air temperature

Previous design of hot air recovery system

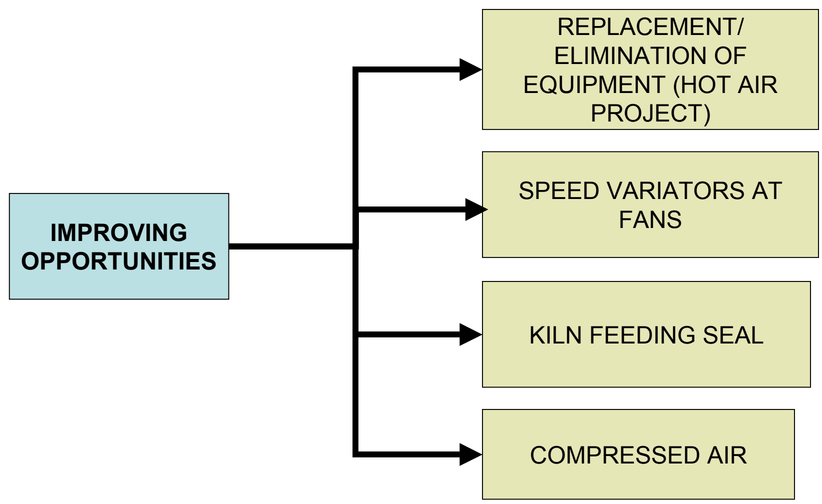


Modified design of hot air recovery system



6.- Lessening of Electricity Consumption

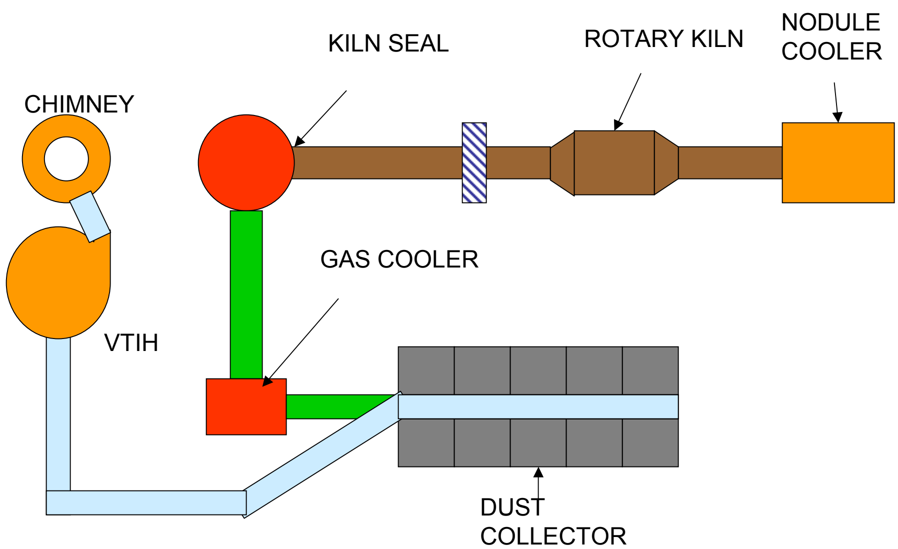
We took advantage of several Improving Opportunities



Feeding Seal

- We modified the design of the kiln feeding seal in order to eliminate false air inflow to the system, and then save gas and electricity

NODULISATION PLANT DIAGRAM



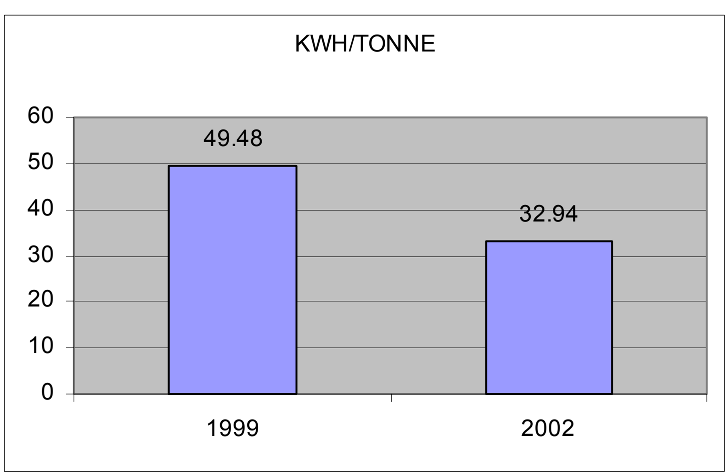
Summary of measures implemented and electricity savings

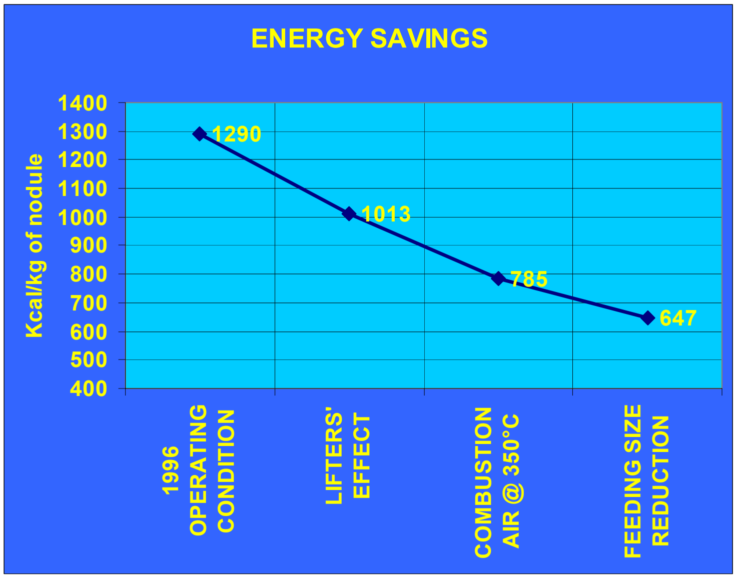
Equipment	Power (HP)	% Savings	Saved Power (HP)	Measures
VX-2	300	100	300	Hot Air Fan (HAF)
VDQS	150	100	150	Hot Air Fan (HAF)
VDQI	150	100	150	Hot Air Fan (HAF)
VAR	250	80	200	Speed Variator
VE-3	125	30	38	Speed Variator
VE-4	100	70	70	Speed Variator
VTIH	1,000	10	100	Seal
Compressor	250	80	200	Use of a smaller compressor
Total Savings			***1,208***	

Electricity savings results

- Previously, we operated an electricity generating plant with 3 generators of 2 MW each one (total nominal capacity: 6 MW)
- Currently, we operate a generator of 2 MW and other one of 2.75 MW. (total capacity: 4.75 MW). Maximum demand is 3.6 MW

Reduction of unit consumption of electricity at the plant





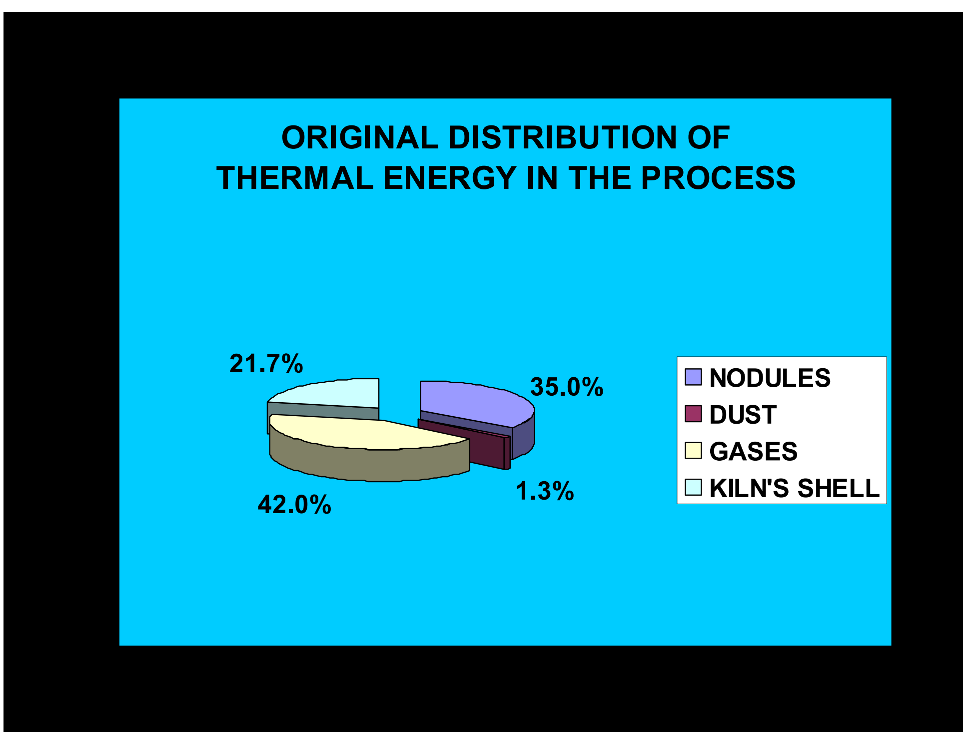
Cost – Benefit Analysis

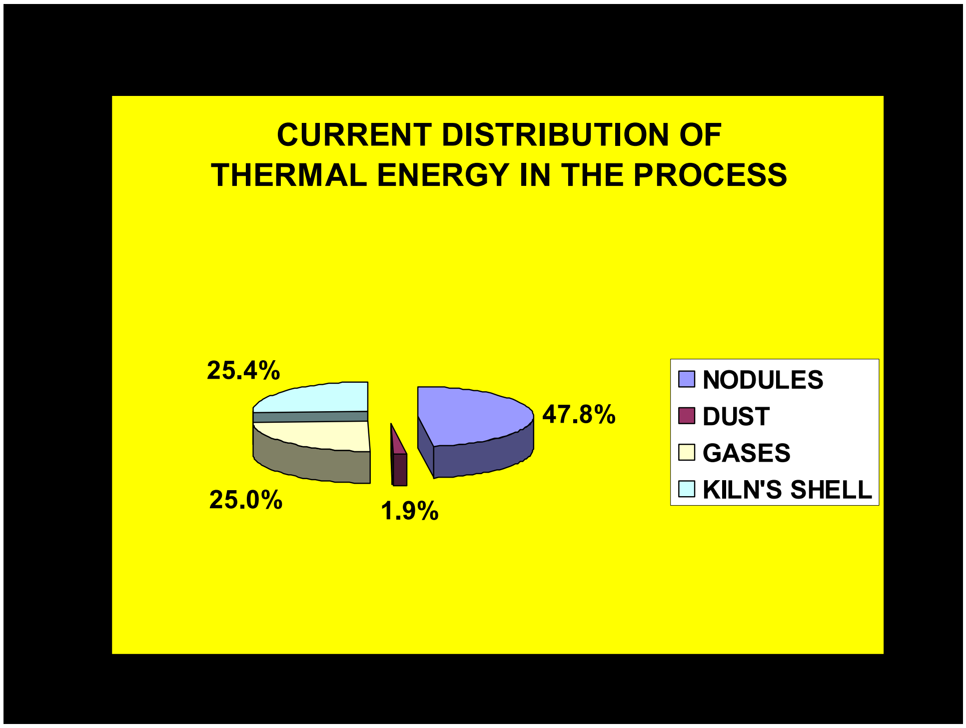
- 1996 – ytd investments concerning energy savings
  - **USD 350,000**

- 1996 – ytd financial savings:
  - **USD 15,210,200**

Conclusion

- All companies are able to look for energy saving opportunities in a lesser or a greater extent.
- This usually implies positive economic, environmental and social impacts.
- It is a paramount duty keeping our interest in looking for new improving opportunities and following up the relevant decisions.





CURRENT DISTRIBUTION OF
THERMAL ENERGY IN THE PROCESS
25.4%
47.8%
25.0%
1.9%
NODULES
DUST
GASES
KILN'S SHELL

ENERGY CONSUMPTION OF THE CHILEAN COPPER MINING SECTOR 1992-2000

PIMENTEL, SARA
International and Environmental Affairs Unit
Chilean Copper Commission
CHILE

ABSTRACT

This paper presents a diagnosis of the Chilean copper mining industry situation in regards of its energy consumptions. At the same time, it is analyzed the form in which the global and unitary consumptions of the different areas of copper processing have evolved within the period that this study covers (1992 – 2000), as well as the key factors in the changes occurred.

The base information used to build the study was given by the copper mining companies in a disaggregated form, released by areas, stages and processes, distinguishing between consumption of electric energy and the different types of fuels.

The results show that while the country's copper production increased 138% in a period of 9 years, the consumption of energy associated to this production only increased 90%.This is also reflected in the reduction of the global unitary coefficients of energy consumption which decrease about 20%, impelled mostly by a reduction in fuels consumption.

The consumption of energy of the copper mining sector in Chile, in the period covered by the study, fluctuates around 8% of the total energy consumed by the country, reaching its maximum value in the year 2000, with a participation of 10%. If it is considered that the contribution of the mining sector to the national GDP in the same period is about 8%, then, it is possible to conclude that the copper mining activity consumes energy proportionally to its contribution to the GDP .

1. INTRODUCTION

In order to fulfill the commitments acquired by the country when ratifying the United Nations' Framework Convention on Climate Change, in 1998 the Chilean Copper Commission actively participated in the elaboration and revision of the chapter corresponding to the copper mining sector of the National Inventory of Green House Gases which was based on the years 1993 and 1994. The inventory was made following the methodology established by the Intergovernmental Panel on Climate Change (IPCC) on the basis of the energy consumptions, fuel and electric energy, of each one of the areas of the copper refining process.

It is within this context that the Chilean Copper Commission decided to carry out a project focused on determining the evolution of the sector's energy consumptions, in the period between the years 1992 and 1998, which it was later complemented with the data obtained for the years 1999 and 2000 by the Efficient Use of Energy Group of the Clean Production Framework Agreement of the Large Scale Mining Sector.

The study's objective was, in one hand, to establish the unitary and global energy consumption coefficients (fuels and electric energy) for each one of the copper processing stages and through them, to analyze the way in which the sector's energy consumption has evolved along the decade, due to changes on technological and commercial product portfolio, and other factors.

2. METHODOLOGY

In order to approach the study, the copper refining process was determined by defining the different areas, stages and processes that generate flows of characteristic materials, whose volume decreases as the product's refining degree improves.

With these definitions we generate a survey and sent it to the main producing and refining companies, covering approximately a 97% of Chile's copper production. The survey was specific and segmented, considering the areas, stages and characteristic processes of each company, according to the knowledge the Chilean Copper Commission has of them.

The survey aimed to obtain data, as disaggregated as possible, in respect to energy consumption (fuels and electric energy), flow of inter-area material, technologies, production in each stage, generation and disposition of residues, among other antecedents.

With the information provided by the companies, the consumption of fuels and electric energy in each one of the copper production areas, in the period considered by the study, the Specific Unitary Coefficients of each fuel consumption (kg, m^3 or tons per metric ton of fine copper produced) were calculated for each one of the mining operations and areas. Then, we calculated a Global Unitary Coefficient of fuel consumption (Megajoule per metric ton of fine copper produced), based on the gross calorific values of each one of them[1]. In the case of electric energy, the corresponding Specific Unitary Coefficient was calculated (KWh and Megajoule per metric ton of fine copper produced).

The unitary values of each mining operation were weighed based on their respective production, to obtain a sectorial average value representative of each production area of the Chilean copper industry.

Afterwards, with the unitary values determinated for each year and area, the total energy consumptions (fuels and electric energy) of the copper mining sector were estimated, based on the data available in COCHILCO, in regard to copper production in each one of the process areas.

3. ENERGY CONSUMPTION IN THE CHILEAN COPPER MINING INDUSTRY

3.1. GLOBAL UNITARY COEFFICIENTS

TABLE I
FUELS CONSUMPTION BY PROCESS AREA

	1992	1993	1994	1995	1996	1997	1998	1999	2000
OPEN PIT (MJ/Tonne of fine copper in mineral)	4,443	4,305	5,111	4,758	4,403	4,139	4,255	3,643	3,985
UNDERGROUND MINE (MJ/ Tonne of fine copper in mineral)	514	532	577	587	525	425	482	550	753
BENEFICIATION (MJ/ Tonne of fine copper in concentrates)	505	393	153	342	259	291	231	218	192

[1] Source: National Energy Balance 1979 – 1998 Chile, from the National Energy Commission.

OXIDES TREATMENT (MJ/Tonne of fine copper in EW cathodes)	**951**	**808**	**966**	**3,099**	**2,977**	**2,457**	**2,406**	**3,650**	**3,597**
SMELTER (MJ/Tonne of fine copper in Blister)	**11,497**	**11,477**	**11,300**	**10,632**	**9,881**	**9,398**	**8,621**	**7,577**	**7,773**
REFINERY (MJ/tonne of fine copper in ER cathodes)	**1,142**	**1,140**	**1,092**	**1,042**	**1,025**	**768**	**800**	**1,033**	**1,011**
SERVICES (MJ/Tonne of total fine copper)	**1,084**	**447**	**350**	**370**	**297**	**321**	**402**	**403**	**427**

MJ: Megajoule
Source: Data processed by the Chilean Copper Commission

TABLE II
ELECTRIC ENERGY CONSUMPTION BY PROCESS AREA

	1992	1993	1994	1995	1996	1997	1998	1999	2000
OPEN PIT (MJ/Tonne of fine copper in mineral)	**956**	**775**	**781**	**750**	**710**	**581**	**586**	**505**	**452**
UNDERGROUND MINE (MJ/ Tonne of fine copper in mineral)	**1,051**	**1,105**	**1,102**	**1,023**	**972**	**902**	**932**	**1,152**	**1,195**
BENEFICIATION (MJ/ Tonne of fine copper in concentrates)	**5,384**	**5,470**	**5,749**	**5,572**	**5,032**	**5,075**	**5,458**	**5,816**	**6,144**
OXIDES TREATMENT (MJ/Tonne of fine copper in EW cathodes)	**10,210**	**8,990**	**9,647**	**9,921**	**9,878**	**9,512**	**9,588**	**9,842**	**10,096**
SMELTER (MJ/Tonne of fine copper in Blister)	**2,633**	**2,760**	**2,967**	**2,816**	**2,719**	**2,896**	**3,081**	**3,432**	**3,464**
REFINERY (MJ/tonne of fine copper in ER cathodes)	**1,325**	**1,266**	**1,252**	**1,182**	**1,192**	**1,195**	**1,201**	**1,230**	**1,241**
SERVICES (MJ/Tonne of total fine copper)	**566**	**563**	**559**	**536**	**596**	**567**	**630**	**498**	**476**

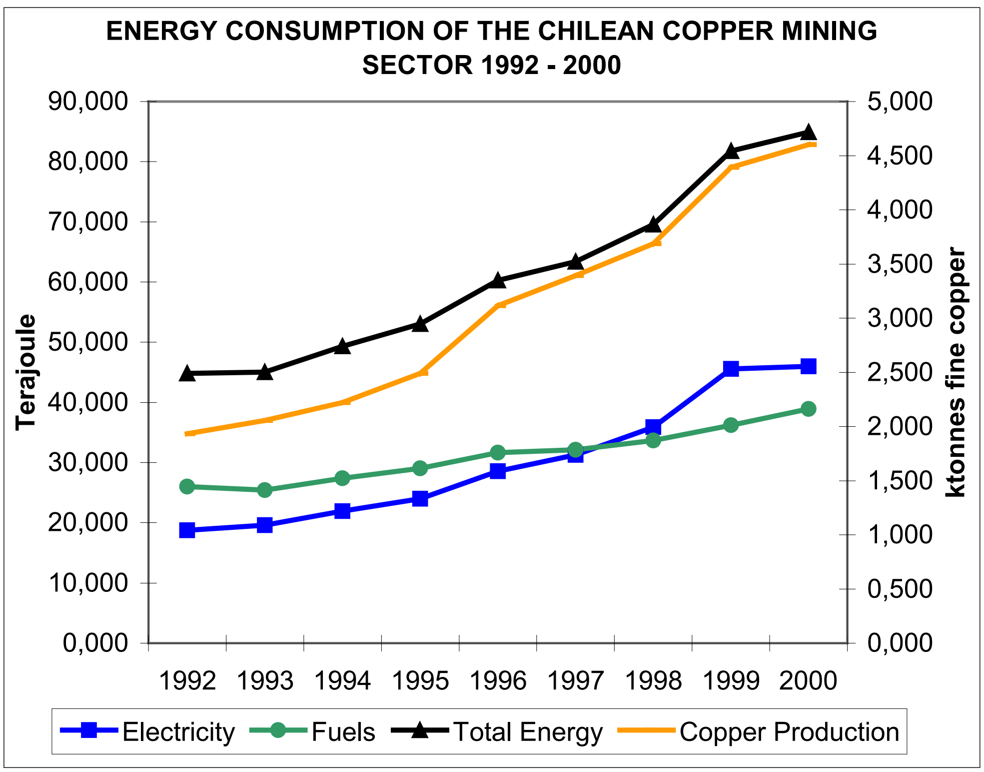
Source: Data processed by the Chilean Copper Commission

3.2. TOTAL ENERGY CONSUMPTION AND GLOBAL UNITARY COEFFICIENTS

Based on these global unitary coefficients of fuels and electric energy consumption determined for each copper processing area and on the intermediate productions considered in each area, an estimation of total energy consumption was made, regarding fuels as well as electric energy, for all the copper mining sector; i.e., including the production of those companies that did not inform energy consumption levels. In addition, an average Unitary Global Coefficient was calculated for Chilean copper mining.

As seen in Figure I, the total energy consumption for the copper mining sector increased 89.5% between the years 1992 and 2000. It may be emphasized that, in the same period, the country's fine copper production increased by 138,1%. The energy consumption as fuel grew by 49.5% during the same period, whereas the electric energy increased by 145,1%.

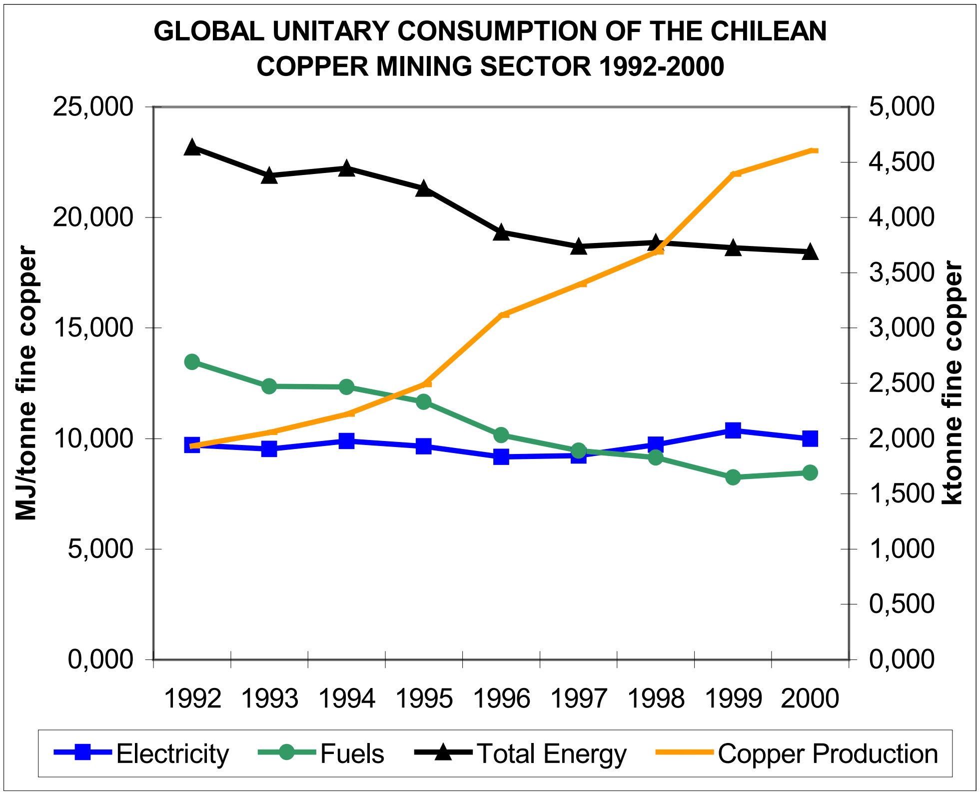
FIGURE I



Source: Data processed by the Chilean Copper Commission

The global unitary coefficients (Figure II) of the sector's total energy consumption experienced a sustained decreasing tendency, with a 20.4% diminution between the years 1992 and 2000, impelled by the decreasing values of fuel consumption's global unitary coefficients, which decreased by 37.2% in the period, while the electric energy coefficients, although show slight fluctuations, stay quite stable, in general.

FIGURE II



Source: Data processed by the Chilean Copper Commission

Previous results are explained basically by changes in the copper production portfolio (EW cathodes, ER cathodes, concentrate, blister) and technological changes, some of which have been impelled by environmental measures.

Since 1994 large scale mining projects of oxides began producing. The fine copper production originated from oxide mining, increased by 913% between 1992 and 2000. In 1992 the production of EW cathodes was only a 7% of Chile's total fine copper production, whereas 30% in the year 2000.

Fine copper originated from sulphide minerals increased its production by an 80%, with a change in the end product portfolio. In 1992, a 66% corresponded to refined products (blister/anodes, fire-refined copper and ER cathodes), which decreases to a 45% in the year 2000.

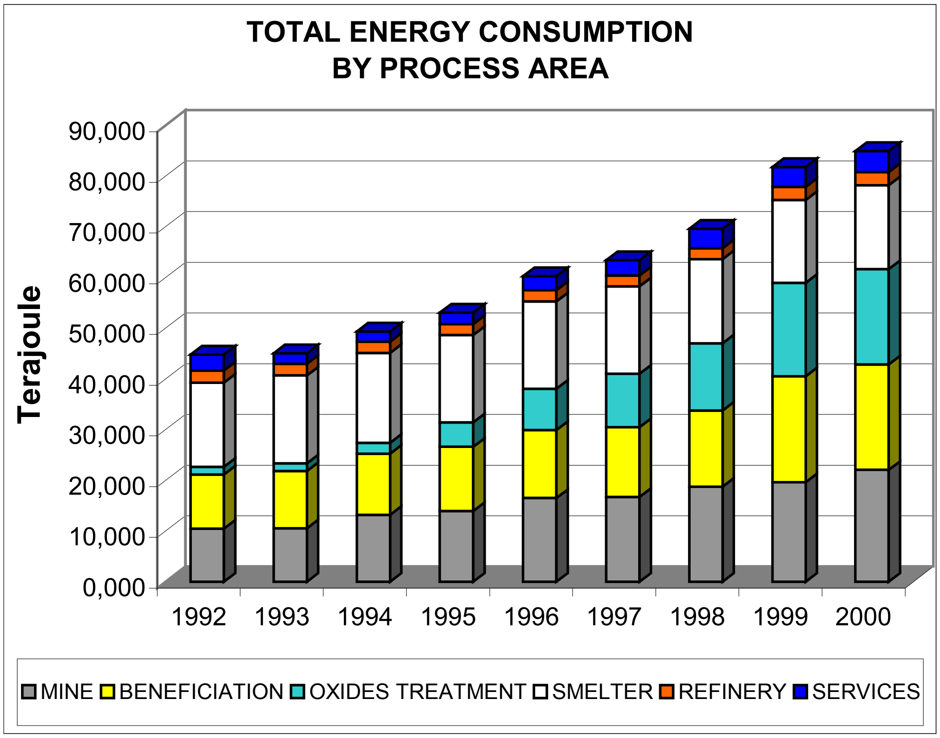
On the other hand, the environmental measures oriented to improve air quality in the surrounding areas of copper smelter facilities and to fulfill the standards, impelled technological and operational changes in copper concentrate smelters. Since 1994, reverberatory furnaces that operated in the country, which were big fuel consumers, have been changed by other smelting units. Currently, smelters operate with Flash furnaces and Teniente converters, which allow an autogenous smelting of concentrates and, therefore, lesser fuel consumption.

Another factor that has also implied lesser fuel consumption is the change of copper concentrate thermal drying to a highly efficient mechanic filtering, which is being implemented in most mining operations.

3.3. CONTRIBUTION OF PROCESS AREAS TO ENERGY CONSUMPTION

As a result of the change in the end product portfolio indicated above, changes have also occurred in regards to relative energy consumption of each stage of the copper production process, which may be seen in the following figures.

FIGURE III



Source: Data processed by the Chilean Copper Commission

The mine and beneficiation plant consume almost half of the total energy consumed by the copper mining sector, a situation that has kept practically unchanged during the study period (47% in 1992 and 50% in the year 2000).

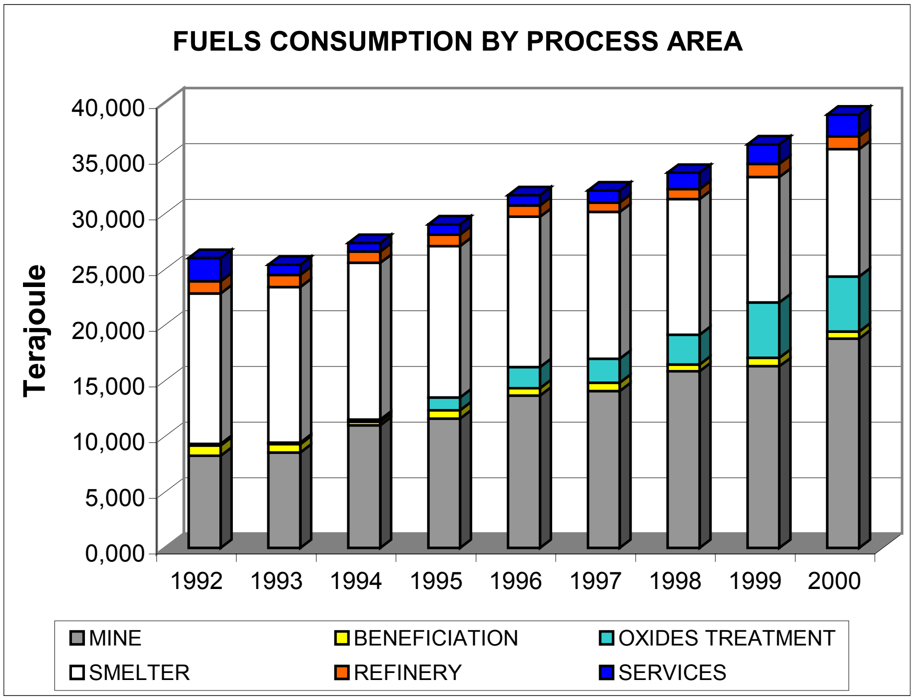
In one hand, the energy consumed by the treatment of oxide minerals (leaching/ solvent extraction/ electrowinning) strongly increases its participation between the years 1992 and 2000, being initially of 3% to reach a value of 22%, due to starting-up of large projects in this area.

On the other hand, smelting process decreases its participation in the sector's total consumption of energy from 37% to 19%, due to technological changes impelled by environmental measures. Participation of the refining area in copper mining's total energy consumption is not relevant and fluctuates between 3% and 5%.

In what refers to fuels consumption per area (Figure IV) in copper mining, mine and smelting account for about 80% of the total fuels consumed by the sector.

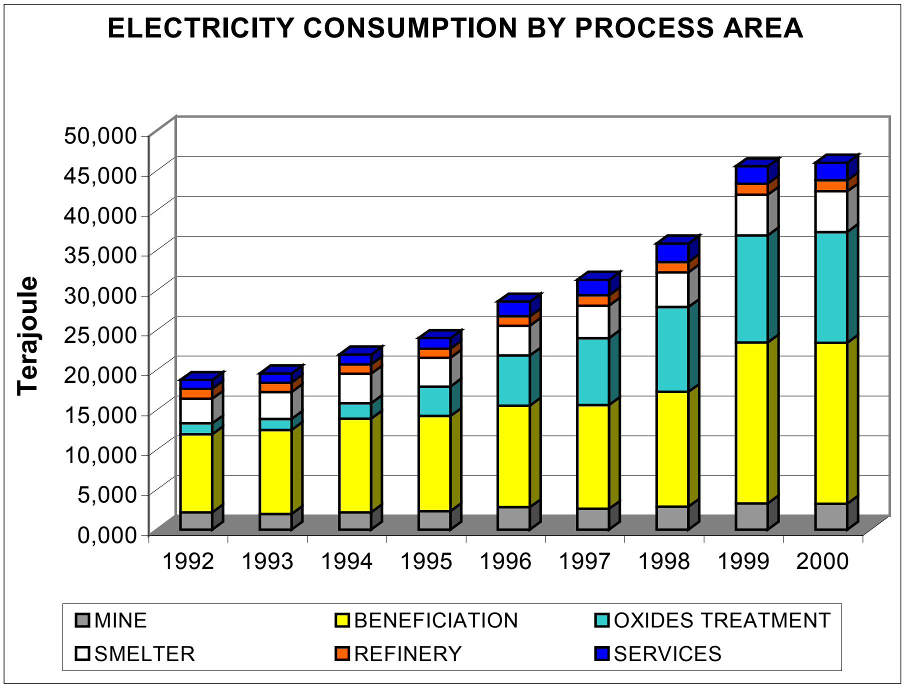
At the beginning of the decade, smelting area consumed more than half of the total amount of fuels consumed by the Chilean copper mining sector (52%); however, its participation decreased through the years due to technological changes in smelters, as explained earlier, and it consumed only 29% of the total fuels in the year 2000.

FIGURE IV



Source: Data processed by the Chilean Copper Commission

FIGURE V



Source: Data processed by the Chilean Copper Commission

In regards to electric energy (Figure V), the minerals beneficiation processing area which at the beginning of the period consumed 52% of the total electric energy used by copper mining sector, decreased its relative participation to a 44%. In this area, electric energy is used mainly in crushing and milling of minerals and the unitary consumption values are a variable that depends on the mineral hardness index, which is characteristic of each mining operation.

The smelting of concentrates, which in the year 1992 was the second area regarding electric energy consumption, with a share of 17%, even when it increases the unitary consumption values, due to the installation of systems to capture and handling gases and sulphuric acid plants, decreases its relative share to an 11% at the end of the period, being displaced by the treatment of copper oxide minerals.

The treatment of copper oxides, which at the beginning of the 90's had a share of 7% in the sector's total electric energy consumption, increased to 30% in the year 2000, due to the explosive increase of copper production from this type of minerals (913% between 1992 and 2000).

The four areas of the copper production process in Chile that consume about 90% of the total energy (both fuels and electricity) consumed by the sector are the following: open pit mines, beneficiation of copper sulphide minerals, treatment of oxide minerals and the smelting of concentrates, including sulphuric acid plants.

The copper mining energy consumption patterns also changed strongly during the decade. In the year 1992, a 58% of the total energy consumed by the sector corresponded to fuels, while in the year 2000, the electric energy accounted for a 54% of the total consumption.

Finally, the copper mining sector's energy consumption in Chile, in the period considered by the study, fluctuates around 8% of the total final energy consumed by the country, reaching a maximum value in the year 2000, with a 10% share. Considering that the mining sector's contribution to the national GDP in the same period was also around 8%, then, it is possible to conclude that the copper mining activity consumes energy in proportion to its contribution to the GDP.

Analyzing the final consumption of energy products in the country (that is, in the suitable form for its final use, which means that electricity includes hydro and thermoelectricity), of the total amount of energy consumed, an average of 14% belongs to electric energy and 86% to a variety of fuels. Copper mining sector consumption is significantly more intensive in the use of electric energy than the national average, with a period average of 48% of electric energy consumption and a 52% in fuels, a tendency that accentuates in the last years, reaching 54% of electricity and 46% of fuels of the sector's total energy consumption in the year 2000. Of the total fuels consumed by copper mining industry, more than 90% are Diesel and Fuel Oil, while the share of other fuels (coal, firewood, kerosene, LPG and gasoline) is marginal.

Regarding the share of copper mining in the country's final consumption per energy type in the year 2000, the sector consumed an average of 30% of the total electric energy consumed by the country and only 5% of total fuels.

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ENERGY CONSUMPTION COPPER MINING SECTOR IN CHILE 1992 - 2000

Sarita Pimentel

International and Environmental Unit

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The present study is a diagnosis of energy consumption, both fuels and electricity, for the copper mining industry in Chile.

It also analyses the evolution of Global Unitary Coefficients in each defined process area, their contribution to the total use of energy and the factors that have been relevant for changes in pattern of consumption.

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METHODOLOGY

- Definition of copper mining process in areas, stages and unitary processes
- Generation of a survey which was sent to the most important copper producers and refiners, covering around 97% of the chilean copper production
- The survey was specific, considering typical areas, stages and unitary processes of each company.

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- The objective of the survey was to obtain information, as disaggregated as possible, in respect to energy consumptions, different fuels and electricity, flows of inter-area materials and other data.
- With the data provided by the companies, **Global and Specific Unitary Coefficients** for energy consumption in the mine, beneficiation plant, smelter, refinery, oxide treatment (LX-SX-EW) and services were calculated.
- Unitary consumptions are refered to fine copper content in minerals, concentrates, blister, ER and EW cathodes, as appropriate.

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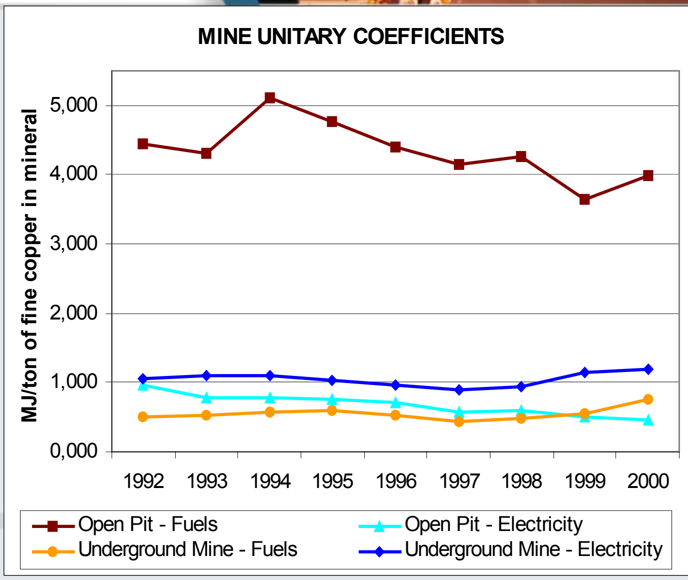

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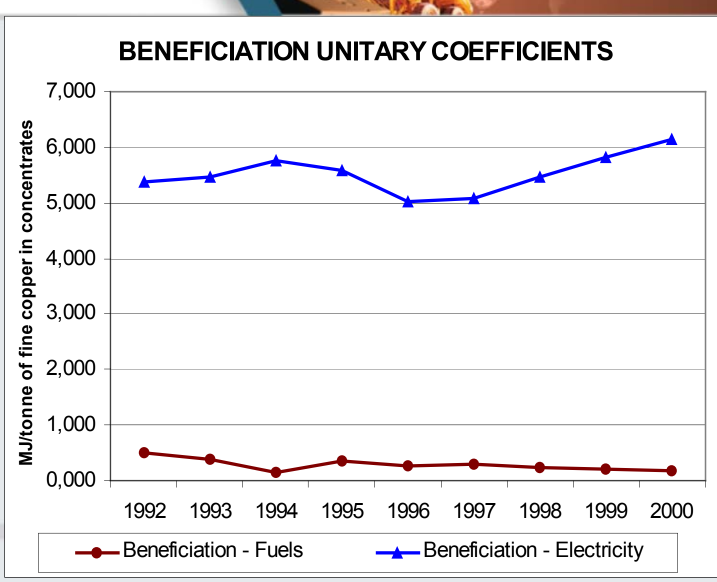

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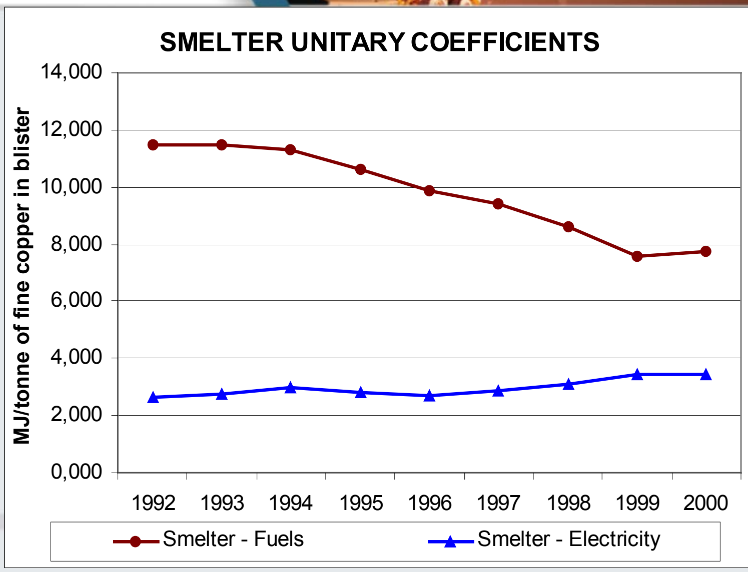

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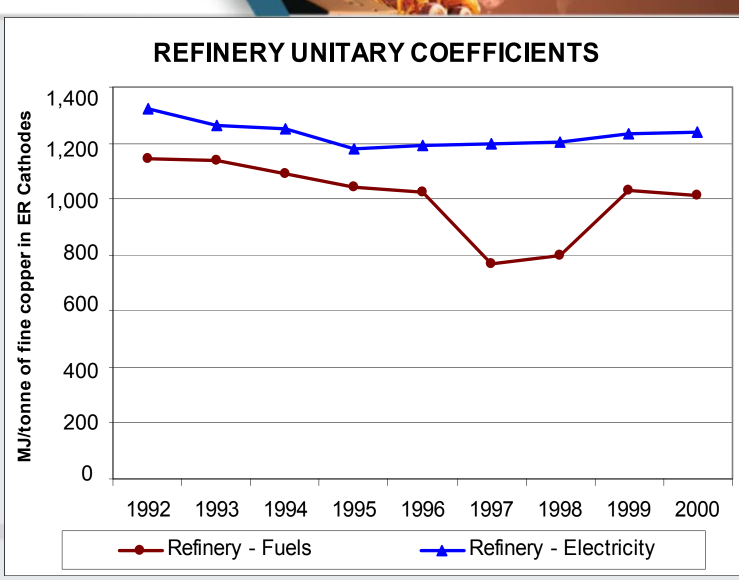

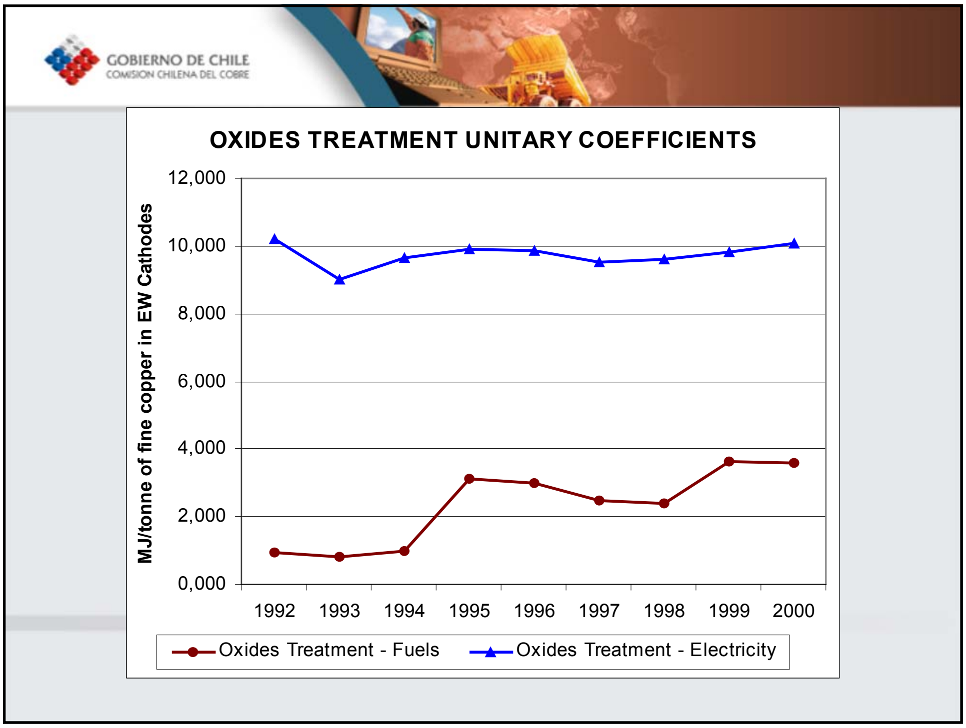
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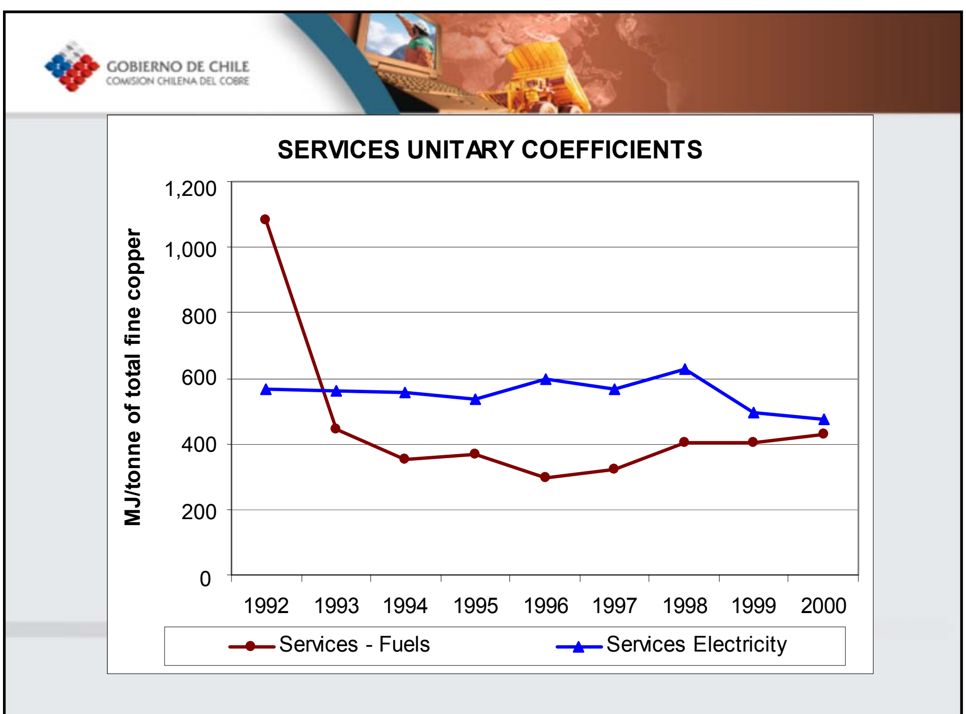
OXIDES TREATMENT UNITARY COEFFICIENTS
MJ/tonne of fine copper in EW Cathodes
12,000
10,000
8,000
6,000
4,000
2,000
0,000
1992
1993
1994
1995
1996
1997
1998
1999
2000
Oxides Treatment - Fuels
Oxides Treatment - Electricity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SERVICES UNITARY COEFFICIENTS
MJ/tonne of total fine copper
1,200
1,000
800
600
400
200
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
Services - Fuels
Services Electricity

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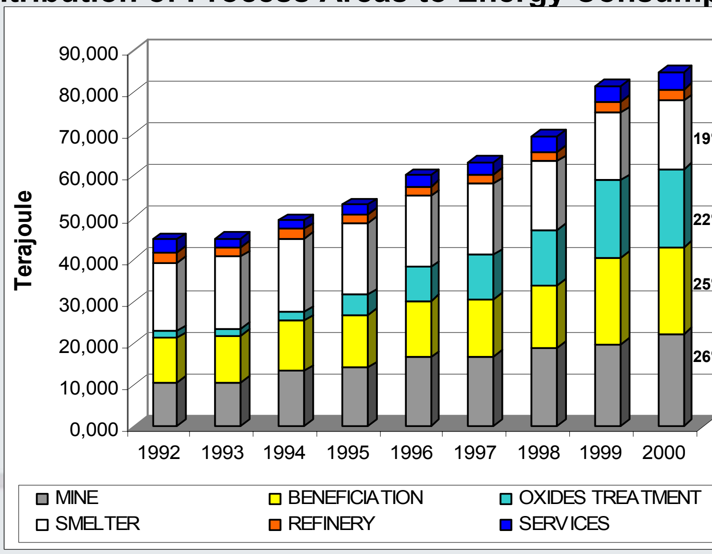
Contribution of Process Areas to Energy Consumption



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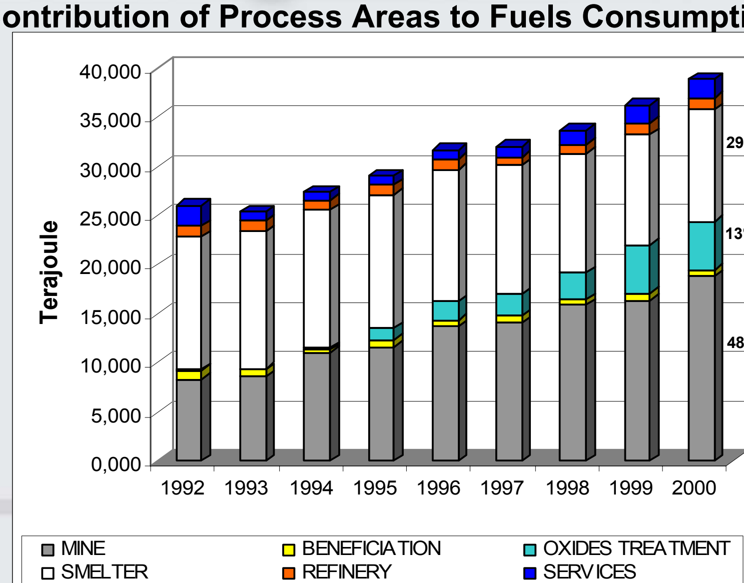
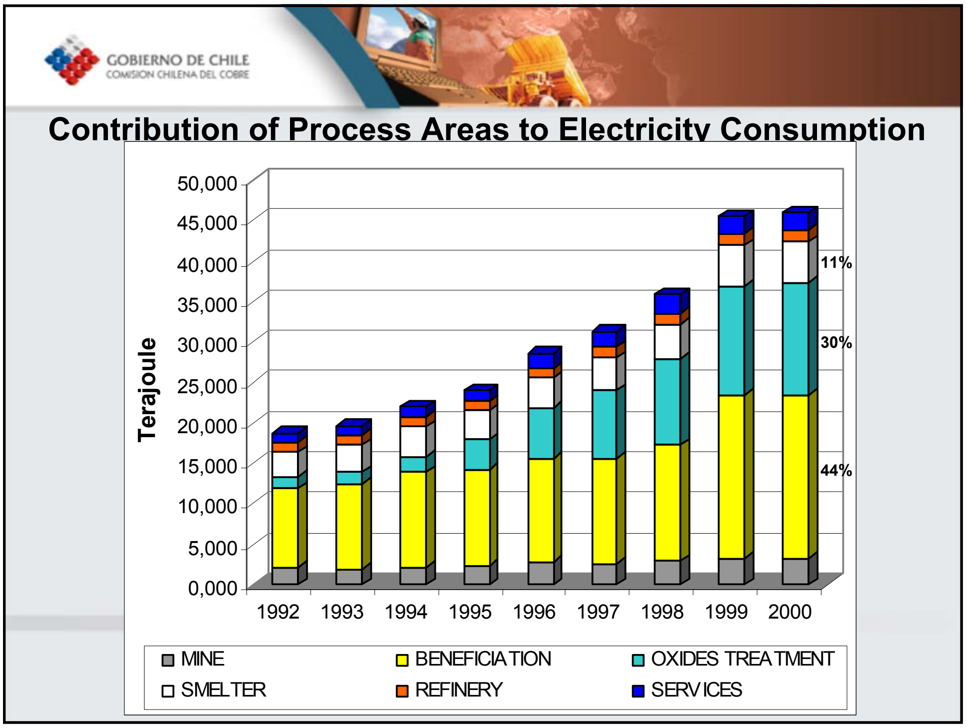
Contribution of Process Areas to Fuels Consumption

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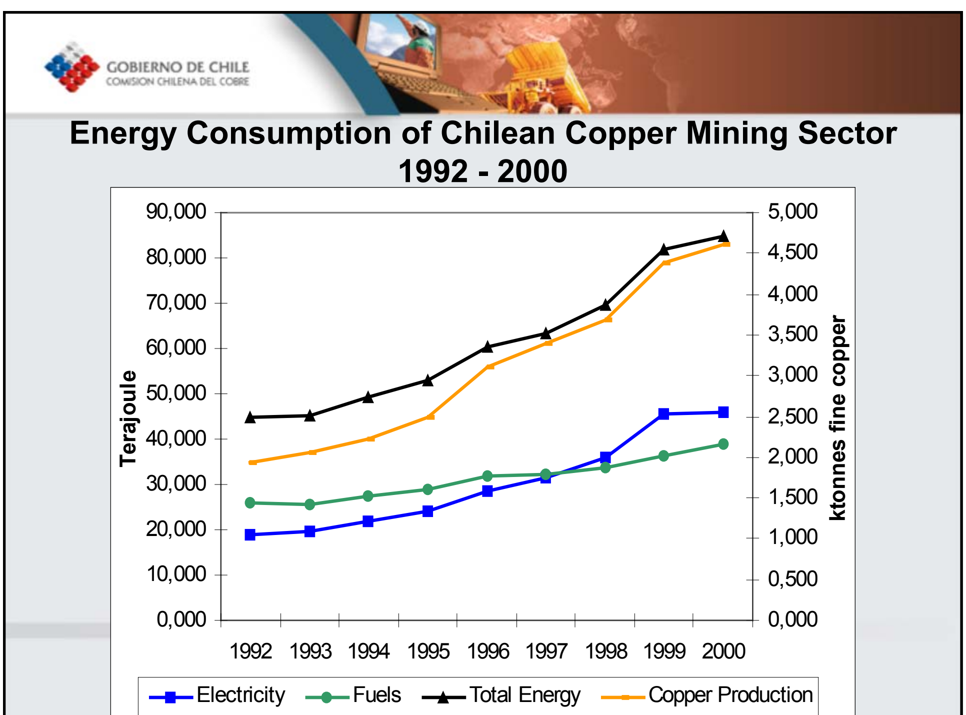
Contribution of Process Areas to Electricity Consumption
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0,000
Terajoule
1992
1993
1994
1995
1996
1997
1998
1999
2000
11%
30%
44%
MINE
BENEFICIATION
OXIDES TREATMENT
SMELTER
REFINERY
SERVICES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Energy Consumption of Chilean Copper Mining Sector
1992 - 2000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0,000
Terajoule
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
0,500
0,000
ktonnes fine copper
1992
1993
1994
1995
1996
1997
1998
1999
2000
Electricity
Fuels
Total Energy
Copper Production

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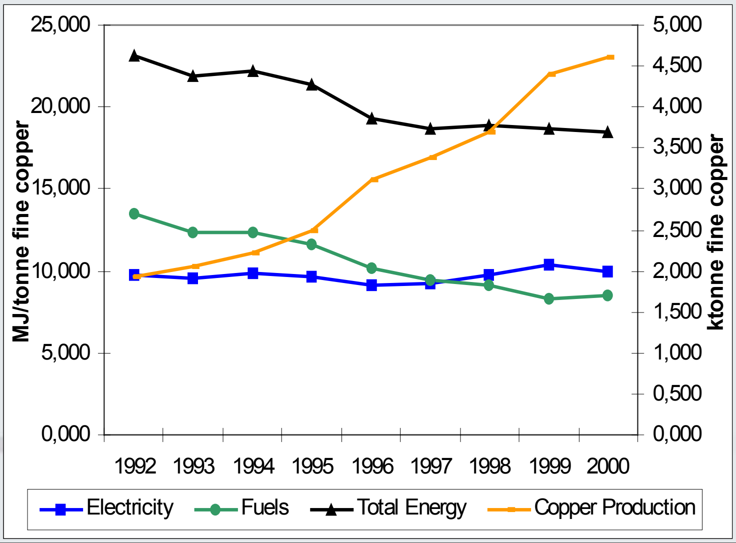
Unitary Consumption of Chilean Copper Mining Sector 1992 - 2000



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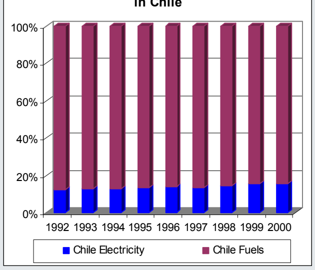
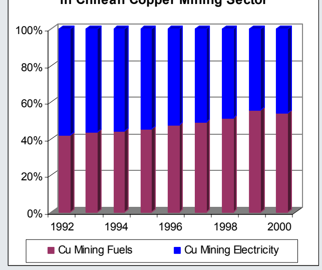
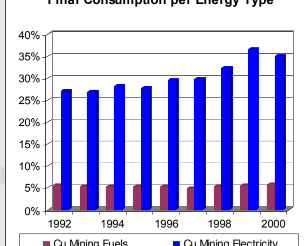
Final Consumption of Energy Products in Chile



Final Consumption of Energy Products in Chilean Copper Mining Sector



Share of Copper Mining in the Country Final Consumption per Energy Type



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CONCLUSION

Having in mind the results of the study and the areas where energy consumption is most relevant, to improve energy efficiency the chilean copper mining industry may focus its efforts to:

- Fuels consumption in open pit mines and smelters
- Electricity consumption in beneficiation and oxides treatment plants

Using Control for Adding Value to Energy Efficiency of Mineral Processing Plants
Uso del Control Automatico para Aumentar la Eficiencia Energetica de Plantas Mineralurgicas

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Abstract. Because of globalization and international competition, mineral processing plant managers seek at reducing production costs. These plants are major energy consumers and therefore energy efficiency is becoming an important objective. Other incentives are the energy cost that will probably continue to rise and the environmental and social pressures for reducing energy consumption. Using more energy efficient equipment is a first approach. Better plant operation using on-line data processing, as described in this paper, is another way to improve energy efficiency. On-line data processing consists in using the measurements provided by sensors and the knowledge of the plant behaviour to automatically, continuously and adequately manipulate plant actuators. An ideal on-line data processing is made up of three hierarchic layers: process observation, process control and process optimization. The layers, their interaction and their energetic benefits are described. Some case studies illustrate the energy efficiency improvements provided to mineral processing plants by using on-line data processing techniques.

Resumen. Como resultado de la globalización de mercados y la competencia internacional, las empresas mineras se han visto en la necesidad de reducir sus costos de producción. Estas empresas son grandes consumidoras de energía y por ende la eficiencia energética es para ellas un objetivo crucial. Otros incentivos son el costo creciente de la energía y las presiones ambientales y sociales para reducir el consumo de energía. El uso de equipos más eficientes del punto de vista energético es una alternativa. Una mejor operación de las plantas existentes mediante el tratamiento en-línea de la información disponible, tal como se explica en este artículo, es otra alternativa, a menudo menos onerosa. El tratamiento en-línea de datos consiste en usar las mediciones de instrumentos y el conocimiento del proceso para manipular automática, continua y adecuadamente los distintos accionadores existentes. Idealmente, un tratamiento en-línea de datos está compuesto de tres niveles jerárquicos: observación, control y optimización del proceso. Estos tres niveles, su interacción y sus beneficios energéticos son descritos en este artículo. Algunas experiencias prácticas ilustrando las mejoras energéticas logradas en plantas mineras mediante el uso de técnicas de tratamiento en-línea de datos son asimismo presentadas.

1. Introduction

Nowadays, with globalization and increasingly furious international competition, mineral processing plant managers are constantly seeking at reducing the production costs while increasing the throughput and the product quality. Since these plants are intensive energy consumers, improving their energy efficiency may obviously contribute to reduce the production costs. Furthermore, the energy efficiency challenge becomes unavoidable since the energy cost will more than likely continue to rise and as a result of increasing environmental and social pressures for reducing energy consumption.

To illustrate the existing pressure for energy efficiency, Hydro-Québec (Quebec hydroelectrical producer and distributor) offers financial assistance to large-power customers for new projects designed to reduce specific electricity consumption [1]. Hydro-Québec operates the most extensive transmission system in North America with 32539 km of lines and makes it available to customers inside and outside Quebec. For the Quebec market, Hydro-Québec supplies a heritage pool of up to 165 TWh per year, 93% being hydroelectric. The objective of the first Hydro-Québec program is to save 100 GWh of electricity from 2003 to 2006. The financial assistance budget is Cdn 8.5 M$. The program aims at encouraging customers to present electricity conservation proposals. To be eligible, participants must agree to take measurements before and after the project implementation to show savings achieved. The financial assistance objective is to reduce the payback period to one year. The customer must pay at least 25% of the total costs and the project must be completed within 18 months. Hydro-Québec also offers financial assistance to major customers for an energy consumption analysis at the industrial site or for the demonstration that the first-time implementation in Quebec of a new technology would result in energy savings.

A first approach for the plants to increase their energy efficiency is to use equipment that consumes less energy. This initiative may consist in replacing the existing equipment with more efficient ones or by installing new equipment aiming at reducing the specific energy consumption of existing processes. Improving energy efficiency may also be attained through better plant operation. This can be achieved by making a judicious on-line use of process sensors and large plant operation databases. The next section is devoted to a description of the on-line data processing approach. Section 3 presents some case studies to illustrate the benefits of this energy saving method. The last section concludes the paper.

2. Process observation, control and optimization to improve energy efficiency

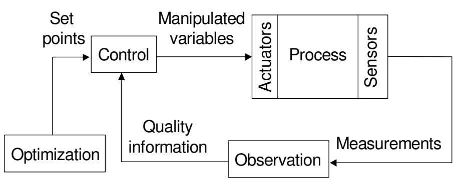

Figure I - On-line data processing

On-line data processing consists in using the measurements provided by plant sensors and the knowledge of the dynamic plant behaviour (evaluated from measurement databases recorded during plant operation) to automatically, continuously and adequately manipulate plant actuators, such as valves and variable speed drives, in order to achieve a specific objective. An ideal on-line data processing, often referred to using the generic name of control, is made up of three hierarchic layers (Figure I): process observation, process control and process optimization.

Process observation aims at getting useful on-line information about the plant behaviour, therefore allowing to "see" the process states and thus detecting operation problems, abnormal performances, etc. The basic equipments needed are reliable sensors. However, using data processing techniques such as fault detection and isolation (FDI) [2], data reconciliation [3] and observers [4], may greatly improve the process "picture". FDI rapidly detect and physically localize problems such as sensor biases and leaks, whose rapid correction will reduce bad consequences on the production. Data reconciliation techniques improve the quality of the noisy measurements by forcing them to be consistent with the knowledge engineers have about the plant, such as mass and energy conservation laws. Observers are soft-sensing algorithms; they infer signals that cannot be measured (not at all or not frequently enough). They generate new measurements that can be used to improve the plant operation. Even if process observation is based on passive techniques, they certainly help engineers improving their vision of the process states and therefore corrective actions such as equipment or operation changes can be taken.

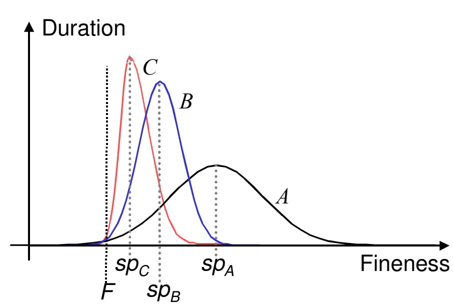

Figure II - Process variability

Once the on-line measurements have been improved by the process observation layer, they may be used to continuously adjust the actuators to provide process control actions [5]. Through feedback and feedforward, process control allows maintaining the measured variables at selected set points despite the presence of disturbances, such as changes in ore properties. A consequence of the process stabilization around a selected operating point is the decrease of process variability, as qualitatively illustrated in Figure II [6]. It compares, for three different control strategies, the time (ordinate) the grinding product fineness is at a given value (abscissa). Control strategy *A* performing poorly, a large dispersion around the set point occurs. Control strategy *B* provides a tighter disturbance rejection and the measurement is more often close to the desired set point. Control *C* would be representative of an advanced control approach that intrinsically takes into account the physical and operational limitations of the process. If the objective is to have the product fineness 95% of the time larger than *F*, a lower set point (sp_C) may be selected for strategy *C* than for strategy *B* (sp_B), whereas *B* set point is lower than *A* set point (sp_A). Since grinding is a very costly operation, decreasing the fineness set point translates in significant energy savings. Furthermore, even if the set points are not changed, better control usually results in a smoother and less costly operation.

The third layer is the process optimization step [7]. It consists in continuously selecting the set points of the control layer to optimize a control objective. The goal could be the minimization of energy consumption (in absolute values, per ton of processed material, per ton of product, etc.). However, the objective is usually related to profit maximization. The profit being obviously dependant on energy consumption, a side effect is often a decrease in the energy costs. Optimization is a very flexible tool that could help in taking into account energy consumption regulations (better energy price if the energy consumption remains below a given threshold, energy price changing depending on the time of the day, etc.). Indeed, one could imagine an optimization strategy that will maximize the profit as long as the energy consumption remains below the threshold.

Process observation, control and optimization are added values for energy savings. Indeed, for several plants, such on-line data processing requires none or very little new equipment. They can also provide many additional benefits such as a better knowledge of the plant, a product quality respecting specifications more often, a throughput increase, an easier-to-operate plant leading to more effective use of personnel, a reduced downtime and a decrease in maintenance costs.

Energy saving estimations are often underestimated because the plant units are usually considered separately. For instance, optimizing a flotation plant does not procure any real energy savings. However the energetic impact on subsequent metal extraction processes and smelting may be considerable. Hence, ideally, plant wise evaluation should be performed.

3. Case studies

Section 3.1 describes a case study where the use of data reconciliation allowed the detection of abnormal operating conditions in a grinding circuit. Even if they are difficult to estimate, the energetic impacts were important. Section 3.2 details the implementation of a grinding control strategy that lead to 9% gain in the specific energy consumption while increasing the tonnage and maintaining the product size distribution. Section 3.3 presents the benefits of using observation, control and optimization to improve the energy efficiency of electric arc furnaces. In particular, the optimization is directly aiming at reducing the energy consumption. Finally, the optimization of an induration furnace is discussed in Section 3.4.

3.1. Case study 1: Observation and control of a grinding circuit

Between 1992 and 1994, LOOP researchers undertook an industrial project aiming at developing and implementing a new control strategy for one of three Kidd Creek's grinding circuits (line B) [8-10]. The control strategy was first evaluated on LOOP's grinding circuit dynamic simulator (DYNAFRAG), which permitted the discrimination between more than a dozen possible control alternatives. The selected control strategy was then configured on the plant DCS in early 1994. At the time of the study, Line "B" processed 150 t/h of ore through an open-loop 3.2 m x 4.9 m rod-mill (Allis Chalmers) followed by a 3.7 m x 5.5 m ball-mill (Allis Chalmers) operating in close-circuit with a cluster of eight 380 mm Krebs hydrocylones. Both mill discharges are mixed in a 12 m^3 non-linear pump-box, where a 12x10 Linatex fixed-speed-drive centrifugal pump withdraws the cyclone feed. The installed instrumentation consisted of a weightometer on the rod mill feed belt, magnetic flowmeters to measure three water additions, a nuclear gamma gauge for cyclone overflow pulp density, and an Outokumpu PSI-200 particle size analyser (which could not be used for control because of operational problems).

The use of DYNAFRAG required previous calibration using industrial data gathered from Kidd Creek concentrator. Three sampling campaigns were conducted. Samples and data were processed to obtain the required unit model parameters (breakage and selection functions for the mills, pulp transport within the mills, cyclone parameters, etc). Data reconciliation revealed some abnormal operating conditions such as extremely high mill circulating load ratios (around 1800%) and very high fines short-circuiting to the cyclone underflow. These observations force the freezing of the project until the company fixed the problems, since there was interest in studying control strategies for a circuit running far from its optimum.

A 1800% circulating load ratio (CLR) implies a cyclone feed flow rate (78% solids) of about 3654 t/h of pulp or 1379 m^3 /h (6000 USGPM). At 500% CLR, the value obtained after circuit adjustments, this flow rate drops to 1154 t/h or 435 m^3 /h (1560 USGPM). A 10x12 Warman pump working at 40 ft head has an efficiency of 65% at 6000 USGPM and 75% at 1500 USGPM (assuming no correction for pulp). These figures lead to a power consumption of 251 HP for the first case and 56 HP for the second case, i.e. a saving of 78%. The high circulating load has another effect on the economy of the process. Assuming 40% ball charge, 40% voids between balls and 120% voids filling by the pulp, a 1800% CLR implies a pulp residence time within the mill of about half a minute, whereas the 500% CLR means about 2 min residence time. In other words a lot more energy was spent in pumping a huge circulating load to achieve very little grinding.

A first control strategy aiming at maximizing the tonnage and regulating the product size distribution was first implemented. However, in November 1994, maximizing tonnage was no longer an issue because the minesite was rate limiting and thus the feed rate and the power target were both lowered by approximately 10%. The instrumentation was also modified at that time (installation of a variable speed drive on the cyclone feed pump, the cyclone vortex and apex were changed). To accommodate these changes the control strategy was also modified (see [8-10] for the details). Because of all these changes, quantifying the energetic and metallurgical improvements is a difficult task. The total costs were around Cdn 0.2 M$ and the revenue improvements were conservatively estimated to Cdn 1 M$/annum.

3.2. Case study 2: Control of a grinding circuit

The following example is the improvement of the grinding circuit control in a Peruvian copper concentrator. The basic grinding circuit is composed of a rod-mill followed by three identical ball-mills in parallel. Each ball mill operates in closed circuit with an hydrocyclone. The crushed ore is dry fed to the rod mill from the fine ore bin via conveyor belt, whose speed is adjusted by a PI controller in accordance with the ore feed rate, measured with a balance underneath the conveyor. The feed rate set point is decided by the operator. Water addition to the rod mill is adjusted by a PI controller to ensure an 80% solids mill operation. The rod-mill discharge is distributed to three parallel ball-mills using a three-way splitter. Ideally, the splitter should guarantee an even distribution among the three ball mills. The pulp distribution among the ball mills is determined by the relative position of two moveable palettes. The operator decides the palettes' position. A bad distribution of the pulp among the ball mills results in an uneven mill operation as detailed later on. Each ball mill discharges to a sump-box where water is added to meet adequate cyclone operation conditions. The water addition is controlled by a PI, whose set point is fixed by the operator. The pulp is drawn from the sump box by a variable-speed centrifugal pump feeding the corresponding cyclone. The pump's speed is adjusted by a PI controller in order to maintain a desired pulp level in the sump-box. The cyclone overflow is the final product of grinding circuit, whereas the underflow stream, hereafter called circulating load, is sent back to the ball mill for further grinding. Water is added to the circulating load to meet percent solid requirements in the mill. This control strategy did not permit to reach the production objectives of the concentrator. A first analysis indicated that the existing control loops looked more at preventing process upsets than meeting the concentrator production objectives, that is increasing tonnage, which was rather manually done by the control room operator.

As previously indicated, an ill operation of the splitter led to an uneven distribution of the rod mill discharge among the three ball mills. This was a common situation either resulting from changes in ore hardness or by the entanglement of small broken rods in splitter passages. In such a case, the mill receiving more feed usually went into overloading conditions, its discharge got coarser, and the hydrocyclone underflow stream became larger, thus raising the pump box level. To keep the level at its set-point, the variable speed pump automatically increased the motor speed, thus increasing the cyclone feed which deteriorates the situation even more, since the coarser cyclone overflow disrupts the flotation circuit operation. In many cases, the only solution was to stop feeding the ill ball mill and to reduce the circuit feed (rod mill feed). A final and usual problem arose from changes in ore hardness. In such a case, the operator had to adjust the rod mill feed as quickly as possible to avoid mill content build-up. Sometimes the field operator realized too late the existence of such a situation, in such a way the only solution was a drastic reduction of the rod mill feed or shutting it off completely (for harder ores). In summary, problems associated to the existing control strategy are mainly related to the lack of adequate sensors, resulting from the age of the concentrator (built in the 50's) and to the uneven distribution of pulp to the three ball mills.

A new control strategy [11] was design and partially implemented (Figure III) aiming at increasing plant throughput and stabilize the mills operation. The following actions were considered:

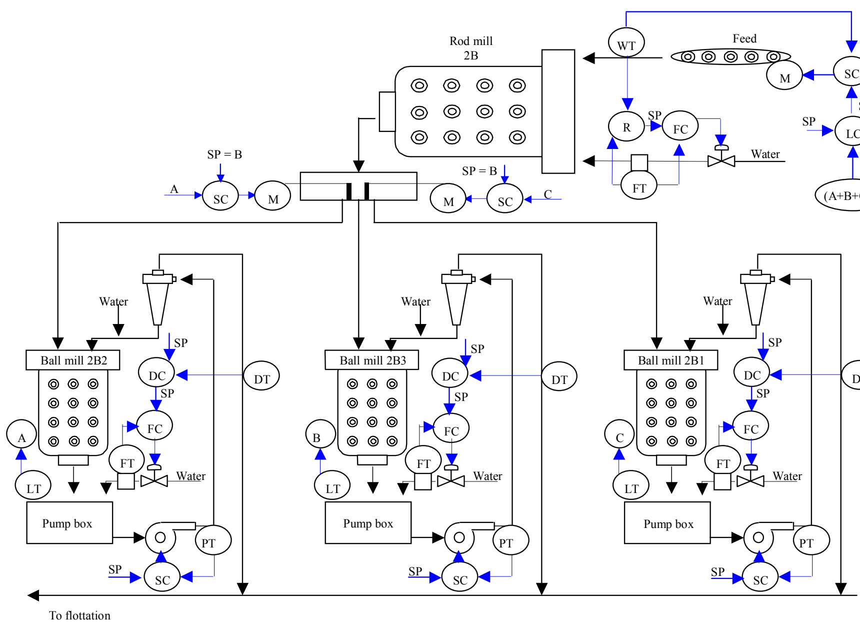

Figure III - New grinding control

- Implementation of a rod-mill percent solids control using a ratio control (instead the original feedback PI); this control accelerates the water addition to the rod-mill based on the amount of ore fed.
- Elimination of the sump-box level control by handling the pump's speed, since it did not produce any concrete benefit except avoiding sump-box overflows.
- Implementation of an automatic control of the rod-mill discharge distribution (splitter); this most important action addresses the heart of the problem. As a result of the previous action, the sump-box level becomes sensible to circulating load fluctuations and rod-mill feed changes and mineral hardness changes. At equilibrium the level of the three sumps should be equal but if one of them is different, the two palettes will automatically move to equalize the three sump levels.
- To maximize the processed tonnage, a control loop was implemented to modify the circuit ore feed rate (conveyor speed) according to the average (three) sump-box level. For instance, if the mineral hardness suddenly decreases, the mills would grind finer and the cyclone will report more material to the overflow, the circulating load would decrease and the average sump-box level would decrease. The control loop would then decide to increase the circuit throughput to take advantage of this softer ore.

The following results were observed after implementation of this new control strategy:

- Much better stability of the circuit operation, particularly of the three ball mills.
- Increased circuit tonnage from 245.7 t/h to 253.6 t/h (2 % to 4% increase).
- An important reduction in energy consumption (1607750 kWh to 1528797 kWh; specific energy from 9.20 kWh/t to 8.42 kW/t; 8% to 10% decrease) despite the increased throughput obtained and a slightly

finer product. Since the concentrator possesses eight similar lines and assuming 362 day of operation per year, the total amount of energy saving would then be 900000 kWh.
- A greater availability of floor operator, since the continued surveillance of the circuit operation was reduced by the implementation of automatic control.

3.3. *Case study 3: Observation, control and optimization of electric arc furnaces*

Electric arc furnaces consume a large amount of energy in ferroalloy and steel industries. Even if the overall electric metering of these processes is generally adequate from an operational point of view, almost no direct measurement of how the energy is used inside the furnace is made. In that context, the final steps of an optimization procedure are thus difficult to achieve. The arc signature, which corresponds to the voltage-current characteristic at the tip of the electrode, is able to provide on-line information about the internal behavior of the furnace. Observation of that signature is obtained using an electrical model of the furnace and the electrode voltage and current signals. The signature gives the possibility to infer strategic variables regarding the arc such as length, stability, symmetry, dynamic resistance and power dissipation. These variables could be used to observe furnace states, close control loops on non measurable variables or optimize operating practices. Arc signature systems have been tested and installed on different furnace types: submerged arc furnaces (40-55 MVA; 100-150 volts) and long arc furnaces with foamy slag (10-130 MVA; 150-1300 volts). The main objectives of these projects were the optimization of the energy usage and the reduction of the production costs.

In a typical submerged arc furnace application, the implementation of an arc signature system combined with the modification of the control strategies has given the following results:
- The specific consumption (MWh/t) was reduced by 5%.
- The furnace stabilization allowed the increase of operating power and thus the production rate by 25 %.
- The introduction of corrective loads to stabilize the furnace was reduced by 30 %.
- The signature is used to support operation, anticipate and prevent problematic situations.

A pilot campaign on a furnace that produces steel by melting scrap (long arc with foamy slag) has highlighted the following opportunities:
- The reduction of the tap-to-tap time by 8% by the optimization of charging procedures and the improvement of the electrode control. This has a direct impact on the specific consumption and the overall plant production capacity.
- The reduction of foamy slag (coke and oxygen) consumption by 10% by using non measurable variable to control the injection.

3.4. *Case study 4: Optimization of an induration furnace*

Preparation of iron oxides for iron and steel-making industries requires concentrate agglomeration in pelletizing drums or discs, then sintering of pellets in induration furnaces to give them the required mechanical properties for their handling and transportation to the oxide reduction and iron or steel making site. Induration furnaces are high-energy consumption processes and iron companies have increased recently their efforts to reduce furnace energy consumption [12, 13], while at the same time increasing production levels, and improving product quality control. It is difficult to achieve these goals at the same time because a large number of interacting process variables are involved in the process as shown in Figure IV. Several phenomena occur during the sintering process: pellet drying, heating, hardening and cooling, and coke combustion, magnetite oxidation, and limestone and dolomite calcination. The furnace is divided into seven zones where energy is exchanged between the pellet bed on the traveling grate and the gaz flows: upwards drying (UD), downwards drying (DD), pre-cooking (PC), primary cooking, secondary cooking, primary cooling, and secondary cooling. The main energy sources of the process are the coke added to the pellets, the fuel injected in the burners ($F_{m,PC}$, $F_{m,C1}$ and $F_{m,C2}$) and the electrical power of the five fans (V_1 to V_5) used to force the gas flow within the furnace.

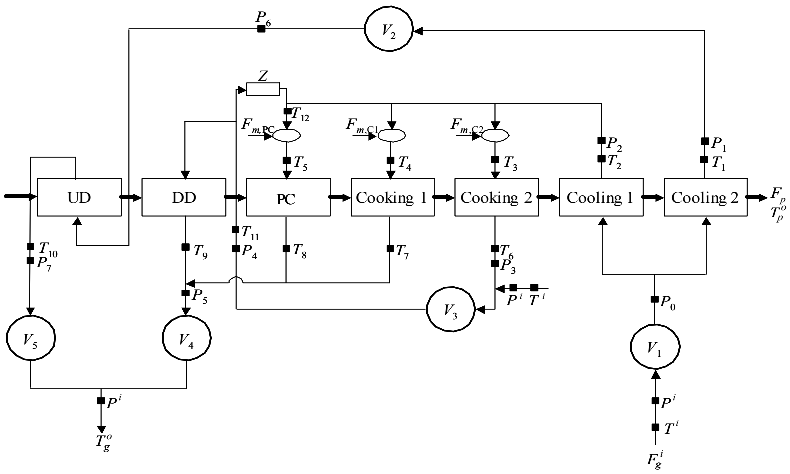

Figure IV - Induration furnace scheme

At the process design level, the energy efficiency is maximized by using counter-current flow of pellets and gas (thick lines in Figure IV indicate pellet flows, while thin lines identify gas streams), thus recycling the energy from the cooling zones to the drying and cooking zones. At the operation level the energy efficiency is managed by selecting optimal operating conditions and by controlling the gas temperatures and pressures (letters T and P respectively in Figure IV). The problem is to optimize a production criterion with respect to 11 manipulated variables (the five fans, the three burner zones, the grate speed, the bed height, and the coke concentration), while keeping process variables in a given sets of constraints imposed by equipment limits, safety rules or quality requirements of the pellet buyer, and coping with the numerous process variables (pellet humidity, size and chemical composition, gas leaks or infiltrations, heat losses…) that disturb the process.

The definition of the operation optimization criterion is critical and must reflect precisely the producer objectives. Usually it is to maximize the net revenue, i.e. the product value minus the production costs. Since energy costs are quite important in the present case, this may lead to a minimization of the total consumed energy, but not necessarily. Another criterion could be to maximize the production rate at constant energy consumption. This would lead to the minimum energy consumption per ton of pellet produced, but not to the minimal total energy consumption. Another option is to maximize the product quality to increase the product value at constant production rate. Obviously this will not be optimal for energy consumption, except if the total energy consumption is constrained at a predefined value. A different point of view could also be to find, at constant production rate and product quality the distribution of consumed energy between the coke addition, the three burner zones and the five fans, which minimized the energy cost. In any case, the optimal conditions will strongly depend upon the selected criterion and the relative cost of electrical power, fuel and coke, factors which may drastically vary from country to country and as a function of the changing world energy market prices.

Table I - Optimization results

Simulation run	1	2	3	4	5	6	7
Production rate	*Max*	*Max*	*Nom*	*Opt*	*Opt*	*Nom*	*Opt*
Fuel consumption	*Nom*	*Nom*	*Opt*	*Nom*	*Nom*	*Min*	*Opt*
Fuel distribution	*Nom*	*Opt*	*Opt*	*Nom*	*Opt*	*Opt*	*Opt*
Pellet quality	*Constr*	*Constr*	*Max*	*Max*	*Max*	*Constr*	*Constr*
Fuel (%) at PC, C1, C2	4, 10, 86	0, 5, 95	0,13, 87	4, 10, 86	0, 5, 95	0, 6, 94	0, 5, 95
Production rate index	107	109	104	101	100	103	110
Total fuel (kg/s)	0.820	0.820	0.858	0.820	0.820	0.674	0.818
Energy index per ton	100.5	101.0	100	100.6	100.7	101.3	100.9
Normalized profits ($)	108	110	103	101	100	105	111

Both the optimization and control levels are difficult to manage because of the high number of manipulated and disturbance variables, and the various criteria and constraints that may be formulated. For such complex processes, simulators are powerful tools for finding guidelines leading to optimal energy efficiency. To illustrate this approach, a simulator of the induration furnace, based on physical and chemical models, has been developed to find optimal operating conditions [14, 15]. Table I presents the results of various simulation strategies. *Max or Min* stands for the criterion that is maximized or minimized, except for run 7 where the net revenue is maximized. *Nom* stands for a variable that is kept at its nominal value, while C*onstr* stands for a variable that is maintained at its low constrained value. Finally O*pt* stands for a variable that is calculated at the criterion optimal value. The results show that the total energy per ton of product does not much vary, while the total fuel consumption can widely vary and, as a consequence, that the furnace tuning should be significantly changed when the fuel price is changing. The results also show that the maximum profit is not necessarily a good criterion to maximize energy efficiency, and that it is important to properly distribute the energy inputs to the process.

4. Conclusion

Observation, control and optimization are on-line data processing techniques that can help in increasing energy efficiency while providing several other benefits. Observation gives the opportunity to "see" the process states. Abnormal operating conditions can then be detected. Signals that cannot be measured otherwise may also be estimated and used to improve the plant control and optimization. The aim of control is to reduce the process variability by a better rejection of disturbances. Related benefits are the possibility of better set point selections and a smoother operation. On-line optimization is a flexible tool that can directly be used to improve energy efficiency of the plant operation. Several plants have already most (if not all) the equipment required for the implementation of on-line data processing. The implementation of such techniques improves the energy efficiency at very reasonable costs. But very importantly, throughout the implementation procedure, the plant personnel will most likely discover problems with some equipment or with the plant operation strategy and they will improve their knowledge about the plant and its operation.

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Using Control for Adding Value to Energy Efficiency of Mineral Processing Plants

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OUTLINE

- Introduction
  - Energy efficiency and the mineral processing plants
  - Example of pressure for energy effciency
  - Two approaches to increase energy efficiency
- On-line data processing
  - Process observation
  - Process control
  - Process optimization
- Case studies
  - Observation and control of a grinding circuit
  - Control of a grinding circuit
  - Observation, control and optimization of electric arc furnaces
  - Optimization of an induration furnace
- Conclusion

INTRODUCTION - Energy efficiency and the mineral processing plants

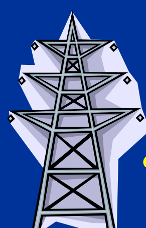
Globalization

International competition

Environmental and social pressure for energy efficiency

Energy costs

Energy efficiency challenge becomes unavoidable.



Intensive energy consumers

Objectives:
- **Reducing production costs**
- **Increasing throughput**
- **Increasing product quality**

INTRODUCTION
Example of pressure for energy effciency

Hydro-Québec:

- Quebec hydroelectrical producer and distributor.
- Most extensive transmission system in North America (32539 km).
- Pool up to 165 TWh/year (93% hydroelectric).
- Offers financial assistance to large-power customers to reduce specific energy consumption.

INTRODUCTION
Example of pressure for energy effciency

First program:

- Objective: to save 100 GWh from 2003 to 2006.
- Financial assistance budget: 8.5 M$.
- Customers must present their proposals.
- They must agree to take measurements before and after to show savings.
- Payback period: 1 year.
- Project completion: 18 months.
- Customers must pay 25% of the total costs.

INTRODUCTION
Example of pressure for energy effciency

Second program:

Financial assistance for

- an energy consumption analysis at the industrial site, or
- the demonstration that the first-time implementation in Quebec of a new technology would result in energy savings.

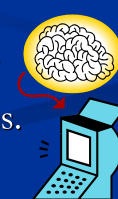
INTRODUCTION - Two approaches to increase energy efficiency

Approach 1:

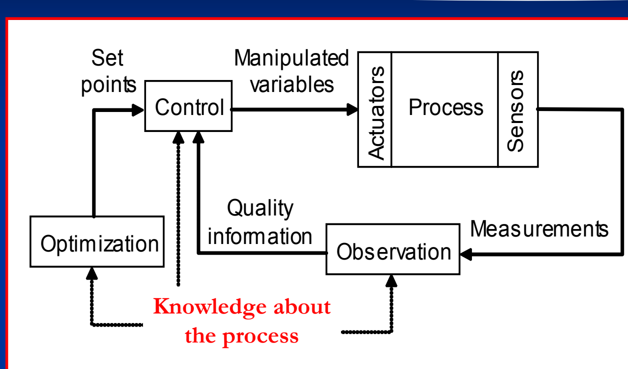
- Replacing existing equipment with more efficient ones.
- Installing new equipment aiming at reducing specific energy consumption of existing processes.

Approach 2:

On-line data processing: judicious on-line use of process sensors and large operation databases.

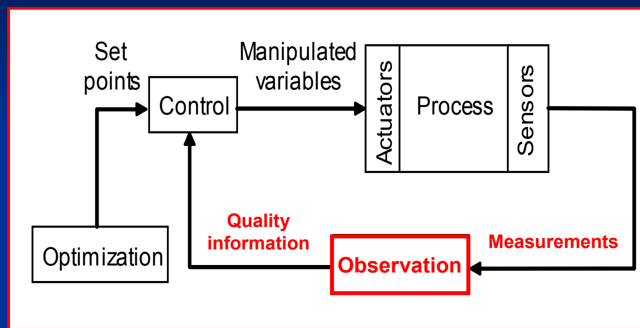


ON-LINE DATA PROCESSING



Measurements + knowledge = Possibility to automatically, continously and adequately manipulate actuators to achieve a specific objective.

ON-LINE DATA PROCESSING
Process observation



- To see the process states, to obtain a better picture of the process.
- To detect operation problems, abnormal performances, etc.

ON-LINE DATA PROCESSING
Process observation

Fault detection and isolation:

- Rapidly detect and physically localize problems such as sensor biaises, leaks, etc.
- Allow rapid corrections reducing bad consequences on the production.

Data reconciliation:

- Improves the quality of noisy measurements.
- Makes them consistent with process knowledge such as mass and energy conservation laws.

ON-LINE DATA PROCESSING
Process observation

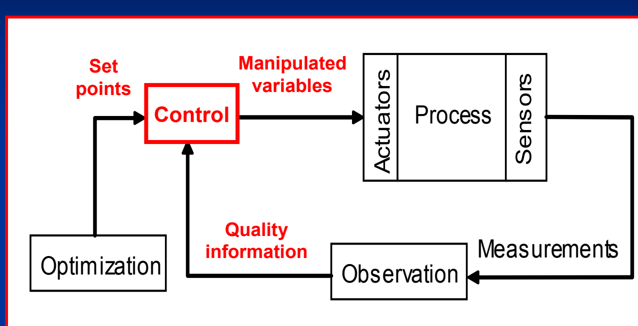
Observers:

- Soft sensor algorithms.
- They infer signals that cannot be measured.
- The availability of these signals can improve the plant operation.

Process observation:

- Even if no automatic actions are taken, a better vision allows engineers to modify equipment or change operation when required.

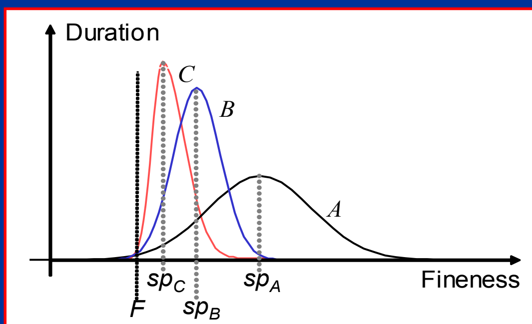
ON-LINE DATA PROCESSING
Process control



- To maintain the measured variables at selected set points by automatically and constinuously manipulating the actuators.
- Makes use of feedback and feedforward.

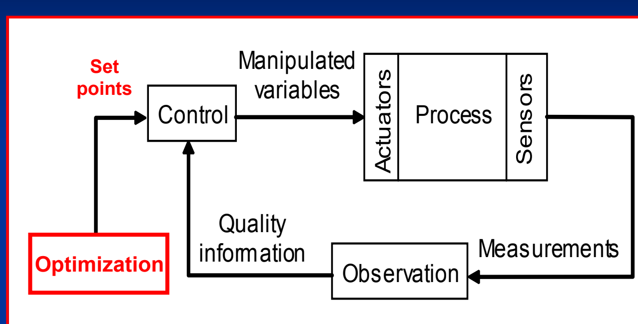
ON-LINE DATA PROCESSING
Process control

- Disturbances (such as changes in the ore properties) must be quickly rejected.
- Provides stabilization around the set points and a decrease of the process variability.



- Smoother operation.
- Less costly operation (even if set points are not changed).

ON-LINE DATA PROCESSING
Process optimization



To automatically select the set points by optimizing a cost function:

- minimization of energy consumption,
- maximizing profits,
- etc.

ON-LINE DATA PROCESSING
Process optimization

Very flexible tool:

- Selection of the cost function.
- Addition of constraints such as taking into account energy consumption regulations.

ON-LINE DATA PROCESSING

- Added values for energy savings.
- For several plants, no or little new equipment needed.
- Several additional benefits:
  - Better knowledge of the plant.
  - Product quality respecting more often the specifications.
  - Throughput increase.
  - Easier-to-operate plant thus more effective use of personnel.
  - Decrease in the maintenance costs.

ON-LINE DATA PROCESSING

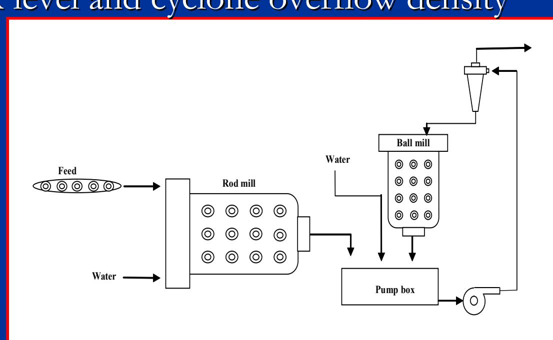
- Energy savings are often underestimated because the plant units are considered separately.
- Example: the optimization of a flotation plant
  - Does not procure any real energy savings.
  - May have important energetic impacts on subsequent processing (meal extraction and smelting).
- Plant wise evaluation should be performed (however, a difficult task).

CASE STUDIES - Observation and control of a grinding circuit

Kidd Creek grinding circuit control:

Objectives (none related to energy):

- Increase plant throughput (not an issue 2 years later).
- Prevent pump box level and cyclone overflow density upsets.
- Stabilize product quality.



CASE STUDIES - Observation and control of a grinding circuit

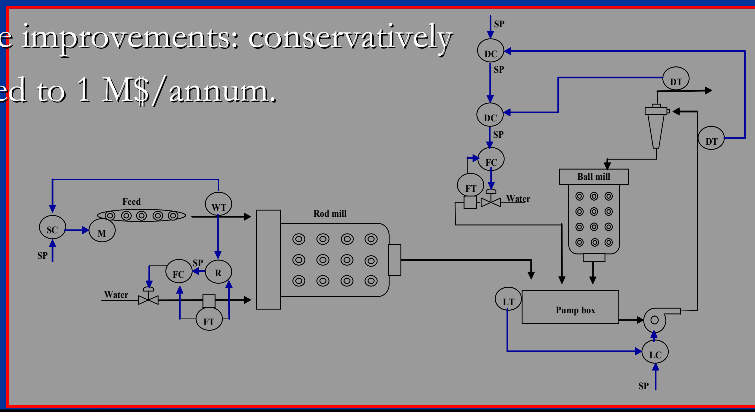
- Design based on a phenomenological simulator (Dynafrag).
- Dynafrag required to be calibrated: 3 sampling campains.
- Data reconciliation revealed some abnormal operating conditions such as extremely high mill circulating load ratios (CLR) (around 1800%).
- 1800% CLR: 3650 t/h of pulp at the cyclone feed (250 HP for pumping)
- 500% CLR: 1154 t/h of pulp at the cyclone feed (55 HP for pumping)

CASE STUDIES - Observation and control of a grinding circuit

- 1800% CLR: a pulp residence time within the mill of about 0.5 minute.
- 500% CLR: 2 min residence time.
- In other words: a lot more energy was spent in pumping a huge circulating load to achieve very little grinding.

CASE STUDIES - Observation and control of a grinding circuit

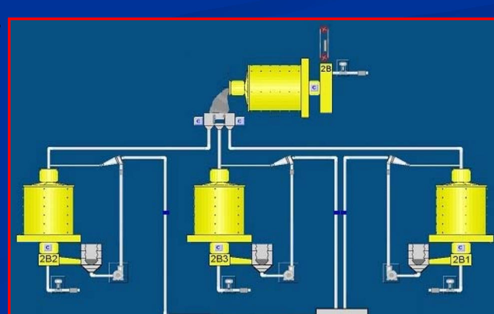
- Because of equipment and objectives changes, difficult to quantify the energetic and metallurgical improvements.
- Total costs: around 0.2 M$.
- Revenue improvements: conservatively estimated to 1 M$/annum.



CASE STUDIES
Control of a grinding circuit

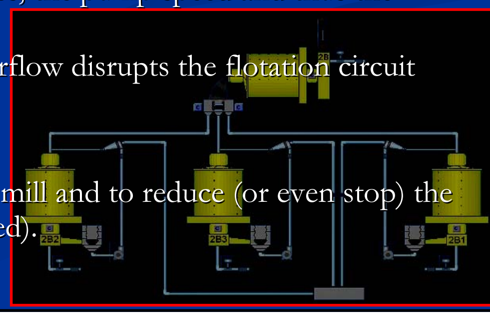
Toquepala grinding circuit control:

- The rod-mill discharge is distributed to 3 parallel ball-mills using a three-way splitter.
- The operator decides the splitter palettes' position.
- Level of 3 sump boxes controlled with variable speed pumps.



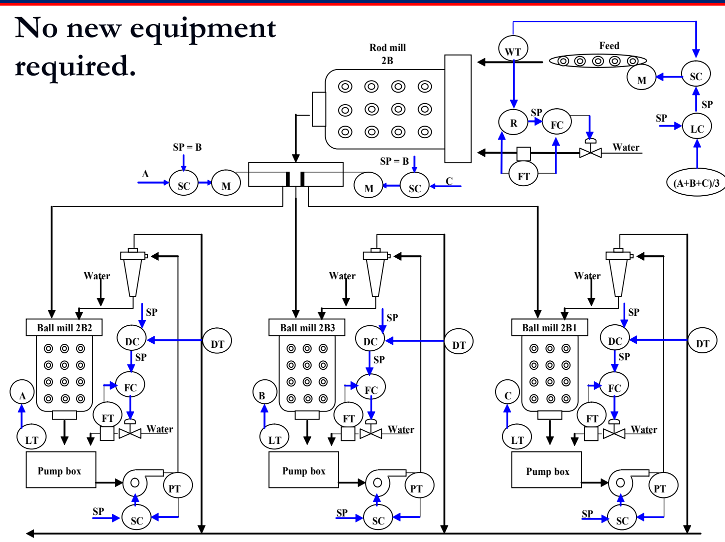
CASE STUDIES
Control of a grinding circuit

- Ore hardness variations or spitter entanglement by small broken rods:
  - the ball mill receiving more feed overloads,
  - the discharge gets coarser and the hydrocyclone underflow stream becomes larger,
  - the sump box level raises, the pump speed and thus the cyclone feed increase ,
  - the coarser cyclone overflow disrupts the flotation circuit operation.
- Solution:
  - Stop feeding the ill ball mill and to reduce (or even stop) the circuit feed (rod mill feed).



CASE STUDIES
Control of a grinding circuit

No new equipment required.



CASE STUDIES
Control of a grinding circuit

Results:

- Better stability of the circuit operation, particularly of the three ball mills.
- Tonnage increase from 245.7 t/h to 253.6 t/h (2 % to 4%).
- Slightly finer product.
- Reduction in
  - monthly energy consumption from 1607750 kWh to 1528797 kWh.
  - specific energy from 9.20 kWh/t to 8.42 kW/t (8% to 10% decrease).
- A greater availability of operators.
- Total gains/year : 4.9 M$
- If applied to the 8 lines of the concentrator: savings would be 8 x 900000 kWh/year.

CASE STUDIES - Observation, control and optimization of electric arc furnaces

Electric arc furnaces:

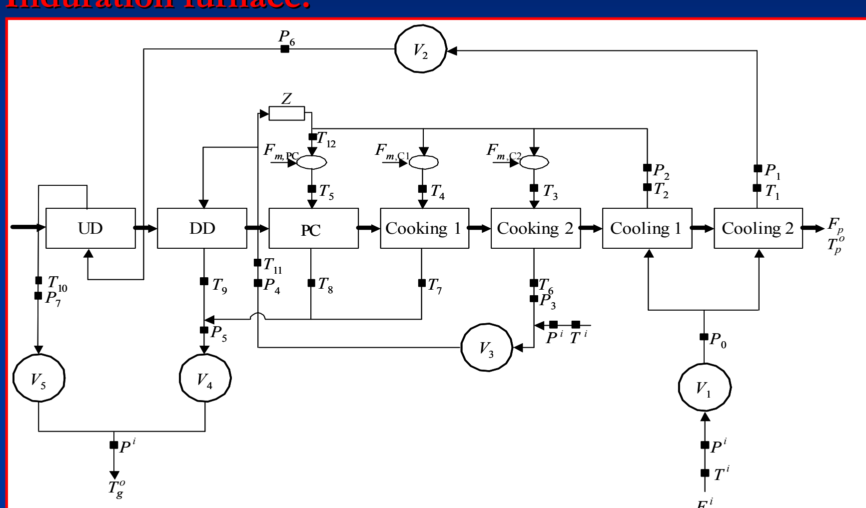
- Consume a large amount of energy in ferroalloy and steel industries.
- No direct measurement of how the energy is used inside the furnace is made.
- On-line information about the internal behavior of the furnace: the arc signature (voltage-current characteristic at the tip of the electrode).
- Observation of the arc signature gives the possibility to infer strategic variables such as length, stability, symmetry, dynamic resistance and power dissipation of the arc.

CASE STUDIES - Observation, control and optimization of electric arc furnaces

- Objectives:
  - Optimization of the energy usage.
  - Reduction of the production costs.
- Arc signature system combined to control have been tested and installed on submerged arc furnaces and long arc furnaces with foamy slag.
- Typical results for submerged arc furnaces:
  - 5 % reduction of the specific consumption (MWh/t).
  - Increase of operating power and thus 25% increase of the production rate.
  - 30% reduction in the amount of corrective loads to stabilize the furnace.
  - The signature is used to support operation, anticipate and prevent problematic situations.

CASE STUDIES
Optimization of an induration furnace

Induration furnace:



CASE STUDIES
Optimization of an induration furnace

Optimization criterion must reflect precisely the producer objectives:

- to maximize the net revenue, i.e. the product value minus the production costs; may lead to a minimization of the total consumed energy, but not necessarily.
- to maximize the production rate at constant energy consumption; leads to the minimum energy consumption per ton of pellet produced, but not to the minimal total energy consumption.
- to maximize the product quality (to increase the product value) at constant production rate; will not be optimal for energy consumption, except if the total energy consumption is constrained at a predefined value.
- to find, at constant production rate and product quality, the distribution of consumed energy between the coke addition, the three burner zones and the five fans, which minimized the energy cost.
- etc.

CASE STUDIES
Optimization of an induration furnace

Simulation run	1	2	3	4	5	6	7
Production rate	*Max*	*Max*	*Nom*	*Opt*	*Opt*	*Nom*	*Opt*
Fuel consumption	*Nom*	*Nom*	*Opt*	*Nom*	*Nom*	*Min*	*Opt*
Fuel distribution	*Nom*	*Opt*	*Opt*	*Nom*	*Opt*	*Opt*	*Opt*
Pellet quality	*Constr*	*Constr*	*Max*	*Max*	*Max*	*Constr*	*Constr*
Fuel (%) at PC, C1, C2	4, 10, 86	0, 5, 95	0,13, 87	4, 10, 86	0, 5, 95	0, 6, 94	0, 5, 95
Production rate index	107	109	104	101	100	103	110
Total fuel (kg/s)	0.820	0.820	0.858	0.820	0.820	0.674	0.818
Energy index per ton	100.5	101.0	100	100.6	100.7	101.3	100.9
Normalized profits ($)	108	110	103	101	100	105	111

- the total energy per ton of product does not much vary
- the total fuel consumption can widely vary
- the maximum profit (run 7) is not necessarily a good criterion to maximize energy efficiency

CONCLUSION

Process observation, control and optimization:

- increase the energy efficiency,
- provide several additional benefits,
- often require no or little new equipment.

Through the implementation, the plant personnel will most likely discover problems with equipment or operation.