THE GEOCHEMISTRY OF THE HGP-A GEOTHERMAL WELL:
A REVIEW AND AN UPDATE

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ABSTRACT

The HGP-A geothermal well, located on the lower
east rift system of Kilauea volcano, has provided
steam and hot water to a 3MWe wellhead generator
facility on a continuous basis since December
1981. Since production began there have been sub-
stantial changes in the composition of the reser-
voir fluids that suggest several important con-
clusions regarding the HGP-A well and the reser-
voir associated with the Kilauea east rift zone.
Among these are: that preproduction reservoir
fluids have moderate to low dissolved solids
concentrations; that long-term fluid production
can result in encroachment of heavily modified
seawater into the geothermal system; and that
deposition of secondary minerals from the in-
truding seawater may result in the obstruction and
eventual sealing of the saline aquifers.

INTRODUCTION

The HGP-A geothermal well, located on the lower
east rift zone of Kilauea, was drilled in 1976 to
a total depth of 1966 meters. Initial testing of
this well showed that it had a bottom hole temp-
erature of 358°C and was capable of producing
approximately 50 tonnes of geothermal fluid per
hour (Yuen et al., 1978). The fluid discharged by
this well was composed of approximately 43% steam
and 57% liquid brine (at a separation pressure of
approximately 1200kPa (175psia)) indicating that
the resource encountered was liquid dominated. In
order to demonstrate the technical feasibility of
producing electrical power from the geothermal
reservoir discovered by the HGP-A well, the U.S.
Department of Energy, the State of Hawaii, and
Hawaiian Electric Company provided funds to con-
struct a single-flash 3MWe wellhead generator
facility. This facility was completed in June
1981 and, after a lengthy shake-down period, began
continuous operation in March 1982 (Thomas,
1982). During the subsequent five years of oper-
ation the chemical composition of the reservoir
fluids discharged by HGP-A have been carefully
monitored in an effort to identify the source of
the fluids produced by this well and to provide
technical information that may be of value in the
design of larger commercial geothermal generator
facilities. Some of the more important findings
of this monitoring program are presented below.

HGP-A FLUID CHEMISTRY

Analysis of the steam and brine discharged by the
HGP-A well during initial flow testing found that
the reservoir fluids in the Kilauea east rift zone
contained only moderate concentrations of
dissolved solids (about 3000mg/kg) and gases
(about 0.25%) (Kroopnick et al., 1978, Thomas,
1980). The principal dissolved species found in
the liquid phase were sodium, chloride, and silica
and the major non-condensable gases present were
carbon dioxide, hydrogen sulfide and nitrogen.
Although the levels of dissolved solids present in
the geothermal fluids were well below those
anticipated in the interior of the Kilauea east
rift, continuous production of fluids during the
subsequent five years of operation of the facility
resulted in an approximately tenfold increase in
the solids concentrations (Thomas, 1986). A plot
of chloride ion concentration in the brine phase
versus time shows the general trend of the major
dissolved ions: an initially steep rate of
increase that, with time, has gradually levelled
off. More recently, however the trend has
undergone a reversal with a very slight decline in
the dissolved ion concentrations. Although the
other major dissolved ion concentrations have
followed a similar trend during this period, only
sodium increased at the same rate as chloride
whereas calcium and magnesium increased more
rapidly and potassium and lithium increased more
slowly. It is noteworthy, however, that the
dissolved silica and the non-condensable gases
have not followed the same trend as the dissolved
ions but have maintained relatively constant
values in the brine and steam phases respectively.

DISCUSSION

The concentrations of the dissolved solids present
in the deep reservoir fluids discharged by the
HGP-A well during the initial testing were
substantially below those anticipated on the basis
of the Ghyben-Herzberg model of island hydrology.
This model predicted that, in the location of the
HGP-A well, only a thin (<200m thick) fresh water
layer should have been present and that this layer
would be underlain by seawater saturated basalts
at the depths of the production intervals drawn
upon by the HGP-A well. The presence of only
slightly brackish water at 2km depths suggested
that some mechanism associated with the rift zone

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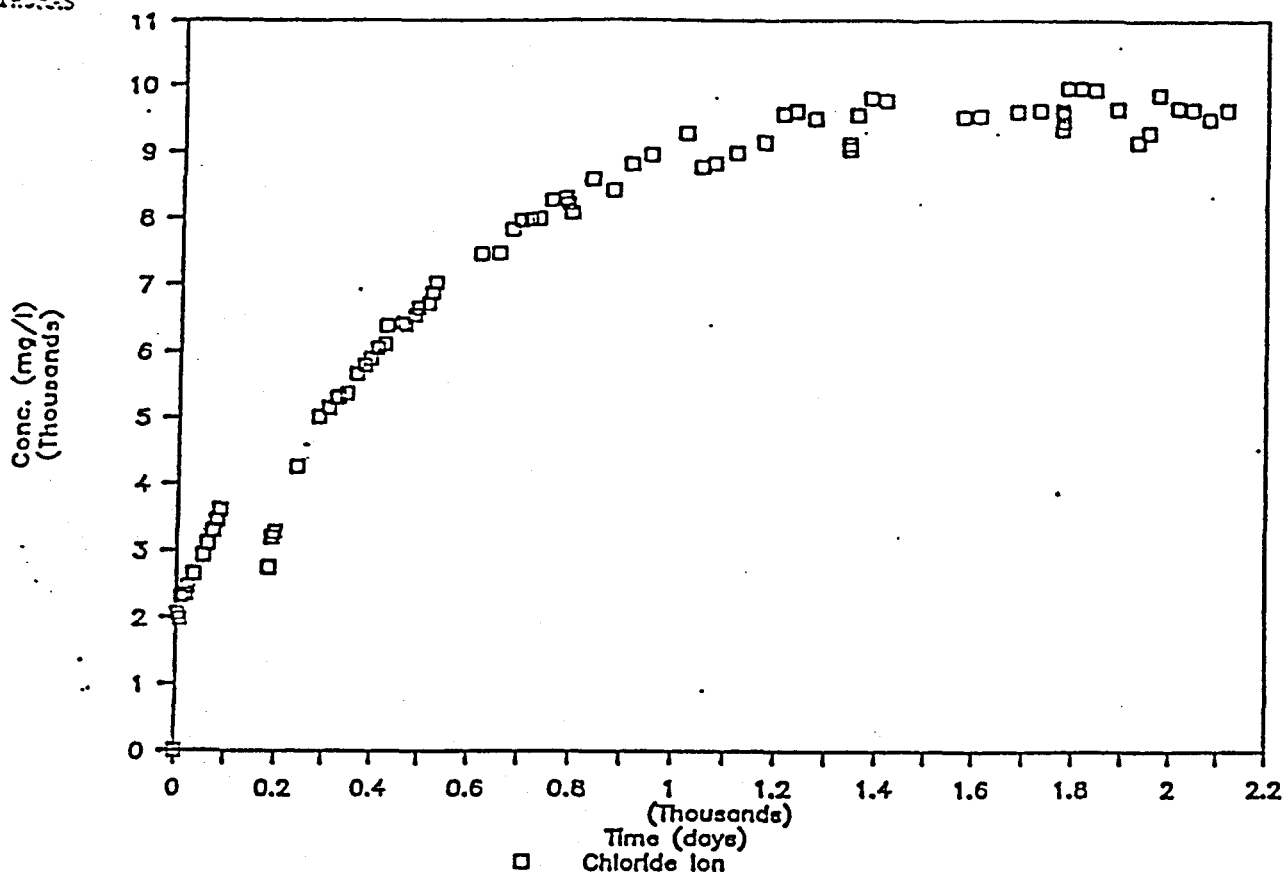
Fig. 2. Chloride concentration in HGP-A brine versus time.

was responsible for exclusion of seawater from the interior of the geothermal reservoir. The mechanisms that have been suggested have included: inhibition of cross-rift seawater intrusion by the less permeable dike complex within the deeper part of the rift; rapid convective overturn and mixing of hot, less dense saline waters with colder, denser, fresh meteoric recharge; or the alteration of the reservoir basalts and the deposition of secondary minerals along the southern boundary of the hydrothermal system (Thomas, 1987). The changes in ion chemistry that occurred during the long-term production of the well now suggests that all three mechanisms may play a role in controlling fluid flow within the lower east rift system.

The very steep increases in the dissolved ion concentrations that accompanied long-term production of fluids from HGP-A suggested that withdrawal of reservoir fluids was permitting seawater intrusions into the hydrothermal system tapped by the well. This inference is substantiated by the coincident increases in the sodium and chloride ion concentrations which have maintained a Na:Cl ratio that is nearly identical to that of seawater. The concentrations of several other major ions, relative to that of chloride, indicated however that the intruding seawater had been heavily

modified: lithium and potassium were enriched in the HGP-A brines relative to seawater, by factors of fifteen and five respectively, calcium was depleted by 40%, and magnesium and sulfate were depleted by more than 99.9%. This pattern of enrichment and depletion is very similar to that found in seafloor hydrothermal vent systems and in laboratory experiments of high-temperature reactions between seawater and basalts (Mottle, 1983; Bischoff and Dickson, 1975). These, and other studies, have shown that seawater undergoes a complex chain of reactions when exposed to high temperature basalts that results in both modification of the seawater composition and intensive alteration of the reservoir basalts.

The degree of enrichment and depletion of the ionic species during the early production period indicated that the seawater:basalt ratios were quite low (<0.1) (Thomas, 1983). However, as the salinity of the production fluids increased with time, the degree of enrichment of lithium and potassium, and the depletion of magnesium, declined while calcium ion concentrations changed from being depleted to being substantially enriched (Figure 2). The observed trend of relative ion concentrations suggest two possible interpretations. The first is that the observed
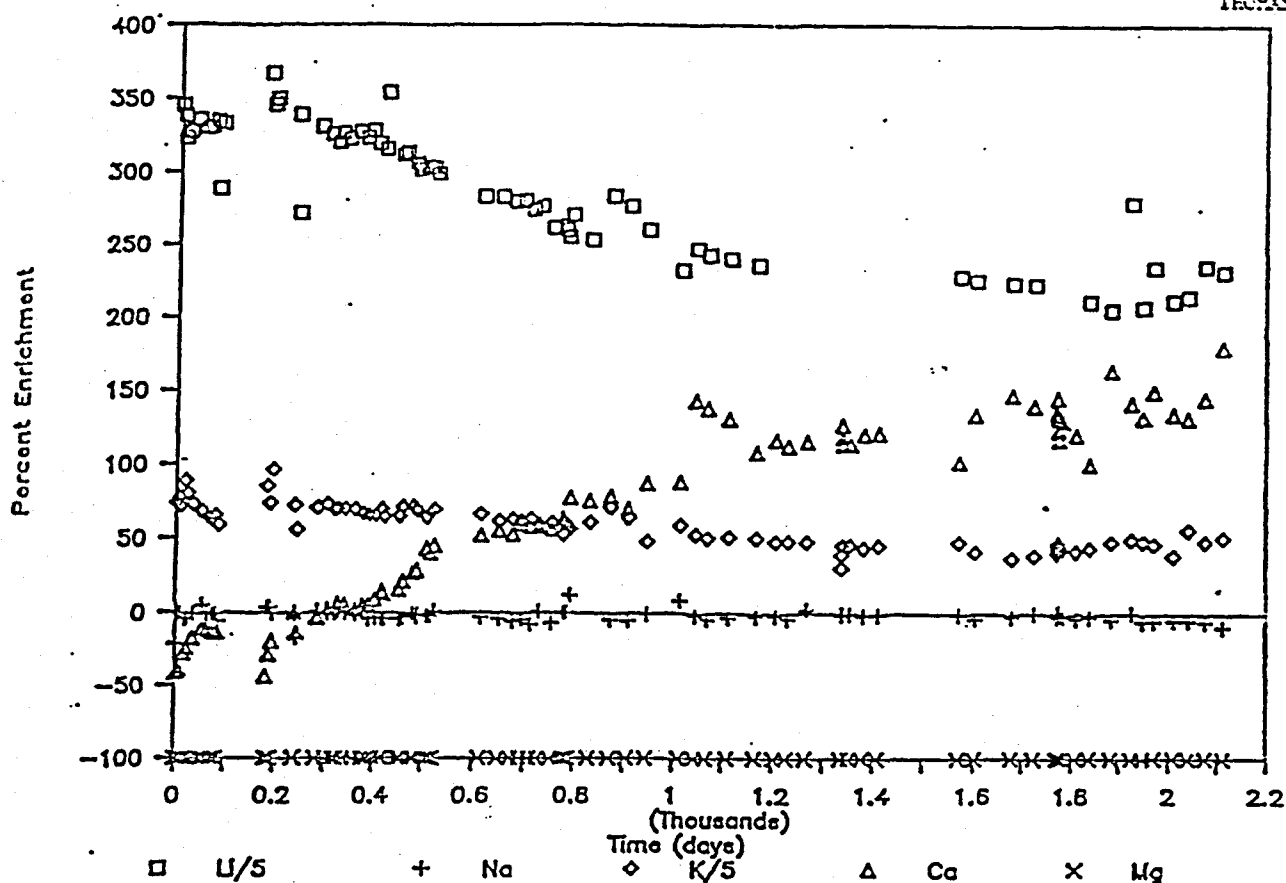
Fig. 2. Percent enrichment or depletion of major cations with respect to seawater of equal chloride concentration.

changes in ion ratios reflect a progressively increasing seawater:basalt ratio in the geothermal reservoir; as progressively more seawater passes through, and reacts with, the wall-rock of the intrusion aquifer, the rocks became progressively altered, depleting more soluble ions from the solid phase. The degree of enrichment of potassium and calcium suggest that the effective water rock (W:R) ratio is currently approximately three. This W:R ratio is well within the range of seawater:rock ratios observed in seafloor hydrothermal systems and in a similar land-based, seawater dominated hydrothermal system on the Reykjanes peninsula in Iceland (Mottl and Seyfreid, 1980).

An alternative hypothesis that could account for the observed changes in the ion ratios is that they reflect a decline in the temperature of the reservoir due to the influx of cold seawater from outside the rift zone. Calculation of the Na-K-Ca geothermometer temperatures through the period of changing fluid compositions shows that there has been an apparent decline in the fluid temperatures with time (Figure 3). The temperatures calculated for the fluids during the first few weeks of production indicated a temperature of approximately 300°C but, after several years of production, the

apparent cation temperature have fallen to less than 240°C. However, as noted above, the silica concentrations have remained relatively stable at about 800-850mg/kg which yield calculated temperatures of approximately 295°C. The apparent discrepancy in the geochemical temperatures is believed to be the result of the difference in the rate at which these geothermometers approach equilibrium. Because silica approaches an equilibrium concentration more rapidly than does the Na, K, and Ca concentration, the former more accurately reflects the actual reservoir temperatures around the well-bore. Because the Na-K-Ca geothermometer achieves equilibrium more slowly, and may be more sensitive to progressive depletion of these ions from aquifer wall rock (i.e., at higher W:R ratios), the apparent decline in the temperatures calculated from these ion concentrations may correspond to the temperatures of the intruding fluids prior to entry into the hydrothermal system. Thus, the changing ion enrichments may be the result of progressive alteration of reservoir rocks exposed to the intruding seawater.

The reactions that accompany the intrusion of seawater into the geothermal reservoir have several important implications for the chemistry of the geothermal reservoir fluids. The

production aquifers in the well; depletion of buffering capacity of reservoir basalts at a faster rate than the depletion of thermal energy could result in continued high fluid temperatures but a disastrous decline in pH of the fluids produced; or the deposition of alteration minerals could result in the eventual obstruction of the intrusion aquifers. As noted above, the silica temperature has remained relatively constant and thus suggests that a decline in reservoir temperature is not imminent. However, an observed decline in the brine pH from pH 7.4 (@25°C) to 6.5 (an increase in the hydrogen ion concentration by nearly a factor of 10) indicates that some depletion of the buffering capacity of the reservoir rocks has occurred and that further decline in the pH is quite possible. Nonetheless, the decline in the dissolved ion concentrations in the brine phase that have recently been observed suggest that the fractures through which cold seawater from south of the rift is entering the geothermal system are gradually becoming obstructed and are thus choking off the flow of seawater into the production horizon tapped by HGP-A.

IMPLICATIONS FOR FUTURE GEOTHERMAL DEVELOPMENT ON THE KILAUEA EAST RIFT ZONE

Although a projection of the expected production characteristics of an entire geothermal field on the basis of the results derived from a single exploration well must, of necessity, be highly speculative, two tentative conclusions are suggested by the operating history of the HGP-A well. These are as follows:

1. Wells drilled in the interior of the rift are likely to encounter low to moderate salinities but those drilled along the southern boundary of the rift are more likely to encounter a seawater dominated hydrothermal system.

2. Wells drilled along the southern boundary of the rift are more likely to encounter either lower permeabilities or much more acid geothermal fluids than those drilled in the interior of the rift system.

ACKNOWLEDGEMENTS

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Table 1

REPRESENTATIVE DATA

KS-1A WELL

Preliminary

8"x14"

HGP-A ?

	STEAM CONDENSATE	BRINE	STEAM	BRINE
Na	0.19	10000		
K	0.1	2500		
Ca	<0.1	860		
Mg	≤0.1	1.7		
Fe	0.04	8.6		
Mn		8.1		
B	<0.5	7.0		
Br		80		
I		<20		
F		0.91		
Li	<0.01	8.6		
Cl	<2	18500		
Nh_3	0.16	0.13		
SO_4	7.1*	20		
Hg		<0.001		
As	≤0.01	0.6		
$S^=$				
$SO_3^=$				
Conductivity/umho/cm)	110	65000		
pH	3.6	4.6		
Density		1.03		
Total Alkalinity	<10	≤10		
HCO_3	0	≤12		
CO_3	0	0		
C/a				
Tss (Total Suspended Solids)		1100		
Tds (Total Disolved Solids)	<10	32000		
$S_{1}O_2$	1.3	1500		

Results reported in mg/l unless otherwise noted.

* Suspected to be incorrect and responsible for low pH reading.

< Indicates below the detection limit indicated.

Brine 17% by Weight

Need also T + P s ?

Supplied to AEI

Table 2

Preliminary noncondensible gas composition of KS-1A
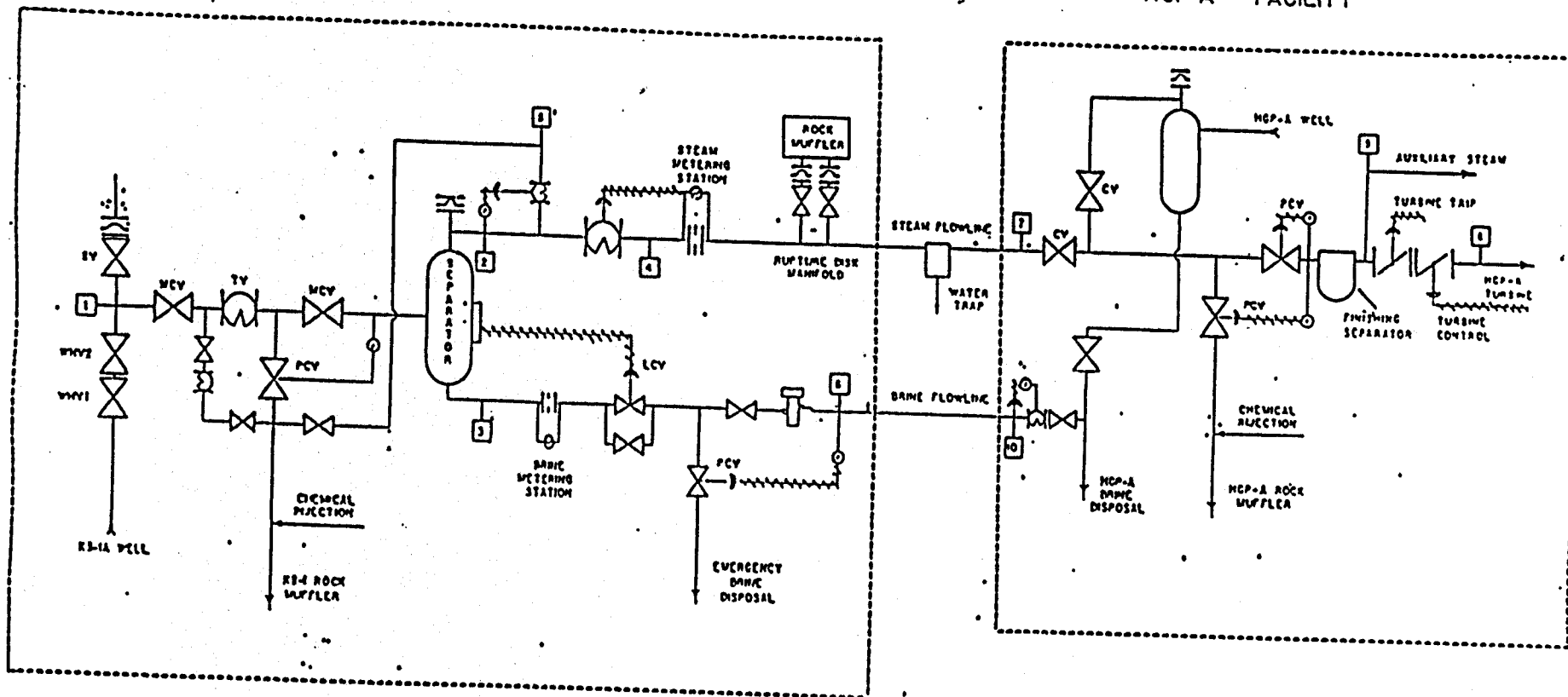produced fluids by weight.

Concentration (ppm)

Sample	H_2O	CO_2	H_2S	NH_3	Ar	N_2	CH_4	He	H_2	Total NCG w/o H_2O
10-Day	9.98×10^5	4.27×10^2	1.01×10^3	<1.31	3.14	2.12×10^2	$<1.32 \times 10^{-1}$	$<5.03 \times 10^{-3}$	1.0×10^1	1662
16-Day	9.98×10^5	3.52×10^2	1.49×10^3	<1.31	4.11×10^{-2}	7.54	$<9.48 \times 10^{-2}$	$<3.62 \times 10^{-3}$	5.34	1885

← HGP-A

$<$ (symbol) indicates below the detectable limit

KAPOHO STATE 1 WELL PAD

HGP-A FACILITY

STEAM METERING STATION

ROCK MUFFLER

STEAM FLOWLINE

RUPTURE DISK MANIFOLD

WATER TRAP

HGP-A WELL

AUXILIARY STEAM

TURBINE TRIP

FINISHING SEPARATOR

TURBINE CONTROL

HGP-A TURBINE

SEPARATOR

LCV

BRINE METERING STATION

BRINE FLOWLINE

CHEMICAL INJECTION

HGP-A BRINE DISPOSAL

HGP-A ROCK MUFFLER

PCV

EMERGENCY BRINE DISPOSAL

CHEMICAL INJECTION

KS-1A WELL

KS-1 ROCK MUFFLER

WHV2

WHV1

LEGEND

WHV = Wellhead Valve
SV = Stop Valve
TV = Throttle Valve
WCV = Water Control Valve
PCV = Pressure Control Valve
CV = Control Valve
LCV = Level Control Valve

APPROXIMATE FLOW CONDITIONS

POINT	1	2	3	4	5		7	8	9	10
PRESSURE (psig)	175	170	170			300 / 150	150	145	145	250 / 150
TEMPERATURE (F)	377	372	372			372	358	354	358	?
STEAM FLOW (lbm/hr)		39,400		32,750	6,650		32,500	31,000	1,300	
WATER FLOW (lbm/hr)			15,400			15,400				15,400

B+S   B   B   B