VERTICAL DISCHARGE DIFFUSER FOR GEOTHERMAL PRODUCTION WELLS

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ABSTRACT

Energy Development Corporation (EDC), a known leader in wet steam technology with its hundreds of production wells, operates five geothermal steamfields and most geothermal power plants in the Philippines with a combined capacity of 1,100 MWe. Production wells in these projects traditionally go through a series of standard testing of 30 minutes vertical discharge followed by horizontal discharge. Environmental observation and experience around some wells showed that vertical discharge causes defoliation of surrounding plants and trees. EDC's mandate on social responsibility and compliance with environmental regulations has led to the conceptualization, innovation and development of a Vertical Discharge Diffuser (VDD) by the company's Technical Services Sector. The Vertical Discharge Diffuser is intended for the Northern Negros Geothermal Project (NNGP) whose expansion and sustenance of its geothermal field operation is dependent on the success of environmental safeguards undertaken during production well testing. The project area is surrounded by a dense forest cover that needs to be protected during vertical discharge. It is located in the western flank of Kanlaon Volcano in the island province of Negros Occidental, approximately 535 km SSE of Manila.

This paper discusses the method for controlling, if not totally eliminating, brine spray during initial discharges of newly drilled or worked-over geothermal production wells. The Vertical Discharge Diffuser is an innovative and modified catchment extension facility of a production well's vertical discharge procedure purposely done to contain the discharge fluid. Here, a 30" Ø pipe is inserted to the 10" production well spools. From the 30" Ø pipe, two-phase fluid is conveyed to the silencers for separation into brine and steam. The brine is contained, collected and conveyed to a nearby holding pond, while the steam is dispersed into the atmosphere.

The test conducted in the Leyte Geothermal Production Field (LGPF) in October 2007, showed favorable results utilizing medium enthalpy (1400-1600 KJ/kg) geothermal Well 403. A succeeding test was conducted utilizing a low enthalpy geothermal production well and a conclusion was drawn that the Vertical Discharge Diffuser is an effective protective measure during production well discharge especially in new and environmentally-critical areas where initial and prolonged vertical discharge of a production well is necessary. Such initiative is geared towards environmental protection for future generations and for sustainable geothermal development.

1.0 INTRODUCTION

As early as 1976 the Philippine government created the Philippine National Oil Company-Energy Development Corporation (PNOC-EDC) to explore and develop indigenous energy resources including geothermal. In three decades, the company was able to contribute more than 60% of the country's indigenous geothermal energy source. Geothermal energy in the country now accounts for about 23% of its total energy requirement. The success of the government in making the Philippines a world leader in geothermal energy development led to a crucial decision of privatizing the company (now called Energy Development Corporation (EDC) in 2007 to further boost geothermal energy.

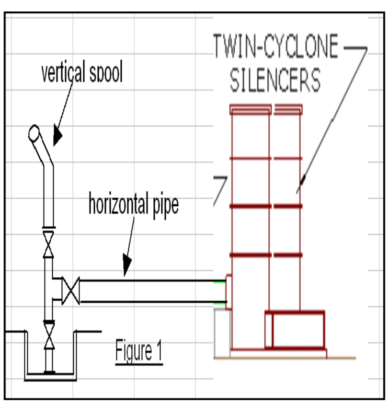
In the Philippines, geothermal production wells produce steam-brine mixture (in some cases with suspended solids), which is predominantly brine. For newly drilled or worked-over production wells, vertical discharge is necessary to clean the well from debris, gases or other unsuitable fluids. The well is allowed to be discharged vertically followed by horizontal discharge through a well silencer. The vertical well discharge into the atmosphere has no suitable control and the current practice is to fully open the valves.

Allowing full bore discharge especially for wells with low enthalpy yielded immense liquid atmospheric spray resulting to defoliation of the surrounding vegetation. Recovery of most trees was observed at least four months after exposure to discharge. To avoid such environmental effect, EDC set a limit for vertical well discharge to only thirty (30) minutes as a matter of policy. However, in some instances, it is necessary to conduct vertical well discharge beyond the thirty (30) minute limit to allow the production well to discharge the cold fluid, build up pressure and stabilize as two phase flow. Shifting from vertical discharge to horizontal discharge is only undertaken when the well becomes stable thus avoiding the costly air/gas compression/lifting procedures. Horizontal discharge for at least one month is conducted to determine sustainability of production and to define well characteristics.

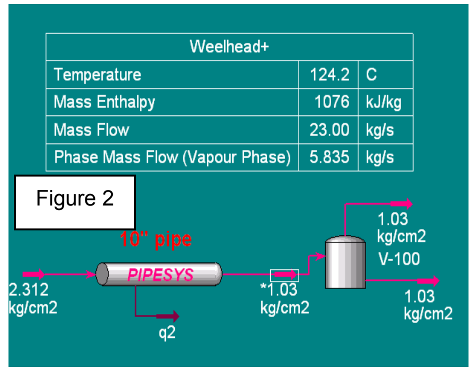
With the planned entry of EDC to the Buffer Zone of the Mt. Kanlaon Natural Park, different departments from the company convened to formulate a mitigating measure with the primary objective of protecting the environment from the adverse impact of brine spray from vertical well discharges, as well as to prolong the duration of vertical discharge. The latter is necessary to allow adequate time to build up the required pressure for newly-drilled low enthalpy geothermal wells or worked-over production wells prior to utilization in the Fluid Collection and Re-injection System (FCRS) for power generation. Being a newly identified environmental measure, a series of field tests were conducted in the Leyte Geothermal Production Field (LGPF) to determine its effectiveness and to allow for design improvements. The project is expected to give benefits to both environmental protection and geothermal steam production.

2.0 DESIGN CONCEPT

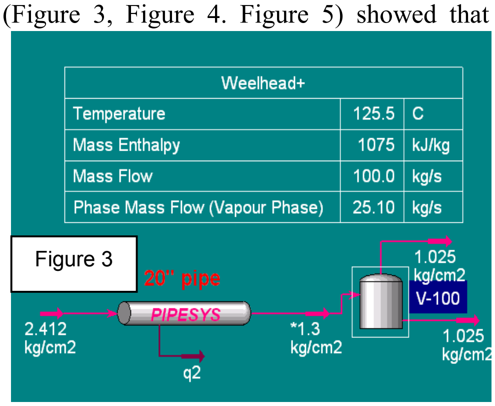
The design concept is a result of re-evaluation of EDC's practice of vertical and horizontal discharge. Figure 1 shows the standard configuration of a geothermal well. From a standard 10”∅ well, vertical discharge is conducted with the use of a 10”∅ pipe extension spool measuring 2 to 3 meters in length. From the well head tee, another horizontal pipe measuring 20m to 40m length is connected towards the atmospheric silencer.



On the concept of attaining the maximum flow at low production well head pressure during the geothermal well discharge, the above ground pipe extension pressure loss was evaluated. The result of the hydraulic simulation using Aspen Hysis software showed that for a typical geothermal production well, the constraint was found on the horizontal discharge piping system (Figure 2). For an assumed well mass flow of 23 kg/s (~2.6 MWe) and a two phase enthalpy of 1076 kJ/kg, the pressure drop along the 10”∅ line is approximately 2.3 kscg. Increase in mass flow would increase the pressure drop thereby increasing the well head pressure of the production well. For a minimum 3 MWe commercial well output, it was concluded that the use of a 10” horizontal pipe is not appropriate due to pressure increase at the well head that may result to the inability of the well to sustain flow during the discharge process. Such inability to sustain discharge is attributed to additional pressure loss on the above-ground piping.



Considering the power potential range of 3 MWe to 10 MWe production well output, several diameters of pipes were considered in the pressure drop calculation targeting the pressure to nearly atmospheric condition at production well head. Pipe sizing was conducted using the AspenHysis software assuming various pipe diameters with a pipe terminal pressure of 1.3 ksc(a), minimum pressure loss at the silencer, mass flow of 100kg/s and a steam flow of 27kg/s. The result of the simulations (Figure 3, Figure 4. Figure 5) showed that minimum pipe pressure loss occurs on the larger diameter pipes. The design of the vertical discharge diffuser (VDD) was essentially based on minimum pressure loss to avoid any increase in production well head pressure during well clearing.



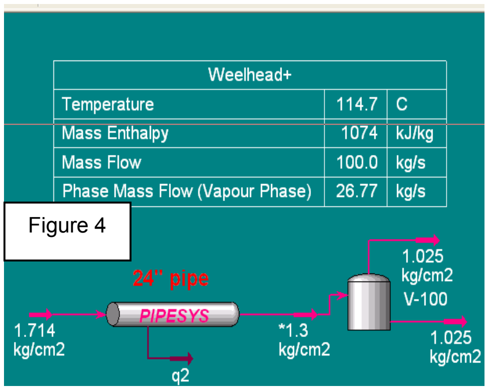


Figure 4

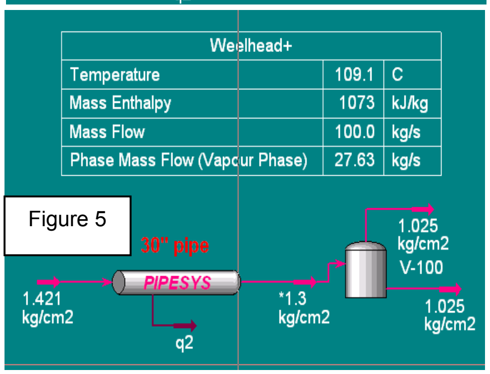
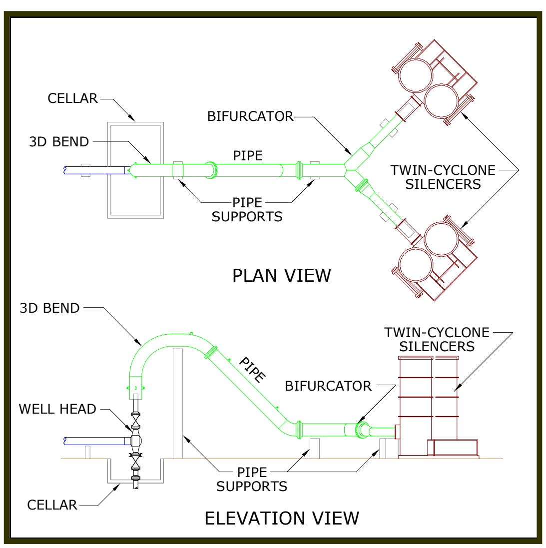


Figure 5

3.0 GENERAL DESIGN CONFIGURATION

The Vertical Discharge Diffuser set-up uses similar materials and equipment as in geothermal installations. The assembly is composed of wrought carbon steel pipes and 3D bend, placed directly above the wellhead, elbows, forged steel flanges, bifurcator; eccentric reducers, two twin-cyclone steel silencers and pipe supports. Two piping systems using 3D bends are designed for self discharging wells and wells that need air compression to discharge steam. For a self discharging well, a 90° angle 3D bend pipe is designed and 45° angle 3D bend for compressed wells. The drawing below illustrates the general configuration of



the VDD assembly.

During well discharge, the two-phase fluid coming from the wellhead is conveyed to the silencers connected at the end. The 3D bend (sweep bend) is used to provide a sweep flow for the two-phase fluid without affecting its properties. Upon reaching the silencers, the two-phase fluid is separated into brine and steam. The brine goes to the silencer tank/outlet and then conveyed to the pad sumps using alvenius pipes or hot water canal. The brine held in pad sumps will then be injected back to the geothermal reservoir through the re-injection well, thus attaining a zero disposal process. The steam, on the other hand, goes out in a vertical direction through the top shell opening of the silencers and will disperse into the atmosphere. In this process, the brine with high concentration of chloride is expected to be contained and thus no immense brine spray occurs.

Thus, the contact of chloride with the surrounding vegetation is prevented, avoiding foliage/plant tissue harm.

Another beneficial use of the VDD is that well testing and drilling can be simultaneously done, which would consequently avoid rig standby time and consequently increase in rig time utilization.

4.0 DESIGN

The assembly was designed considering the maximum power potential of a 10 MWe production well.

4.1 Piping

Stress run analysis was performed considering the 1.30 kg/cm^2 pressure at the end of the pipe system (at inlet of the silencers). Although the system is in atmospheric condition, the designer chose to use Schedule 30 in lieu of the Schedule 20 pipe in consideration of the long term application. The considerations in the design of pipe thickness include extreme conditions where it can be subjected to pipe erosion, geothermal field environment corrosion, and possible pipe dents/damage especially during mobilization.

4.2 Structural

The pipe supports were designed to be stable with a well discharge of 10MWe.

Piping loadings, specifically uplift and thermal forces, are critical factors in the design of pipeline supports for the vertical discharge diffuser. The main concern for the design of structural supports is to resist overturning and uplift forces including displacement during discharge. However, structural supports should be designed as portable and movable supports. The focus here is to design supports subjected to uplift, thermal and pressure loadings by means of providing demountable foundations. Final type and design of pipe supports was generally based on loads obtained from a full three-dimensional pipe stress analysis.

Below are the parameters used in designing the pipe supports.

Dead Loads

Piping
- allow 5% extra on basic weight of steel pipe for reinforcing, plates, insulation, etc.
- additional allowances required for valves and major equipment.

Fluid Loads
- density of hot brine 900kN/m³
- 2 phase lines 100% filled (for gravity load combinations)

Concrete
- normally reinforced 24kN/m³
- mass concrete 23kN/m³

Structural Steel 77kN/m³

Family Name:

Given Name(s):

Affiliation:
office address:
office phone number:
office fax number:

Home address:
home phone number:
mobile phone number:

E-mail address:

Passport Number:
good until: (yyyy.mm.dd)
issued by: (country name)
Mr./Ms.

Live Loads

Live loads were not considered

Thermal Expansion and Friction Loads (T)

Coefficient of friction for sliding supports was taken as 0.3.

Wind Loads (W)

Wind loads will not normally be critical for design of pipe supports.

Seismic Loads (E)

Horizontal seismic design acceleration of 0.25g was considered.

Pipe spans were limited so as to keep period of vibration of pipelines less than or equal to 0.1 seconds.

5.0 TEST WELL

To prove the efficiency of the VDD assembly, an actual field test was performed on October 26, 2007**,** utilizing Well 403 of Leyte Geothermal Production Field (LGPF).

Well 403 was spudded last April 4, 1980 and completed on July 11, 1980 with a top elevation of 812.40 masl and a total depth of 2,464.90m. Discharge test data on conducted last January 16, 2008 has the following results:

WHP (MPag)	**MassFlow** (kg/s)	**Enthalpy** (kJ/kg)	**Remarks**
0.5	21.74	1,589	full-bore discharge
2.0	14.68	1,255	side-valve with B2 back-pressure plate (~2.31"Ø opening)

With the continuing testing of Well 403 discharge data last of February 7, 2008 showed the following:

WHP (MPag)	**MassFlow** (kg/s)	**Enthalpy** (kJ/kg)	**Remarks**
1.5	24.10	1,444	(A2~3.42"Ø)

With the above discharge data, Well 403 has a power potential of 3.5 MWe.

6.0 VDD INITIAL TESTING & RESULTS

6.1 Test Procedure

6.1.1 Environmental monitoring was carried out to determine the extent of brine spray during testing of the VDD:

1. Note the environmental conditions before, during and after, to include as follows:
   a. Temperature
   b. Relative humidity
   c. Wind speed and direction
   d. H_2S at different locations (radiating distance from the silencers
2. Collect samples for monitoring of volume, pH, B and Cl

6.1.3 Water carryover monitoring

a. Distribute papers (beakers) at 3m, 6m & 10m from the center of the 2 silencers (at line & arc of the different locations: 1Q1..1Q8, 2Q1..2Q8, 3Q1..3Q8)
b. Collect papers/beakers at 30m, 1Hr, 2Hr from full bore opening of well and determine volume/content (if beakers are used)
c. Analyze samples collected for pH, Boron, Chloride, after measuring volume

6.1.4 Plant sensitivity to geothermal fluids

a. Select 2 types of seedlings (sensitive and non-sensitive) and distribute seedlings at different locations (1Q1..1Q8, 2Q1..2Q8, 3Q1.. 3Q8) but at the center of the line & arc retrieve seedlings after 30min, 1hr and 2hrs interval from full bore opening of well.
b. Observe seedlings for at least 1month from VDD testing.

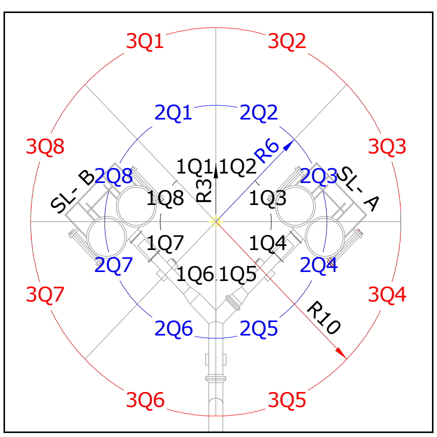
6.2 Test Results

6.2.1 Condition Control

Temperature= 24.3°C ~ 25.0°C
Temperature= 24.3°C ~ 25.0°C
Relative humidity= 95%
Wind direction= North-East

6.2.2 Relative Locations of Beakers

Beakers were installed at locations of 3m, 6m and 10m radii; refer to Drawing 2, from the center of the two twin-cyclone silencers. Each radius was divided into eight divisions, 1q1..1q8, 2q1..2q8 and 3q1..3q8.



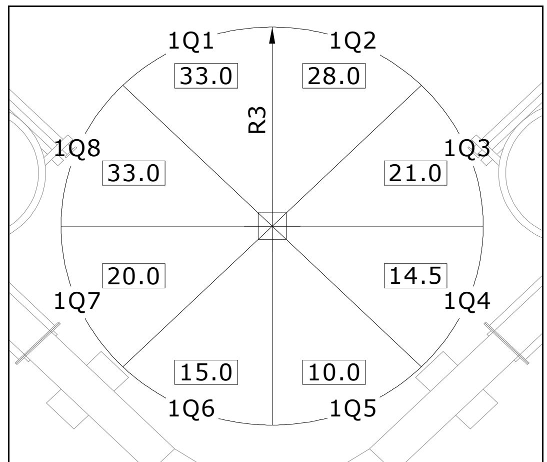
Drawing 2. Relative locations of beakers

6.2.3 Water Carryover Collected

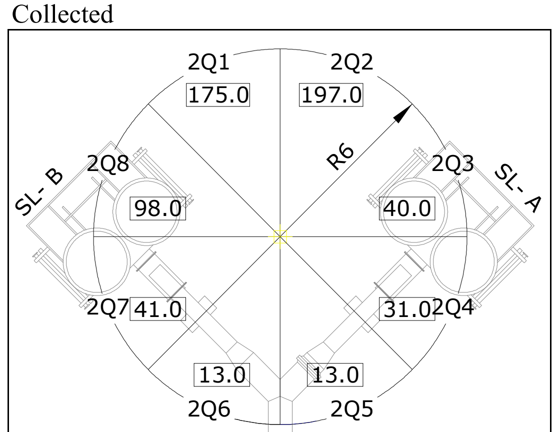
The following table and drawings show the amount of brine collected during testing of the VDD on the different beaker locations.

Beaker Location	Volume (mL)	Beaker Location	Volume (mL)	Beaker Location	Volume (mL)
1Q1	33.00	2Q1	175.00	3Q1	166.50
1Q2	28.00	2Q2	97.00	3Q2	78.00
1Q3	21.00	2Q3	40.00	3Q3	32.00
1Q4	14.50	2Q4	31.00	3Q4	67.50
1Q5	10.00	2Q5	13.00	3Q5	0.00
1Q6	15.00	2Q6	13.00	3Q6	0.00
1Q7	20.00	2Q7	41.00	3Q7	27.00
1Q8	33.00	2Q8	98.00	3Q8	145.00

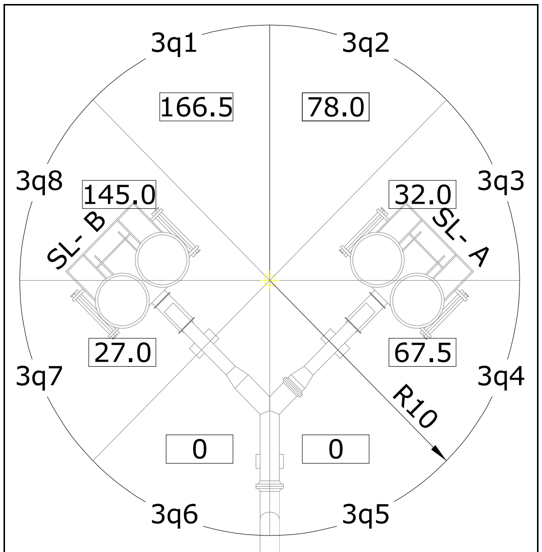
Table 1. Amount of collected brine



Drawing 1. 1ST Layer of Water Carry Over Collected



Drawing 2. 2nd Layer of Water Carry Over Collected



Drawing 3. 3rd Layer of Water Carry Over Collected

Aside from the above locations, beakers were placed along the direction of the wind (NE) about 20m, 30m and 52m away from the silencers. The result was a remarkable decline in the amount of brine collected. Refer to Table 2 below for thecollected data.

Table 2. Extend of brine spray during VDD testing

Location	Vol. of Carry Over Collected, mL
20mNE	1.3
20mNE	0.7
20m NE	0.2
30mNE	0.7
30mNE	0.1
30mNE	0.1
Pad entrance	0.3
52mN20E	1.3
52mNE	0.3
52mNE	0.2
52N50E	0.1

6.2.3 Plant Monitoring

Prior to testing of the VDD, various test plant seedlings were located in the vicinity of the silencers, ranging from 25m to 70m. The seedlings were Dao, Hagakhak, Kalantas, Almaciga, Red lauan, Golden shower, Fire tree, Mahogany, Tindalo and Nato. Table 3 shows the effect of brine spray to test plant seedlings

Table 3. Effect of brine spray to test plant

Plant Seedlings Monitoring

Location	Distance	Plant Seedling	Remarks
N78	25m	dao hagakhak	defoliate brownish
N75E N75E N75E	50m 30m 50m	kalantas kalantas almaciga	defoliate defoliate unaffected
N60E	15m	red lauan	tip of leaf become brownish
N50E	30m	golden shower	leaf becomes yellowish but did not defoliate
N60E	30m	firetree	defoliate
S50E	70m	mahogany firetree tindalo almaciga	no effect no effect no effect no effect
1Q1-1Q8	30min	Nato Dao Red Lauan Kalantas Almaciga Goden Shower	tip of leaf brownish defoliate tip of leaf brownish defoliate no effect no effect
2Q1-2Q8	1hr	Nato Dao Red Lauan Kalantas Almaciga Goden Shower	tip of leaf brownish defoliate tip of leaf brownish defoliate slightly affected leaf margin brownish
3Q1-3Q8	2hr	Nato Dao Red Lauan Kalantas Almaciga Goden Shower	tip of leaf brownish defoliate tip of leaf brownish defoliate slightly affected black spot

Wind direction: NE

6.2.4 Twin-Cyclone Silencers

Two types of twin-cyclone silencers were used; circular baffle type (B) and spiral baffle type (A). This was done to determine which of the two types will serve better on the separation of the two-phase fluid.

On the performance of the silencers during the discharge test, the circular baffle type silencer was observed to produce brine water carry over reaching 60 meters towards downwind direction. The spiral baffle type silencer was observed to be efficient in separating brine from steam as there was no observed brine spray. The difference on separation efficiency is found to be influenced by the design of baffle installed inside the tangential section of the silencer stock. It was observed the spiral formation baffle is more efficient as compared to circular baffle.

7.0 OBSERVATIONS AND CONCLUSION

The temperature of the water carry over ranged from 24 to 25C vs the ambient temperature of 23.4C.

More fluids were carried-over at Silencer B than Silencer A.

Negligible water carry over already observed after 30m from silencer location even at Silencer B.

It was made possible to conduct a continuous vertical discharge 2¾hrs.

Brine spray impact on test plant seedlings was limited to 30 meters from the silencer, exposed for a period of 2 hours and 45min.

The affected plants were able to recover from defoliation three weeks after exposure to brine spray.

Based on the testing of well 403 and the recent testing of a low enthalpy (1100-1300 KJ/kg) production well at the Mahanagdong sector of LGPF, a conclusion was drawn that a Vertical Discharge Diffuser is an effective protective measure during prolonged production well discharge especially in environmentally-critical areas. The impact of the discharge is minimal compared to the traditional vertical discharge testing where brine spray could reach up to 100 meters from the well.

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