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PHASES MECHANISM DISTRIBUTION IN A GEOTHERMAL STEAM PIPE USING SODIUM AS A TRACER

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ABSTRACT

In the horizontal pipelines carrying geothermal steam, the fluids tend to be multiphasic and multicomponent. Therefore, is convenient to know the way these phases are distributed, and also the mechanism whereby the brine and the non-condensable gases are distributed between these phases.

In the present work, results of experimental tests carried out in steam pipelines of Cerro Prieto geothermal field are shown, where measurements of pressure drops, mass rates, insulator peripherical temperatures, and weather conditions were taken, in addition to diametral sodium content utilizing a transversable-retractable impact probe between two separated points along the pipe. A mechanism of longitudinal dilution of sodium is proposed and the quantity of condensate used is verified by conventional equations.

INTRODUCTION

Exploitation process of liquid dominant geothermal sistems, requires liquid-vapor separation on the land surface. Bottom Outlet Cyclone (B.O.C.) separators or Webre type have been a common ocurrence in Cerro Prieto geothermal field, and they can be installed in single form or two of them in series.

Physical chemistry nature of the separation causes non-condensable gases to be carried in the steam core according to their partition coefficients. Dissolved and suspended solids are transported in the separate brine.

Although, B.O.C. separators are very efficienty, some brine, with high solid content are dragged into the steam pipeline. These solids are harmful from the view point of problems related to scaling, corrosion, and erosion of pipe, instruments and power generation equipment. However, some authors [1] reported evidences on solids action working as corrosion inhibitors, produced by the acid non-condensable gases action conjointly with the condensate generated along, steam conduction.

Wet geothermal steam is exposed during its conduction to progressive condensation due to heat losses through pipe walls. Down stream expansion produces flash evaporation attenuating steam condensation. Final result is lost of sistem energy, the steam being conducted in a polytropic way instead of isentropic or isenthalpic way.

At normal operational range, the steam flows in a stratified flow pattern with the film condensate flowing mainly on the pipe bottom. This is presumably due to gravitational effect and that lower pipe wall is colder than the upper pipe wall. The last situation could be caused by the outside boundary layer and by shaded surfaces. This phenomenon has been observed [2], in the experimental part of this work, and it was predicted correctly by the Mandhane's diagram [3].

However, drag forces keep some of the liquid suspended in the steam core, and the walls are slighty wet. In a strictly sense, a mixed flow pattern exists, and it can be described like a semiannular-dispersed-stratified flow pattern.

In the present work, sodium waS selected as a tracer, because its natural ocurrence and abundance in the geothermal fluid. Moreover, sodium compounds are very soluble in water and they can be used like wet detectors in the vapor phase.

SISTEM DESCRIPTION

This work was carried out at Cerro Prieto geothermal field using the steam horizontal pipeline of the well E-15. This pipeline is located between the B.O.C. separator and the main collector. Pipe design characteristic are shown in Table I.

TABLE I

Pipe characteristics

Pipe material	C.S.-A285-C
Nominal diameter	16"(ID=15.25")
Insulation type	ASTM-C457-74
Insulation thickness	3"
Insulation cover	polished alum.
Straight length	1242 ft
Equiv. Length	406 ft

Throughout this test, the steam pipeline was operated at 1390 psia well head pressure, 129.5 psia separation pressure, and 131311 lbs/hr mass rate.

Two measure points in the steam pipeline were selected, as far as possible from each other. The first measuring point was located 76 ft down stream from the separator outlet, and at least ten pipe diameters from the orifice plate flow meter to avoid flow disturbance. The second measure point was located 1242 ft down stream from the first measure point before the pipe and the main collector joint. There was a collection pot five pipe diameters down stream from the second measure point.

Pressure and temperature measure outlets were located in each point, together with 2" valves for the insertion of the transversable retractable impact probe.

Pressure and flow measures were taking continously using total pressure and differential pressure trasductors.

Perimetral temperatures measures were taking in each point on insulation surface and on wall pipe surface using thermocouples with surface sensors.

Weather conditions of temperature and wind velocity were taken with portable mercury in glass thermometer and annemometer respectively. They were compared with measures from the Cerro Prieto meteorological station.

The determination of sodium diametral profile in each point was the most important part of the test. Impact retractil probes were constructed according to the ASME[7] criteria for isokinetic sampling flow.

The samples were collected and condensed using the technique described by ASTM [8] and analized by spectrophotometry for sodium ion. Then duplicated diametral samples were taken in each measure point. An ellapsed flowing time was allowed between each sampling operation to avoid sample contamination. Results of these determinations are shown in Figure I, and in Table II

TABLE II

Experimental results

Point 1 pressure	123.356 psia
Point 2 pressure	116.846 psia
Pressure drop 1-2	6.510 psi
Sodium concentration (ppm):	
Brine	8783
Point 0	1.98
Point 1 (avg)	1.7435
Point 2 (avg)	0.8329
Ball valve	2.8075
Gate valve	288.5

THEORETICAL ANALYSIS

In wet steam flow through pipelines, the liquid is distributed between steam core and bulk film on the walls *[1,6].* When steam wetness measurements are taken, the liquid in the bulk film is not considered. According to James R. and Dmitriev [4,5], at moderate pressure, the relationship between the homogeneous steam quality (X^) and the measure steam quality (XJ can be expressed by:

$$X_R = X_M^{\alpha} \qquad (1)$$

This is a distribution in dynamic equilibrium of liquid that is carried in the steam, and it travels from the steam core to the film and conversely through the steam film interphase.

Explanation of condensation mechanism is not an easy matter. Some authors [9] consider that in the vapor phase nucleation may occur, and existing droplets may grow, evaporate, or coagulate with each other or impact on walls and then become absorbed in bulk liquid films.

When highly soluble substances (i.e. sodium compounds) are present, their concentration distribution between the liquid in steam core and liquid film will be strongly affected by a condensation mechanism.

As an obvious approach, we suppose that the controling mechanism is the drop growing in the steam core. Then the process can be described in the following way:

Steam condenses like pure water in mist form, and later liquid water is adhered to droplets in steam core. This phenomenon is promoted by high exposed surfaces. Solids in droplets are diluted by this effect, and growing in a heterogeneous way, and some of them are incorporated to the film. The final result is as follows: Substances dilution in the liquid of the steam core and in the bulk film. Dilution effect is more accentuated in the liquid of the steam core. This phenomenon occurs in many stages along the duct producing a scrubbing effect .According to (1):

$$\left[1 - \frac{MLT}{MT}\right] = \left[1 - \frac{MLV}{MW}\right]^{\alpha} \qquad (2)$$

Where:
MLT: Total liquid flow rate
MLV: Steam core liquid flow rate
MT: Total flow rate
MW: Wet steam flow rate

$$\frac{\ln\left[1 - \frac{MLT}{MT}\right]}{\ln\left[1 - \frac{MLV}{MW}\right]} = \alpha \qquad (3)$$

If MLT and MLV are too small. therefore MT≐MW

$$\frac{\ln\left[1 - \frac{MLT}{MT}\right]}{\ln\left[1 - \frac{MLV}{MW}\right]} \doteq \frac{MLT}{MLV} \approx \alpha \qquad (4)$$

If α has a value of 1.5 [4,9] it may be proved that 2/3 of the total liquid are carried in the steam core.

FIGURE II
The dilution mechanism

	2N	2n+1	2n+2
STEAM CORE	MLV_{2N}	MLV_{2N}	MLV_{2N+2}
	X_{2N}	X_{2N+1}	X_{2N+2}
		CON/3	
FILM			
	Y_{2N}	Y_{2N+1}	Y_{2N+2}

→ FLOW

According to Figure II, a fraction of condensated is formed when the wet steam passes from the volume element 2N to the volumen element 2n+1

$$CON = \frac{CONT}{3} \tag{5}$$

Where R is the number of condensation stages, and CONT is the total condensated formed along the steam pipe. If the liquid transporting between the steam core and the film ocurrs in the volumen element 2n+1, the liquid balance for the full stage becomes:

For liquid in steam core:

$$MLV_{2N+1} = MLV_{2N} + CON \tag{6}$$

$$MLV_{2N+2} = MLV_{2N+1} - CON/3 \tag{7}$$

And for initial condition (0):

$$MLV_{2N+1} = MLV_0 + [2N+3]\ [CON/3] \tag{8}$$

For liquid in bulk film:

$$MLP_{2N+1} = MLP_{2N} + CON/3 \tag{9}$$

$$MLP_{2N+2} = MLP_{2N+1} \tag{10}$$

And:

$$MLP_{2N+1} = MLP_0 + [N+1]\ [CON/3] \tag{11}$$

If X is sodium concentration in the - liquid in steam core:

$$X_{2N+1} = \frac{X_{2N}\ MLV_{2N}}{MLV_{2N}+CON} \tag{12}$$

$$X_{2N+2} = X_{2N+1} \tag{13}$$

And:

$$X_{2N+1} = X_0 \prod_{0}^{N} \frac{3MLV_0 + [2N]\ [CON]}{3MLV_0 + [2N+3][CON]} \tag{14}$$

For the sodium concentration in the film (Y):

$$Y_{2N+1} = \frac{Y_{2N}\ MLP_{2N} + [CON/3]\ X_{2N+1}}{MLP_{2N} + [CON/3]} \tag{15}$$

$$Y_{2N+2} = Y_{2N+1} \tag{16}$$

And:

$$Y_{2N+1} = Y_0\ MLP_0 + [CON/3] \sum_{0}^{N} 2N+2 \tag{17}$$

If the initial and final concentration are known is possible to calculate the total condensate, the liquid distribution and the concentration profile along the steam pipeline.

CALCULATIONS

Sodium average concentrations in points 1 and 2 in Table II, are referred to the full steam core, and they were calculated according to a method published in a previous paper [10]. The method considers a developed velocity profile. and partial flow contributions in semiannular area elements are calculated. The experimental sodium diametral concentration profiles (Fig.I) were used to calculate the sodium global mass rate and the weighting sodium average concentration.

Initial sodium concentration (point 0) was determinated using an ASME multiport fixed probe and corrected according to the sodium diametral concentration profile.

Liquid distribution between the steam core and the film, and sodium concentration longitudinal profiles were calculated utilising the method previously described.

Condensate quantity needed in order to rich sodium concentration detected in points 1 and 2 were also calculated. Figure III and Table III present results of these calculations.

TABLE III
Calculations well E-15

Section 0-1	
Number of scrubbing stages	250
Dragged brine flow rate	44.40 lbs/hr
Total condensate flow rate	13.08 lbs/hr
Total liquid flow rate	57.48 lbs/hr
Sodium concentrations (ppm):	
Steam core	1.74037
Bulk film	8426.51
Section 0-2	
Number of scrubbing stages	250
Dragged brine	44.40 lbs/hr
Tot. condensate flow rate	208.64 lbs/hr
Total liquid flow rate	253.05 lbs/hr
Sodium concentration (ppm)	
Steam core	0.83421
Bulk film	3324.9

Total condensate flow rate in table III were compared with values predicted by the method presented in a previous work[11]. It consist in a computarized model where joint equations from fluid mechanic and heat transfer were taken into account as those which appeared in Holman's book[12], and from the work by Metais and Eckert[13].

This method was applied to a process of polytropic expansion in order to determine the energy losses that the steam suffers when it is conducted through long horizontal pipes of big diameter, which are thermically insulated. The results of this model are shown in Table IV:

TABLE IV
Flow model calculations
Well E-15

Section 0-1	
Pipe lenght	76ft
Initial enthalpy	1191.24 Btu/lb
Enthalpy drop	0.11792 Btu/lb
Point 1 pressure	129.196 psia
Pressure drop 0-1	0.304172 psi
Point 1 temperature	346.843°F
Total liquid flow rate	55.9032 lb/hr
Section 1-2	
Pipe lenght	1648.89 ft
Initial enthalpy	1190.56 Btu/lb
Enthalpy drop	2.16345 Btu/lb
Point 2 pressure	116.662 psia
Pressure drop 1-2	6.695 psi

Point 2 temperature 346.843°F
Total liquid flow rate 227.603 lb/hr

DISCUSSION

Condensate flow rate was calculated with the longitudinal dilution mechanism proposed, and accordance with sodium concentrations determined in points 1 and 2 in the steam pipeline, gave reasonable agreement with the values predicted by the computarized model based on the fluid mechanic and heat transfer equations. This longitudinal mechanism could be representative of the actual conditions within the steam pipeline.

The mechanism proposed is developed in smal' wash steps or scrubbing stages, and it may be considered as analogous to the case of continuous contact sistems. The number of stages is indicative of the process velocity. Therefore, a minimun number of stages must be determined for each case in order to obtain reliable results.

The method has a high sensibility to sodium concentration values, specially to the initial one . Therefore, proven steam sampling techniques are important, and reliable sampling dispositives are required.

The sodium concentration in the liquid carried in the steam core and the sodium concentration in the bulk film are different. This fact could be a useful aid for understanding scaling, corrosion and heat transfer processes.

Liquid distribution knowledge could conduce to different condensate draining dispositive designs.

The mechanism and method proposed can be used also in homogeneous steam quality evaluations and they can be used in the separators performance evaluations.

Aknowledges

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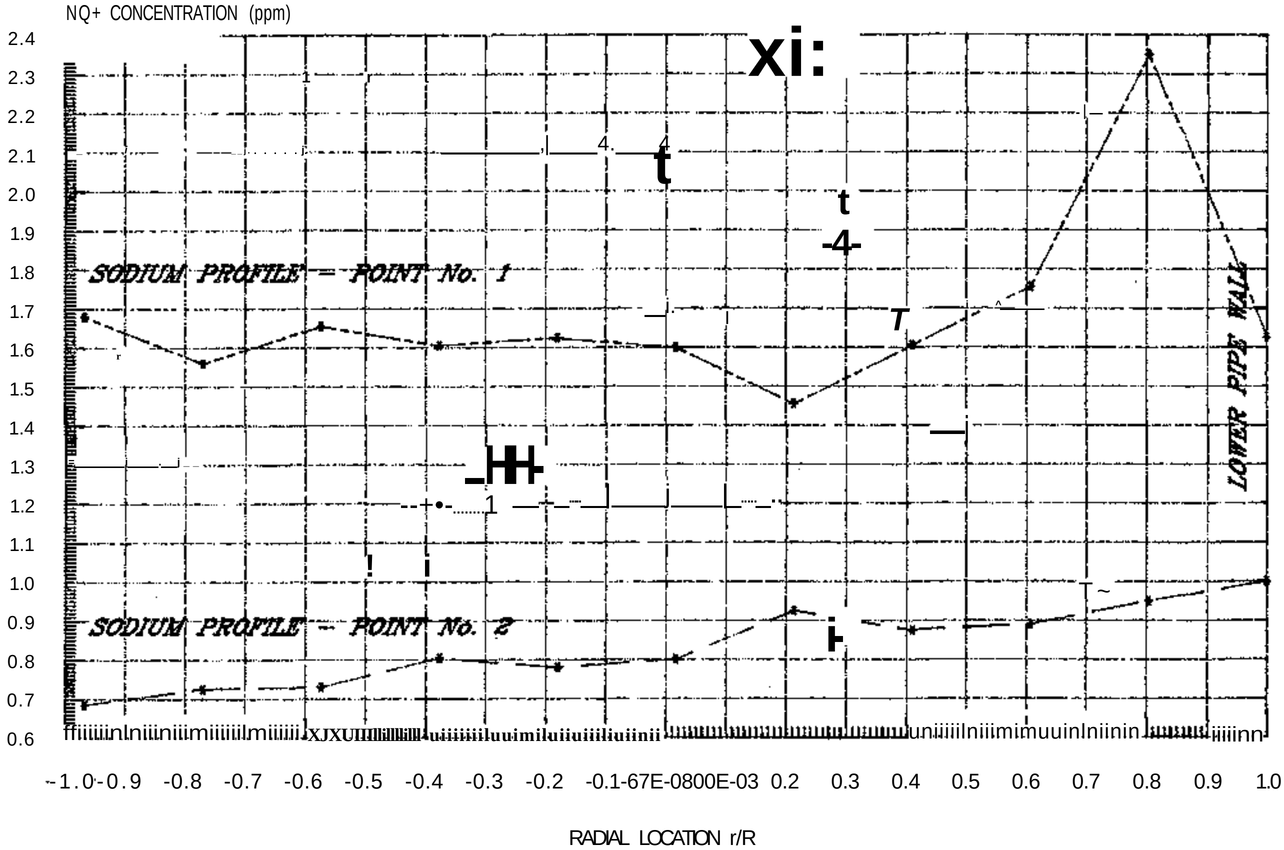
DIAMETRAL SODIUM CONCENTRATION PROFILE

FIG. No X WELL E-15



PIPE LENGHT VS SODIUM CONCENTRATION

FIG No. 2 WELL E-15