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Application of Modified Isochronal Test to Determine Output Curve of Wells at Kamojang Geothermal Field-West Java

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ABSTRACT

Attempts were made at Kamojang Geothermal field, West Java, to apply Modified Isochronal Test to determine output curve from production test of KMJ-73 and KMJ-74 wells. In the past, wells at the Kamojang Geothermal field were tested using Back Pressure Method. The results of the test were satisfactory. However, the test was time consuming. Three months were spent testing a single well. The disadvantages of this test are high cost and delayed revenue gained from the wells.

The result of the modified isochronal test has a good agreement with those obtained from back pressure test. The main advantage of modified isochronal test is duration of the test. Completion of modified isochronal test takes only 10 days. However, before it becomes an alternative method for testing dry steam wells, validation of this method is needed by applying it to other wells.

1. INTRODUCTION

1.1 Field Overview

The Kamojang geothermal steam field is one of the world's few developed dry steam reservoirs, located in an area of high elevation of 1500 masl, 40 km south east of Bandung, Indonesia.

Since 1982, the field, which is operated by PERTAMINA-a state oil and gas company, has been producing steam to supply PLN's 140 MW.

An exploration was started under New Zealand government, and continued until 1974–1975 when five exploration wells were drilled down to 700 m throughout the Kamojang Area.

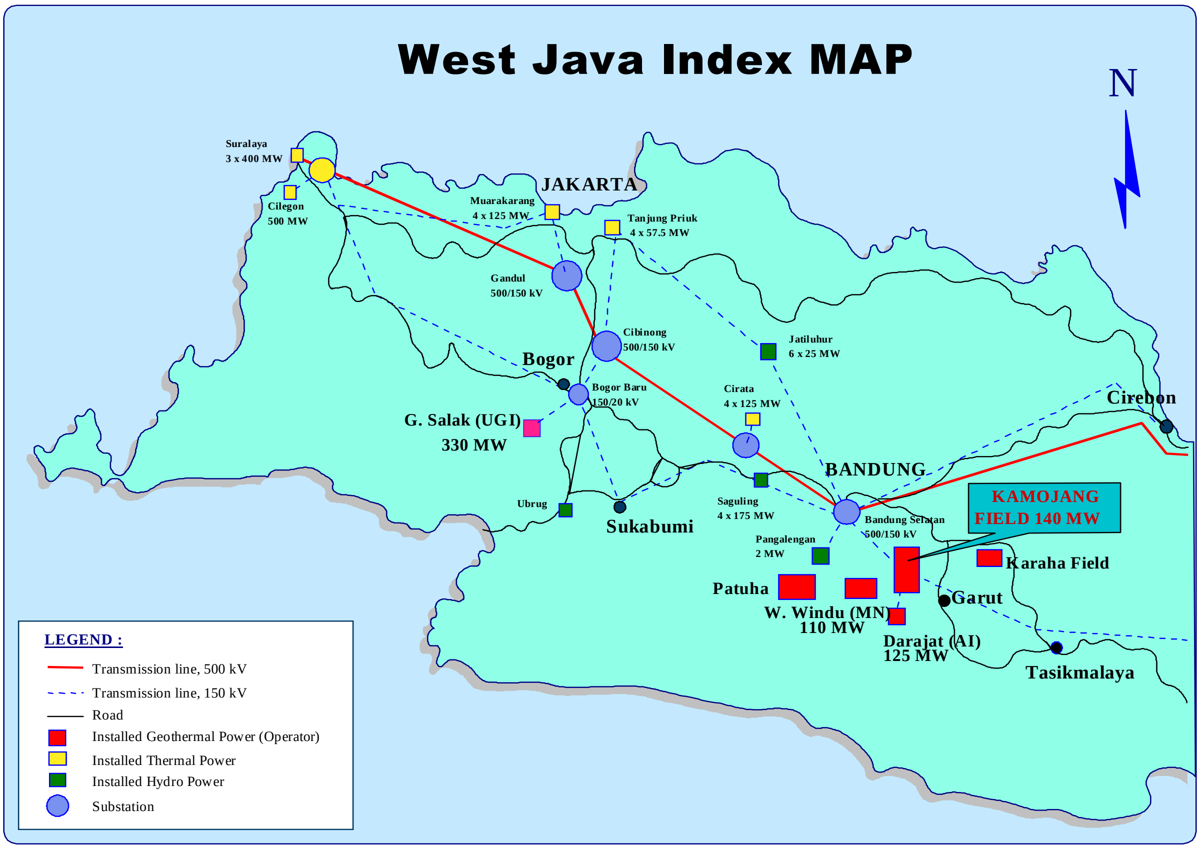

Figure 1: Location map of Kamojang, West Java Indonesia.

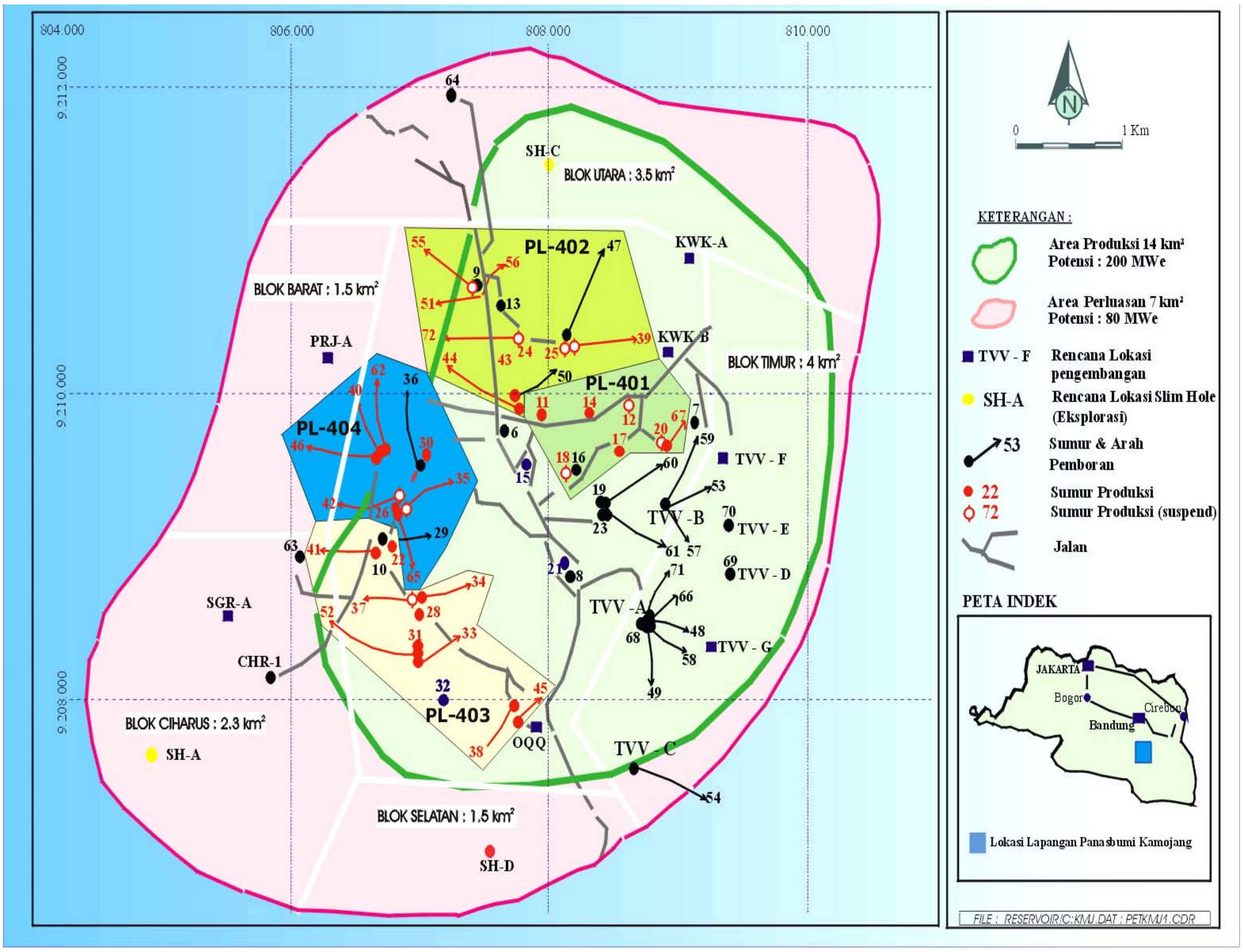

Figure 2: Map of Kamojang field showing boundary of prospect, well bores and development of east sector.

Pertamina continued from 1975 and developed the first geothermal field with the initial state development producing 30 Mwe of utilizing steams from 6 wells.

Commercial operations in Kamojang field started to peak in 1987 from 30 Mwe to about 140 Mwe capacity supplied by 26 wells. To date, 75 wells are drilled in the Kamojang geothermal field within an area of 14 km2 (fig.2). The additional 60 MW power plant is scheduled to start commercial operation in 2005.

1.2 Deliverability Test in Kamojang Field

Deliverability of wells in Kamojang geothermal area is determined using Back Pressure Test, which requires about 50-60 days for completion. The results are high cost/expense, big amount of steam loss and also big opportunity loss. Considering these 3 negative factors, an attempt was made to apply Modified Isochronal Test which is expected to reduce the negative impacts of Back Pressure Test. Starting on 21 September 2001, modified Isochronal Test was applied to new KMJ-73 and of KMJ-74 wells.

2. BASIC THEORY

Production test, which is done in geothermal wells, is a continuos part of field management activity, especially aimed to well deliverability. There are 2 types of tests which are normally conducted as the part of the production test:

1. Vertical Discharge Test

The test which is done soon after heating up finishes. The goals of this test are:

- To clean well hole from dirt resulted from drilling activity e.g. drilling mud and cutting
- To know vapour characteristics
- To estimate well potential (production rate). The estimate of well potential is required to designate orifice and pipe diameter on horizontal discharge test.

2. Horizontal Discharge Test

The test is a further activity of vertical discharge test. The goals are:

- To get more accurate flow rate data for constructing well output (deliverability)
- To find out the details of gas content and gas composition in vapour

As mentioned above, one of the objectives from horizontal discharge test is to determine well deliverability. In general, there are two kinds of deliverability: downhole deliverability and wellhead deliverability. Deliverability tests are made on dry steam wells through the use of the following empirical formula:

$$q = C(P_r^{\ 2} - P_{wf}^2)^n \quad (1)$$

Referring to Sabet (1991), when *n*=0.5, non Darcy flow condition is dominant; and when *n*=1, Darcy flow condition is dominant.

Deliverability at the wellhead could be estimated by measuring the stabilized wellhead pressure, *WHP*, for each flow rate. A deliverability plot is then made and presented according to Equation 1 in much the same way as the downhole deliverability is presented. In wells producing dry steam, term q can be replaced by mass rate (*M*) as follows

$$M = C(P_r^{\ 2} - WHP^2)^n \quad (2)$$

By producing the well at different flow rates while measuring *WHP* and by plotting M versus (P_r^2-WHP^2) on log-log scale, we can get straight line of slope n. The constant, *C*, can then be found from Equation 2.

Basically, there are 3 tests which can be conducted to obtain the above deliverability plot:

- Backpressure
- Isochronal
- Modified Isochronal

2.1 Back Pressure Test

Principle of the test is to give different back pressures. The test is started by closing the well to attain a stable reservoir pressure. After that, the well is flowed for different flow rates until a stable wellhead pressure is attained and (P_r^2-WHP^2) is plotted versus *M* on log-log scale.

2.2 Isochronal Test

The well is closed following each flow period until a stable pressure is attained (P_r) and (P_r^2-WHP^2, which then is plotted versus *M* on log-log scale. Assumption of this test is that effective radius of investigation of a given test is independent of flow rate, *M*. The resulting log-log plot is the transient deliverability. To obtain the semi steady state deliverability, the well is produced at a constant flow rate for an extended period of time and then shut in. Diagram of pressure and flow rate from modified isochronal test can be seen on Figure 3.

2.3 Modified Isochronal

Difference between this method and isochronal test is the well is closed following each flow period for a preset length of time. For the first flow period, P_i^2 is used in place of P_r^2 but for the second flow period the final shut in pressure of the first build up (P^2) is substituted for P_r^2. Diagram of pressure and flow rate from modified isochronal test can be seen on Figure 4.

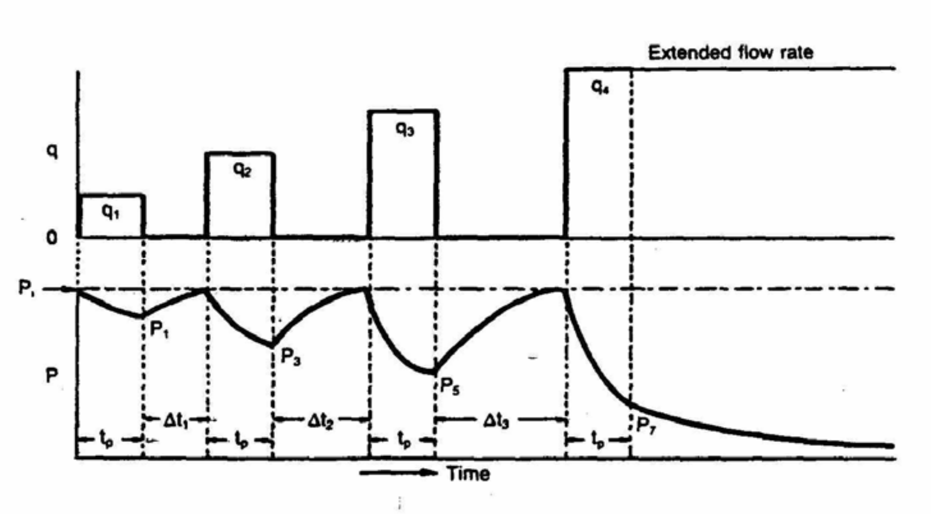

Figure 3: Diagram of pressure and flow rate from isochronal test.1

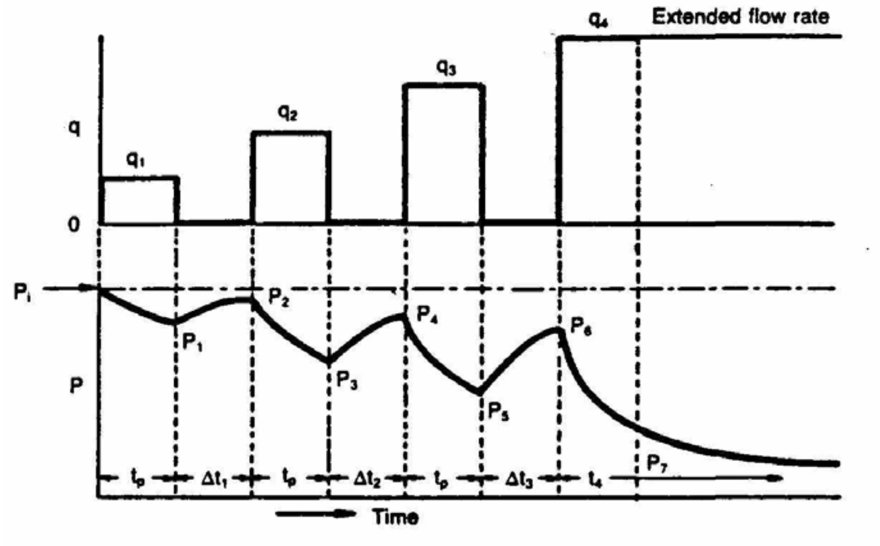

Figure 4: Diagram of pressure and flow rate from modified isochronal test.1

3. FIELD TEST RESULTS

First, the back pressure test was performed on both KMJ-73 and KMJ-74. The objective of the test was to obtain data to which the results of modified isochronal test for both wells will be compared. After the back pressure test was completed, the modified isochoronal test was conducted by first shutting the wells until they reached their stable pressures.

3.1 Back PressureTest

By following the procedure of back pressure test, described in Section 2, the results of field test are presented below. The stable pressures (P_r) were reached at 28.38 ksc and 27.39 ksc for KMJ-73 and KMJ-74 wells respectively before wells were produced. The back pressure test was started from high flow rate to low flow rate and back to high flow rate to find out whether there were any hysterisis.

Table 1: Back Pressure Test of Well KMJ-73

WHP, ksc	M, tonnes/hour
11.7	59.72
12.6	56.55
15.5	50.43
17.7	45.11
20	37.51
17.5	45.83
15.5	48.80
14.4	52.40
12.5	56.60
11.5	58.63

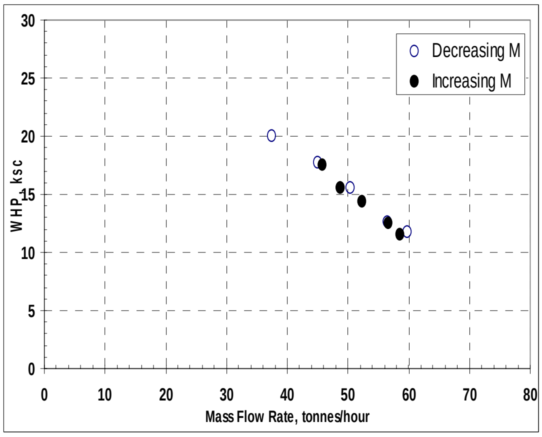

Figure 5: Back Pressure of Well KMJ-73

Table 2: Back Pressure Test of Well KMJ-74

WHP, ksc	M, tonnes/hour
11.2	41.43
12.6	40.22
15.4	36.75
17.9	34.42
20	29.3
16	35.57
14.9	38.76
12.5	42.19
11.9	42.09

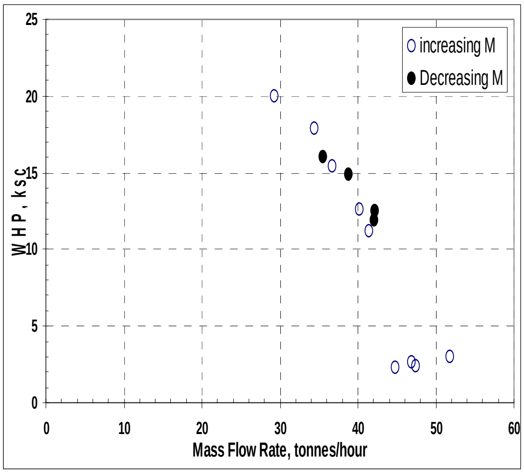

Figure 6: Back Pressure of Well KMJ-74

Table 3: Mod. Isochronal Test of Well KMJ-73

Well Status	WHP (ksc)	M (tonnes/hour)
Initial	28.38	0
Flowing	21.5	36.44
Shut In	27.5	0
Flowing	20	42.56
Shut In	28.1	0
Flowing	17.5	50.4
Shut In	27	0
Flowing	15	57.12
Shut In	27.3	0
Extended Flow	14	53.28

Table 4: Mod. Isochronal Test of Well KMJ-74

Well Status	WHP (ksc)	M (tonnes/hour)
Initial	24.61	0
Flowing	20	28.42
Shut In	24.6	0
Flowing	18	32.66
Shut In	25.67	0
Flowing	16	44.61
Shut In	25.6	0
Flowing	14	50.53
Shut In	25.6	0
Extended Flow	14.5	37.57

3.2 Modified Isochronal Test

The modified isochronal test was conducted by flowing and shutting the wells in the interval of 1 day. Following the last build up, both KMJ-73 and KMJ-74 were produced at a constant flow rate for 11 days and then shut in. Extended flow rates were 53.28 tons/hour on *WHP* 14 ksc for KMJ-73 and 37.57 tons/hour on *WHP* 14.5 ksc for KMJ-74. Result of the modified isochronal test conducted on KMJ-73 and KMJ-74 wells are presented on Table 3 and Table 4.

4. ANALYSIS AND DISCUSSION

4.1 Back Pressure Test

Calculations of log(ΔP^2)and log(M) from back pressure test for KMJ-73 well are shown in Table 5:

Table 5: Mod. Isochronal Test of Well KMJ-73

WHP	M	dP^2	Log(M)	Log(dP^2)
(ksc)	tonnes/hour			
20	37.51	405.67	1.57415	2.60818
17.7	45.11	492.38	1.65427	2.69230
15.5	50.43	565.42	1.70269	2.75237
12.6	56.55	646.91	1.75243	2.81085
11.7	59.72	668.78	1.77612	2.82529
17.5	45.83	499.42	1.66115	2.69847
15.5	48.8	565.42	1.68842	2.75237
14.4	52	598.31	1.71933	2.77693
12.5	56.6	649.42	1.75282	2.81253
11.5	58.63	673.42	1.76812	2.82829

By plotting log (ΔP^2) vs log (M) as shown on Figure 7, we find that the slope represents n value and the intercept is equal to 10^C.

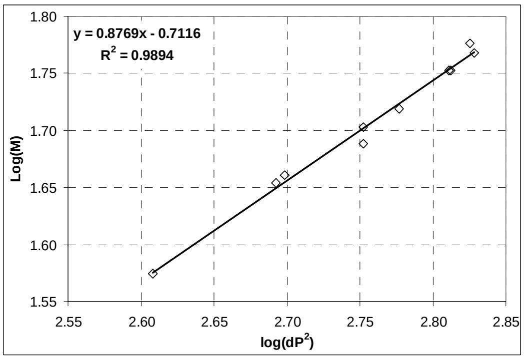

Figure 7: Slope of Back Pressure Test Well KMJ-74

According to the above plot, the deliverability of KMJ-73 well based on back pressure test can be expressed as:

$M=0.19427(P_r^2 - WHP^2)^{0.8769}$

The graphical deliverability of KMJ-73 well is depicted on Figure 8.

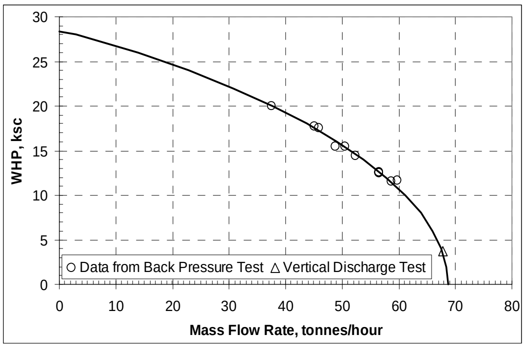

Figure 8: Back Pressure of Well KMJ-73

With the same steps as in calculation of back pressure test for KMJ-73, the deliverability of KMJ-74 well can be expressed as:

$M=0.78307(P_r^2 - WHP^2)^{0.6196}$

Table 6: Mod. Isochronal Test of Well KMJ-74

WHP	M	dP^2	Log(M)	Log(dP^2)
(ksc)	tonnes/hour			
11.2	41.43	624.59	1.61731	2.7956
12.6	40.22	591.27	1.60444	2.7718
15.4	36.75	512.87	1.56526	2.7100
17.9	34.42	429.62	1.53681	2.6331
20.0	29.3	350.03	1.46687	2.5441
16.0	35.57	494.03	1.55108	2.6937
14.9	38.76	528.02	1.58838	2.7226
12.5	42.19	593.78	1.62521	2.7736
11.9	42.09	608.42	1.62418	2.7842

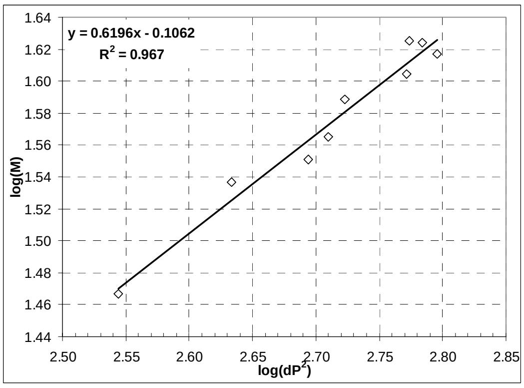

Figure 9: Slope of Back Pressure Test Well KMJ-74

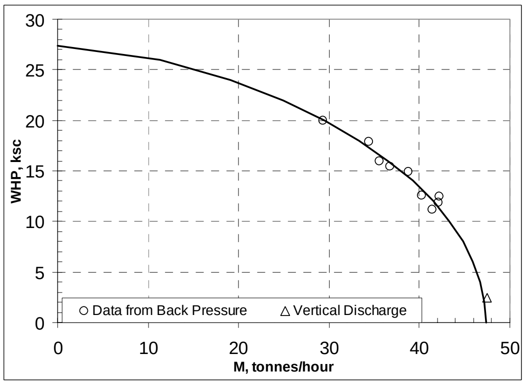

Figure 10: Back Pressure of Well KMJ-74

4.2 Modified Isochronal Test

The slope of plot on Figure 11 and Figure 14 represents the value of *n* but in order to get the value of C, the straight line has to be shifted parallel to the point which resulted from extended flow data. The values of *n* are 0.932 for KMJ-73 and 0.7274 for KMJ-74. The values for C are 0.1347 and 0.3887 for KMJ-73 and KMJ-74 respectively.

Comparison of the deliverability based on modified isochronal test and back pressure test can be seen on Figure 12 and Figure 15. It is clear that the deliverability from modified isochronal tests deviate from back pressure tests. However, when the extended flow data is replaced by the data from vertical discharge test for determination of the value of *C*, the deliverability from modified isochronal test fits that of the deliverability from back pressure test.

Results of back pressure test and modified isochronal test are summarized in Table 9 and Table 10.

Table 7: Mod. Isochronal Test of Well KMJ-73

Shut In Press.	Flowing Press.	M	dP^2	Log(dP^2)	Log(M)	Note
(ksc)	(ksc)	tonnes/hour				
28.38	21.5	36.44	343.42	2.5358	1.5616	
27.5	20	42.56	356.25	2.5518	1.6290	
28.1	17.5	50.4	483.36	2.6843	1.7024	
27	15	57.12	504.00	2.7024	1.7568	
27.3	14	53.28	549.29	2.7398	1.7266	Extended Flow
28.38	3.7	67.76	791.98	2.8987	1.8310	Vert. Discharge

Table 8: Mod. Isochronal Test of Well KMJ-74

Shut In Press.	Flowing Press.	M	dP^2	$Log(dP^2)$	Log(M)	Note
(ksc)	(ksc)	tonnes/hour				
24.61	20.00	28.42	205.65	2.31	1.45	
24.60	18.00	32.66	281.16	2.45	1.51	
25.67	16.00	44.61	402.95	2.61	1.65	
25.60	14.00	50.53	459.36	2.66	1.70	
25.60	14.50	37.57	445.11	2.65	1.57	Extended Flow
27.39	2.40	47.70	744.27	2.87	1.68	Vert. Discharge

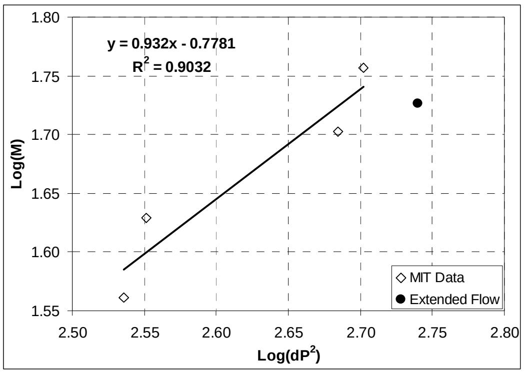

Figure 11: Slope of Modified Isochronal Test Well KMJ-73

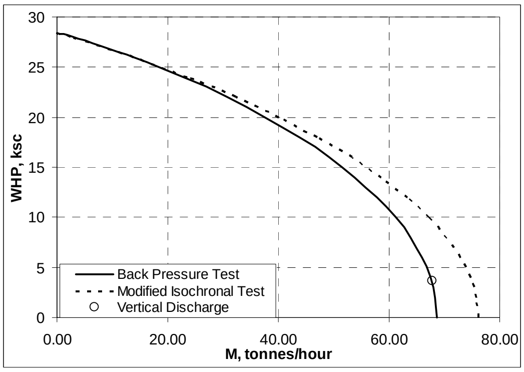

Figure 12: Comparison of Back Pressure and Modified Isochronal Test for Well KMJ-73

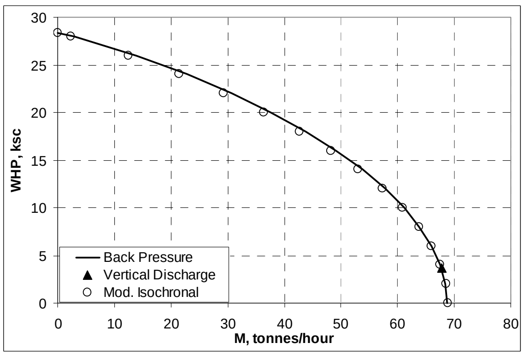

Figure 13: Modified Isochronal Test without Extended Flow Data of Well KMJ-73

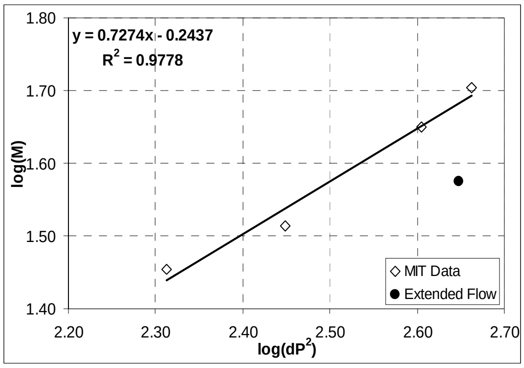

Figure 14: Slope of Modified Isochronal Test Well KMJ-74

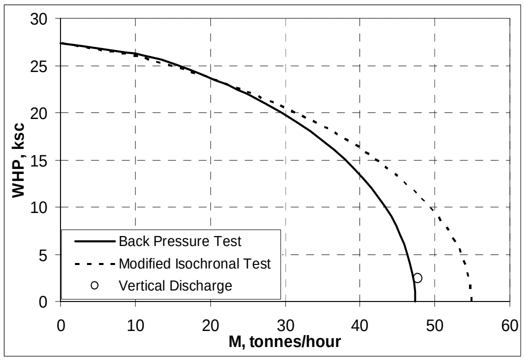

Figure 15: Comparison of Back Pressure and Modified Isochronal Test for Well KMJ-74

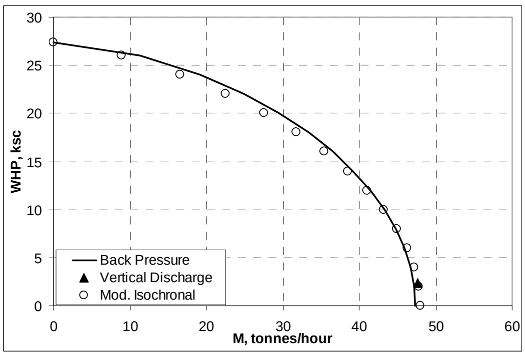

Figure 16: Modified Isochronal Test without Extended Flow Data of Well KMJ-73

Table 9: Summary of Back Pressure Test

	Well	
	KMJ-73	KMJ-74
C	0.19427	0.78307
n	0.8769	0.6196
R^2	0.9894	0.967

Table 10: Summary of Mod. Isochronal Test

	Well	
	KMJ-73	KMJ-74
C	0.1347	0.38871
n	0.932	0.7274
R^2	0.9032	0.9778

4.3. Discussion

The theoretical background of the difference between result of back pressure test and modified isochronal test is not clearly understood. The interesting thing is when the extended flow data is replaced by the data from vertical discharge test for determination of the value of *C*, the deliverability from modified isochronal test has a good agreement with deliverability from back pressure test. If replacement of extended flow data with vertical discharge data can be proved scientifically, it will be very interesting because the duration of vertical discharge test is shorter than extended flow period which is usually done in standard modified isochronal test.

In the back pressure test, time required for wellhead pressure to stable depends on reservoir permeability. Stable pressure of KMJ-73 and of KMJ-74 wells was obtained during about 120 hours or about 5 days. It means that about 50 days are needed for completion of the test. During test, the produced steam from KMJ-73 was about 55,405 tons and from KMJ-74, it was about 31,192 tons. While the modified isochronal test produced only 7,368 tons from KMJ-73 and 5,808 tons from KMJ-74. From economic point of view, application of modified isochronal test will save Rp. 2.1 Billions from KMJ-73 and Rp. 1.1 billions from KMJ-74 (assumed 1 kWh = Rp. 340).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the result and analysis of deliverability test conducted on KMJ-73 and KMJ-74 wells using back pressure and modified isochronal test, some conclusions can be drawn.

Modified isochronal test seems suitable for determining deliverability of dry steam wells such as wells in Kamojang geothermal field.

Modified isochronal test has good agreement with back pressure test if vertical discharge data is used for substitution of extended flow data.

Application of modified isochronal test to KMJ-73 and KMJ-74 wells reduced revenue loss by about Rp. 3.2 billions.

5.2 Recommendations

It is realized that the result of field tests on KMJ-73 and KMJ-74 do not satisfy scientific answers about the applicability of modified isochronal test for determination of deliverability of dry steam wells to substitute back pressure test. Some questions still remain: why extended flow data does not give a good result, is there any reason why vertical discharge test can be used to replace extended flow period and what is the most suitable time interval of flowing and shutting. Further study needs to be done to answer those questions. Field test to a number of wells needs to be conducted to check whether the results will confirm the result of the test of well KMJ-73 and KMJ-74 wells.

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