GEOTHERMAL CYCLONE SEPARATOR PRESSURE LOSSES AT THE WAIRAKEI WEBER SEPARATORS, NEW ZEALAND

Michael **T.** Burgos

PNOC Energy Development Corporation, Merritt Road, Fort Bonifacio, Makati City **1201,** Philippines

ABSTRACT

This report is about geothermal cyclone separator pressure losses and existing empirical equations developed for cyclone separators. An attempt was also made to determine the pressure loss coefficient for the Wairakei Weber separators.

Pressure measurements were conducted in the Wairakei geothermal field using a Keller digital pressure gauge. The existing two-phase and steam line Bourdon pressure gauges were removed and replaced with the digital gauge. The measured pressure drops ranged from 0.194 to 0.528 bars for the six types (according to dimensions) of separators considered.

High steam superficial inlet velocity gives high separator pressure drop. However, pressure drop is also associated with separator design and geometry. For example, steam superficial inlet velocity varies with the inlet pipe size top steam or bottom steam outlet. The six separators tested have a pressure coefficient, K ranging 14 to 30 that is comparable with Shepherd and Lapple correlation, which ranges from 13 to 28.

1.0 INTRODUCTION

This report is about geothermal separator pressure losses, particularly on the 30" diameter and **42"** diameter bottom steam outlet cyclone separators at Wairakei. The most important consideration in the operation of a geothermal separator is low-pressure drop and high separation efficiency (Fassani et al, **1999** and De et al, **1999).** No accepted single equation has been developed for the prediction of separator pressure drop operating in geothermal steam and water. This remains a challenge to the geothermal industry. Initial study in this report showed that Shepherd and Lapple **(1940)** correlation gives close prediction for geothermal separator pressure drop but additional data are needed to prove the reliability of the equation. The same equation was used also by Lazalde-Crabtree **(1984)** in predicting separators operating in water and steam.

Experiments on separators operating with air summarized by Ogawa **(1982)** showed that pressure drop was dependent on the separator geometry and was a strong function of the inlet gas velocity and its density. Similar results were also obtained by Chmielniak and Bryezkowski **(1994)** and White **(1983)** when they derived the pressure losses in swirling and Wairakei Weber separators, respectively.

Pressure drop measurements on the 30" diameter and **42"** diameter Wairakei Weber cyclone separators gave a range of **0.194** to **0.528** bars. There were six types of separators included in the measurements.

2.0 FIELD PROCEDURES

1. Close the upstream and downstream isolation valves for the two-phase pressure gauge. Double isolation is for safety reasons.
2. Remove the two-phase pressure gauge.
3. Open the isolation valves to allow minimum flow. This is to check for blockages.
4. Close both valves to facilitate installation of the digital pressure gauge.
5. Fill the lines from the tapping points to the gauge with clean cold water to protect the sensing element of the gauge.
6. Install and switch on the digital gauge.

7. Slowly open the isolation valves to avoid pressure shock to the gauge.

8. Record several gauge readings.

9. After getting the readings isolate the line, remove the Keller gauge and return the existing Bourdon pressure gauge.

10. Repeat steps 1 to 9 for the steam line.

3.0 DATA AND RESULTS

Please see below reference section.

4.0 DISCUSSIONS

The pressure drop measurements in Table 1 were corrected by deducting the two-phase and steam line pressure drops along the lines since the pressure gauges were located approximately 6 m and 0.5 m from the separator, respectively. The corrected pressure drop ranges from 0.069 to 1.483 bar (Table 3) Eight types of separator (Table 2A and B) were considered but unfortunately, only one set of data was available for each type except for Type 1.

Of the twelve sets of data gathered, only separators WK101, WK67 and WK70 gave high pressure drops (1.058, 1.368 and 1.483 bars respectively). These separators were suspected to have steam line blockage due to silica

Table 1. Pressure drop data

Separator Number	Type	P1[1] Barg	P2[2] Barg	ΔPm[3] Bar	H[4] kJ/kg	Mt[5] kg/s
WK70	1	6.535	5.050	1.485	907.19	42.19
WK67	1	6.613	5.240	1.373	1016.36	44.68
WK101	1	5.932	4.873	1.059	957.00	23.85
WK30	1	5.779	5.291	0.488	980.00	57.74
WK28	1	5.575	5.380	0.195	1050.13	20.27
WK24	2	5.390	4.860	0.530	973.86	32.69
WK26A	3	4.820	4.451	0.369	946.11	47.03
WK108	4	5.024	4.750	0.274	1030.00	60.36
WK71	5	4.913	4.677	0.236	975.34	54.84
WK107	6	4.955	4.736	0.219	1123.14	21.73
WK76	7	4.901	4.782	0.119	931.51	56.28
WK116	8	5.269	5.197	0.072	1009.23	47.70

[1]P1 - Pressure at the two phase line
[2]P2 - Pressure at the steam line
[3]ΔPm - Measured Pressure drop
[4]H - . Enthalpy at wellhead
[5]Mt - Two phase mass flow

Table 2a. Wairakei separators
(all dimensions in inches)

Well No.	Sep. Type	Inlet of Vessel		Steam Outlet	
		Size	Type	Size	Loc.
WK70	1	10	Spiral	8	Bottom
WK67	1	10	Spiral	8	Bottom
WK101	1	10	Spiral	8	Bottom
WK30	1	10	Spiral	8	Bottom
WK28	1	10	Spiral	8	Bottom
WK24	2	8	Tangential	8	Top
WK26A	3	12	Spiral	12	Bottom
WK108	4	14	Spiral	12	Bottom
WK71	5	10	Spiral	10	Bottom
WK107	6	12	Spiral	8	Bottom
WK76	7	16	Spiral	12	Bottom
WK116	8	8	Spiral	12	Bottom

Table 2b. Wairakei separators
(all dimensions in inches)

Well No.	Sep. Type	Vessel		Water Outlet	
		Dia.	Height	Size	Location
WK70	1	30	122	10	Side
WK67	1	30	126	10	Side
WK101	1	30	115	10	Side
WK30	1	30	130	10	Side
WK28	1	30	128	10	Side
WK24	2	30	100	6	Side
WK26A	3	42	148	14	Side
WK108	4	42	146	14	Side
WK71	5	42	140	12	Side
WK107	6	30	107	10	Side
WK76	7	42	158	12	Side
WK116	8	42	174	12	Side

Table 3. Corrected pressure drops

Separator No.	Type	P1 Barg	P2 Barg	ΔP M Bar	ΔP TP[1] Bar	ΔP STL[2] Bar	ΔP Sep.[3] Bar
WK70	1	6.535	5.050	1.485	0.0012	0.0006	1.4831
WK67	1	6.613	5.240	1.373	0.0027	0.0017	1.3686
WK101	1	5.932	4.873	1.059	0.0006	0.0004	1.0580
WK30	1	5.779	5.291	0.488	0.0035	0.0004	0.4841
WK28	1	5.575	5.380	0.195	0.0007	0.0006	0.1938
WK24	2	5.390	4.860	0.530	0.0013	0.0010	0.5278
WK26A	3	4.820	4.451	0.369	0.0003	0.0020	0.3667
WK108	4	5.024	4.750	0.274	0.0008	0.0052	0.2680
WK71	5	4.913	4.677	0.236	0.0012	0.0032	0.2316
WK107	6	4.955	4.736	0.219	0.0013	0.0011	0.2166
WK76	7	4.901	4.782	0.119	0.0004	0.0025	0.1161
WK116	8	5.269	5.197	0.072	0.0004	0.0027	0.0689

depositions. Such blockage was already experienced in WK30 in 1986 (Lew Bacon, pers. comm.). Figure 1 shows the silica deposition inside WK30 separator steam line. The low pressure drop readings of separators WK76 and WK116 could be due to blockages in the pressure tapping points. Blockages in separators WK83, WK110 and WK216 were also experienced so the readings were rejected, as the pressure readings in the wellhead and steam lines were inconsistent. WK71 was also not considered since its calculated velocity was far beyond 40 m/s, which is the ideal inlet design velocity for geothemal separators. Velocities of WK116 and WK71 were also out of range. These could be errors in the measurements. Table 4 shows the summarized model data.

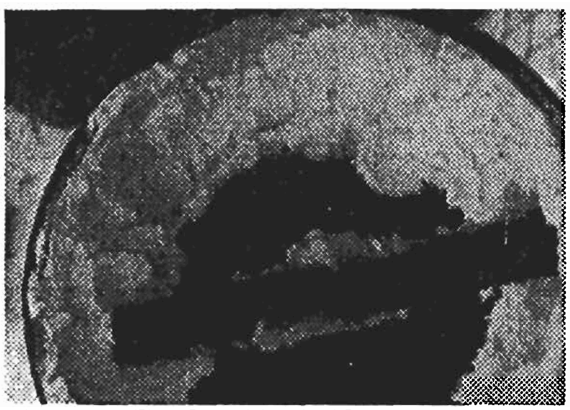

Figure 1. Silica deposition inside of WK30 separator steam line (1986) (Courtesy of Mr. Lew Bacon, Wairakei Power Station)

Table 4. Model data

Well No.	Type	Bars	Inlet Dia. in	'Vel. m/s	Mt kg/s	[2]MS kg/s	Dryness
WK24	2	0.528	8	42.51	32.69	4.61	0.141
WK30	1	0.484	10	44.87	57.74	8.05	0.139
WK26A	3	0.367	12	28.20	47.03	6.32	0.134
WK108	4	0.268	14	32.93	60.36	10.40	0.172
WK107	6	0.217	12	22.81	21.73	4.73	0.217
WK28	1	0.194	10	20.45	20.27	3.56	0.175

[1]MS - Mass of Steam
[2]Vel. - Steam Superficial Inlet Velocity

Figure 2 shows the plot of measured pressure drop against steam Superficial inlet velocity. The measured pressure drop (ΔP) and steam superficial velocity (Vsg) when piotted gives the equation in the form as $AP = 0.88003\ Vsg^2 + 0.00094Vsg$. This represents the relationship of pressure drop and steam superficial inlet velocity. The equation was generated using only the values in Table 4 because of the reasons mentioned above. WK24 was also not considered since it was tangential inlet and top steam outlet. The other separators have spiral inlet and bottom steam outlet.

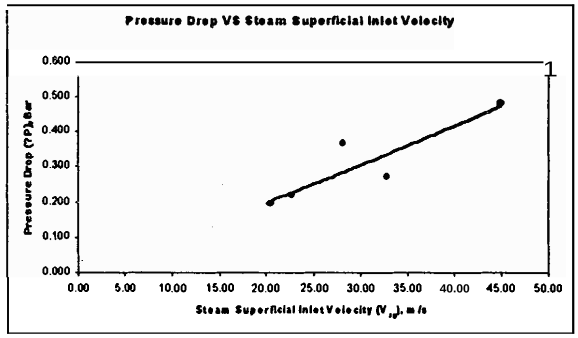

Figure 2. Pressure drop vs. steam superficial inlet velocity

High steam superficial velocity gives high pressure drops and correspondingly low steam superficial velocity gives low pressure drops. This can be associated with the geometry and design of the separator vessel for the reason that the inlet velocity varies with the inlet pipe size. It should be possible to predict separator vessel pressure drop using steam superficial inlet velocity.

The separators with large inlet diameters generally give low pressure drops (Table 4). No trending and relationship can be observed in the pressure drop and steam inlet dryness.

4.1 Pressure Coefficient K for Experiment

Plotting the measured pressure drop result against $\rho V^2/2$ will give a slope representing the frictional coefficient K. This gives the value of K as 20 for Type 1, 17 for Type 2, SO for Type 3, 16 for Type 4, 26 for Type 6. Generally, the average pressure coefficient of all the separators tested is 16.5. Figure 3 shows the plot of the measured pressure drops against $\rho V^2/2$.

Table 5 shows the summary of the values of pressure coefficient K, measured pressure drop and predicted pressure drop from the existing correlations.

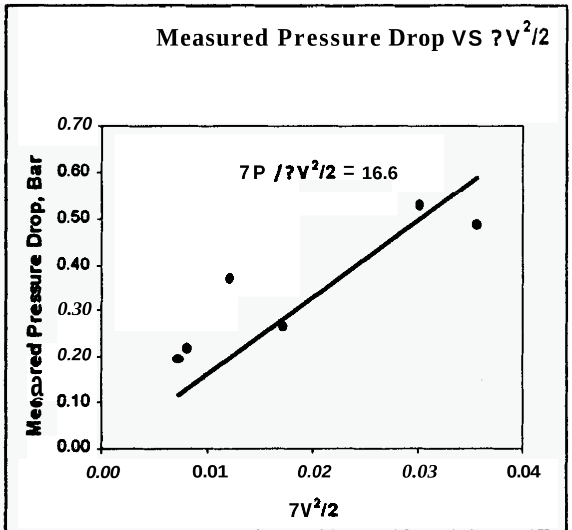

Figure 3. Measured pressure drop vs, $\rho V^2/2$

Table **5.** Pressure coefficients K and pressure drop (bars)

Correlation	K	Predicted	Measured
Linden	17-38	0.191-0.941	0.194-0.528
Lapple	14-23	0.162-0.805	0.194-0.528
Shepherd and Lapple	13-28	0.141-0.700	0.194-0.528
First	6 14	0.075-0.311	0.194-0.528
Alexander	18-40	0.203-1.006	0.194-0.528
Stairmand	7-16	0.073-0.363	0.194-0.528
Casal and Martinez	4-5	0.092-0.144	0.194-0.528
Experiment	14-30	0.194-0.528	0.194-0.528

Shepherd and Lapple correlation gives the closest range of frictional coefficient K (13-28) compared to the measure K (14-30). The same equations were used by Lazalde-Crabtee (1984), Ludwig and Koch (1977) and Lawrence, (1952) for estimating pressure drop.

Figure 4 shows the plot of the measured pressure drop and calculated pressure drop against steam superficial inlet velocity using Shepherd and Lapple correlation. Separators WK108 and WK107 measured pressure drops were close to the calculated results from the Shepherd and Lapple Correlation.

4.2 Problems Encountered

It took 45 to 60 minutes to make measurements for one separator. The following problems were encountered during the measurements:

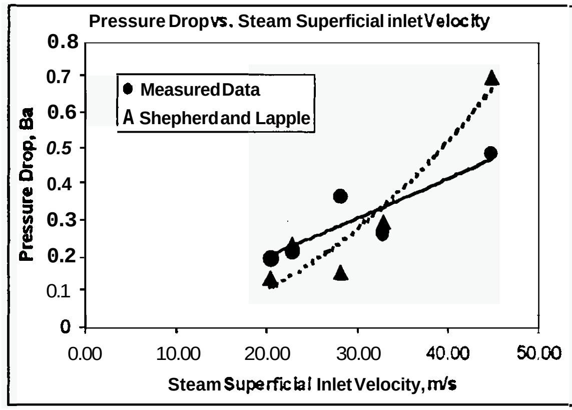

Figure 4. Measured and calculated pressure drop vs. steam superficial velocity

- Rusted tapping points – Fittings cannot be installed because of corroded pipe threads. They were rethreading before the fittings were installed.
- Rusted valves – They were hard to open or shut after they had not been used for a long time.
- Clogged up tapping lines – Clogged up lines could riot be detected visually but some could be purged by the line pressure.
- Limited Access – Some pressure gauges and tapping points were installed very close to the separator vessel and were hard to remove and reinstall.

5.0 CONCLUSIONS

The measured pressure drops for the Wairakei Weber separators ranged from 0.194 to 0.528 bars. The six types separators being tested have an average pressure coefficient K of 16.5. The correlation of Shepherd and Lapple (1940) gives pressure coefficient K from 13 to 28, which is nearest to the calculated pressure coefficient K from 14 to 30 from the measured data. Lazalde-Crabtee (1984) uses the same equation in the prediction of pressure drop for separator operating in water and steam.

High steam superficial inlet velocity gives high pressure drop. This can be associated with the geometry and design of the separator vessel for the reason that steam superficial inlet velocity varies with the inlet pipe size of the separator. No relationship can be observed from the pressure drop and steam inlet dryness.

6.0 RECOMMENDATIONS

- Additional data gathering is needed to have enough range of frictional coefficient K values for the Wairakei type of separators.
- The test rig and pressure tapping points should be internally inspected prior to any experiment or data measurements. This ensures that the lines are free from any blockages that will give non-representative pressure readings.

7.0 REFERENCES

Bangma, P. **(1961).** The development and performance of a steam-water separator for use in geothermal bores. Proc. United Nation Conference on New Energy, Rome.

Chmielniak, T and Bryezkowski, A. **(1999).** Method of calculation of new cyclone type separator with swirling baffle and bottom take off of clean gas - Part 1: Theoretical chemical engineering and processing **441 (20000), pp.441-448.**

De, S. et al **(1999).** An experimental investigation on pressure drop and collection efficiency of simple plate-type impact separator. power technology, **106,** pp 192-1**98.**

Fassani, L.F. and Leonardo, G. **(1999).** A study of the effect of high inlet solids loading on a cyclone separator pressure drop and collection efficiency. Power Technology, vol. **107,** pp. **60-65.**

Freeston, D.H., Lee, K.C., and Hole, H. **(1983).** Utilization of geothermal energy - Two phase studies. NZERDC Report **95,** September.

Lazalde-Crabtee, H. **(1984).** Design approach of steam water separator and steam dryers for geothermal application, Geothermal Resources Council Bulletin, pp. **11-20.**

Lee, K.C. **(2000).** Diploma course lecture notes 2000. Geothermal Production Engineering, The University of Auckland, New Zealand.

Lee, K.C. et al. **(1997).** Long geothermal steam transmission pipelines. Proceedings IPENZ Annual Conference, Wellington, New Zealand, **Vol 2,** pp. **258-262.**

Ogawa, A. **(1982).** Separation of particles form air and gases, **Vol. II.** Ed. Beddow, J.K., CRC Press, Inc., Boca Raton, Florida. Pp. **16-21.**

Rogers, G.F.C. and Mayhew, Y.R. **(1997).** Thermodynamic and transport properties of fluids. Blackwell, Oxford UK and Cambridge USA.

Shepherd, C.B. and Lapple, C.E. **(1939).** Flow pattern and pressure drop in dust collectors. Ind. and Eng. Chem., **31, 972-984** and **32, 1246-1247.**

Stairmand, C.J. **(1949).** Pressure drop in cyclone separators. Engineering **168,** pp. **409-412.**

Stairmand, C.J. **(1955).** The design and performance of cyclone separators. Trans. Instn. Chem. Engrs., **29,1951, 356-383.**

Webre, A.L. and Robinson, C.S. **(1926)** Evaporation. Chemical Catalog Company, New York, N.Y. pp. **476.**

White, B.R. **(1983).** The performance of the bottom outlet cyclone separators (Wairakei-Type). Project Report of Geothermal Institute, University of Auckland, New Zealand, no. **83.27.**