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Determination of Aquifer Hydraulic Parameters from Pumping Test Data Analysis: A Case Study of Akpabuyo Coastal Plain Sand Aquifers, Cross River State, S-E Nigeria.

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Abstract: *Five boreholes namely IkotEdemOdo (Ak3), IkotOyom (Ak7), IkotMbakara (Ak9), AkwaObioInwang (Ak10), and IkotEkpo (Ak11) within the Akpabuyo Local Government Area of Cross River State were subjected to a number of pumping tests: step drawdown, constant discharge and recovery tests to provide some preliminary estimation of hydraulic parameters for the study area. The results indicate that transmissivity T, hydraulic conductivity k, and specificcapacity SC, ranged from 485.0m^2/d to 1346.0m^2/d, 9.7m/d to 27.9m/d, 0.02m^3/d/m to 346.m^3/d/m respectively. Mean static water level (SWL), saturated thickness of the aquifer (b) and borehole drilled depths (BDD) were 30.29m, 48.0m and 64.8m, respectively. The litho-logs of the boreholes confirm that the estimated hydraulic parameters were obtained from unconfined gravelly sandy aquifers underlain by mostly sandy clay (aquitard).*
It is hereby recommended that an observation well should be included in a future research to enable the computation of storativity (S). Since pumping test is expensive, the use of electrical resistivity techniques should be considered for the estimation of aquifer hydraulic parameters in the area.
Key Words*: Pumping tests, unconfined aquifer, hydraulic parameters, litho-logs, coastal plain sand, Akpabuyo.*

I. Introduction

The study area, Akpabuyo Local Government Area (Fig.1), is located approximately between latitudes 4^0 52.5^1 , and $4^0 57.5^1$ North and longitude 8^0 23.5^1 and 8^0 31^1 East. It covers an estimated area of 1300km^2. Five boreholes located atIkotEdemOdo (Ak3), IkotOyom (Ak7), IkotMbakara (Ak9), AkwaObioInwang (Ak10), and IkotEkpo (Ak11) within the study area (Fig.1)were pump tested for their aquifer hydraulic parameters. The determination of aquifer parameters through pumping tests has become a standard step in theevaluation of groundwater resource potential of an area (Freeze and Cherry 1979). A pumping test in essence involves abstracting water from a well at a known rate and then observing the reduction or decline in water level(ordrawdown, s) in the aquifer in the vicinity of the well (Hamill and Bell 1986).The pumping test analysis can provide not only the derived aquifer hydraulic parameters such as transmissivity T, storativity S, permeability(or hydraulic conductivity K), specific capacity SC, but well efficiency, aquifer loss, well loss and perennial yield of the well. It can also be used to determine the effects of the designed abstraction rate on the water level in aquifer, on rivers and hydro-geologic boundaries generally in an environment (Hamill and Bell 1986,Todd 1980). Solutions for the governing equation of ground water flow in an aquifer have been developed for steady state and transient(or non-equilibrium) conditions.They are used for the prediction of the response of aquifers (unconfined and confined) to pumping.The development of steady state(Theim1935) and non-equilibrium equations (Theis 1935, Jacob 1940) were major advances in aquifer evaluation and the analysis of pumping test data. The non-equilibrium method, unlike the steady state approach enables much shorter test to be conducted, required only one observation well and is capable of yielding the value of both formation constants, T and S (Freeze and Cherry 1979, Todd 1980, Hamil and Bell 1986).The non equilibrium equation was solved for less ideal confined aquifer such as leaky aquifer (Hantush and Jacob 1955, Hantush 1956, 1960). Neuman and Whiter Spoon (1969a, b) presented complete solution that include consideration of both release of water from storage in the aquitard and head drawdown in the un-pumped aquifer.This research work is aimed at providing some preliminary estimation of hydraulic parameters (e.gtransmissivity T, hydraulic conductivity (k), static water level (SWL), discharge (Q), drawdown(s), and specific capacity of wells (SC)) for the Akpabuyo coastal plain sand aqifers. The area is hugely populated due to its nearness to Calabar(capital of Cross River State) and Bakassi Local Government Area. The inhabitants of the study area are highly dependent on pipe-borne water by having their water supply for domestic,industrial and agricultural uses from these aquifers. Thus this research will serve as a baseline sturdy for future development of groundwater resources of the area.

II. Materials And Methods

The data obtained for this work was carried out by the authors in conjunction with the Federal Ministry of Water Resources, Abuja and the Cross River Basin and Rural Development Authority, Calabar in 2010. The pumping test techniques were carried out in three sequential stages:

1. The step-drawdown test
2. The constant rate test and
3 Recovery test.

During the pumping test and after the test, data were collated and analysed to determine the following hydraulic parameters:

1. Transmissivity (T)
2. Conductivity (K)
3. Specific capacity (SC) and
4. Drawdown (s)

The pumping was carried out using 5.5HP, submersible pump for locations Ak3, AK8, Ak9, AK10 and 3HP pump for Ak11.

Single hole pumping test was employed in all these five places because no observation well was available. The data generated in such cases were used for the estimation of the transmissivity,T of the aquifer. For wells in places where an observation well was available, both transmissivity T and storativity S, were computed from a semi-log plot of time-drawdown graph (see Figure 4).The slope of this graph is equivalent to $\Delta s=2.3Q/4\pi T$, hence $T=2.3Q/4\pi\Delta s$ and $S=2.25Tt_0/r^2$ where Q=pumping rate
Δs=drawdown difference per log cycle of time, t.
t_0=time when drawdown is zero.
r=radial distance from a pumping well to an observation well.

III. Result And Disscussion

The results of the pumping test are shown in Table 2. The raw data for the five locations are indicated in Table1

Transmissivity (T)

Transmissivity T, is the rate at which water passes through a unit width of
a saturated thickness of an aquifer under a unit hydraulic gradient. The Hydraulic conductivity (K) and Transmisssivity(T) are related by the expression T= Kb where
T = transmissivity in m^2 per day
K = hydraulic or aquifer conductivity in m per day and
b = thickness of the aquifer in m
The drawdown, s for a pumping well is given by the equation, $s = 2.3Q/4\pi T \log 2.25Tt/r^2$ (Cooper and Jacob 1946). T is evaluated from the slope of semi- log plot of time- drawdown curves (Figs 2 and 3) for both constant discharge and recovery aquifer tests using the relation:
$T=2.3Q/4\pi\Delta s$as previously outlined
Q being the constant pumping rate in m^3 per day
Average transmissivity, T from both techniques(constant and recovery tests) are summarized in Table 2. T ranges from **485.0 to 1393.8m^2 / d.**

Storativity

Storativity also referred to as storage coefficient (S) is the volume of water an aquifer releases from or takes into storage per unit surface area per unit change in head. From cooper and Jacob (1946), non – equilibrium equation.,storativity ,
S = **$2.25T\, t_o/r^2$** where
t_o is the time at zero drawdown, S is the storativity of the aquifer, r is the distance from the pumping well to an observation well (m)

This implies that to evaluate S require measurement of r, the distance to an observation wells. There were no observation wells used thus, S could not be calculated; furthermore there are energy losses as water rushes into wellbore so that the head in the aquifer is larger than the water level in pumping well (Petters 1989, Edet 1993). However, the values of S are usually about 0.2 for water table aquifers and 10^{-5} and $10^{-3}$for confined aquifers (Lohman 1972).

Specific Capacity (Sc)

Specific capacity is the discharge rate per drawdown.
Mathematically specific capacity (SC)

SC = Q/s
where Q is the discharge rate in m^3/d.
And s=drawdown in m

The productivity of a well is often expressed in terms of its specific capacity (Freeze and Cherry, 1979).The calculated specific capacity of wells ranged from 9.02 to 346m^3 /d/m with a mean of 82.40m^3d/m.

Hydraulic Conductivity (K)

It is the quantitative measurement of permeability that is the ease in which water can pass through a unit thicknessof an aquifer. Hydraulic conductivity,K
andtransmissivityT are related by the expression).
T =Kb. Thus, K =T /b
where b = saturated thickness of the aquifer. In this work,
K varies from 9.7 m/d (IkotEdemOdo, Ak3) to 27. 9m/d (AkwaObioInwang AK10).

Aquifer Thickness

The thickness of the aquifer for location AK3, Ak7, Ak9, AK10 and AK 11 are 50m, 61m,42m, 36m, and 55m respectively (Table2, Fig5)

IV. Discussion

The upper aquifer of the Akpabuyo area is found to exist from a depth of less than 5m below the surface and its saturated thickness ranges from 45 to 90m with a mean of 48.0m. It is made up of coarse, gravelly sand terminated in a sandy clay substratum. (Fig 4).This aquifer is called upper gravelly sandy aquifer(UGSA) (Amah et al,2008)

The mean depth of drilled boreholes of 46m (Table 2) indicates that the upper aquifer is shallow (Edet and Okereke, 2002). From the mean values of hydraulic parameters (T =77.5m^2/d, k = 21.6m/d and SC = 82.4m^3/d/m), the coastal plain sand aquifer of Akpabuyo area contains enormous quantity of water.
The interpreted results (Table 2) indicate that AK 10 (AkwaObioInwang) has the highest hydraulic parameters and the most productive borehole (SC= 346m^3/d/m).

V. Conclusion And Recommendation

Pumping test data were analysed for five boreholes in Akpabuyo area : namely IkotEdemOdo (AK3), IkotOyom (AK7), IkotMbakara (AK9) AkwaObioInwang (AK10) and IkotEkpo (AK11) in order to determine the

i. yield/ drawdown characteristics of a well (i.e well test) and
ii. hydraulic parameters of the aquifer (i.e aquifer test).

The data so obtained were used for the estimation of transmissivity (T), conductivity (K), specific capacity (Sc) and thickness (b).

The interpreted results indicate that Ak10 aquifer (AkwaObioInwang) is the most productive (SC = 346m^3/d/m, T = 1393.8m^2/d) than any other locations.

The saturated thickness of the aquifer is greater than 45m. The litho – logs reveal that the boreholes were tapping unconfined shallow aquifer underline with a sandy clay horizon.

VI. Recommenation

1. Since pumping test is expensive, the use of electrical resistivity techniques should be considered for the estimation of aquifer hydraulic parameters.
2. The test should be conducted for longer duration of time (2-3hours) in order to give accurate and reliable data as well asan observation well should be included in a future research to enable the computation of storativity (S)
3. Boreholes should be drilled to tap the confined aquifer for water of better quality.

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Fig. 1: Map of Cross River showing the mapped area (after CRBDA, 1982)

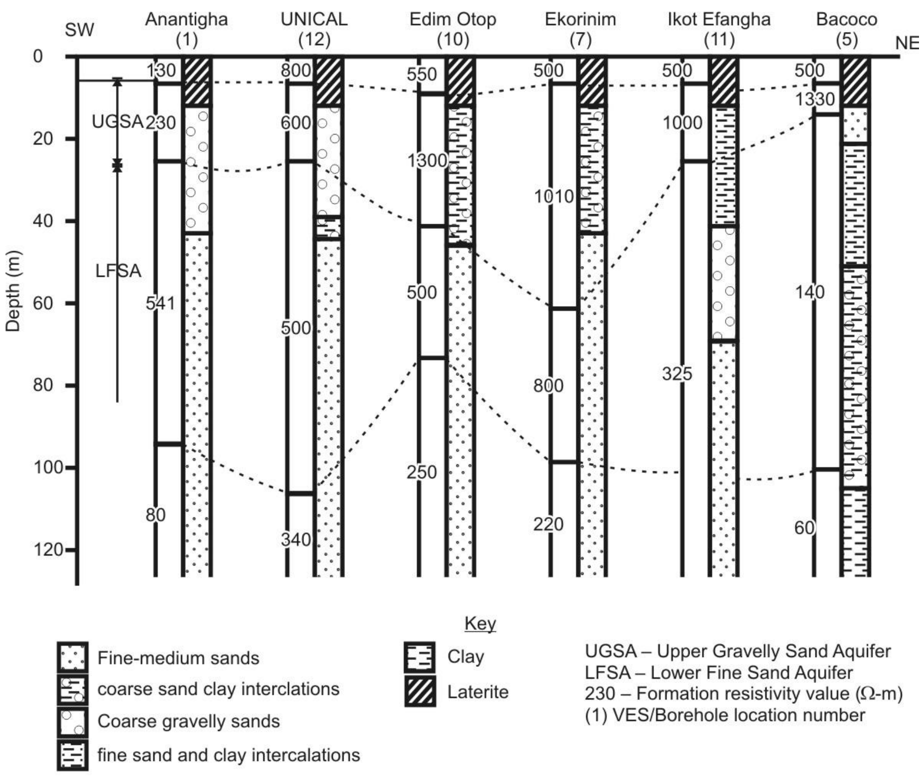

FIG. 3: Geo-electric and litholog section SW-NE Calabar area

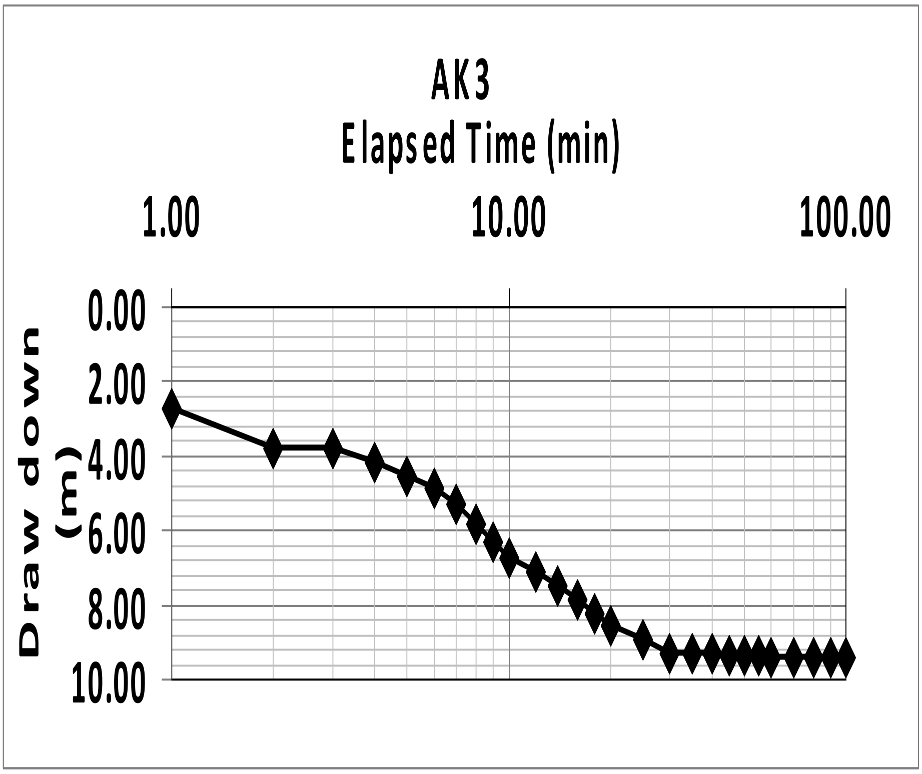

FIG. 4a: Time-drawdown curve for IkotEdemOdo (AK3)

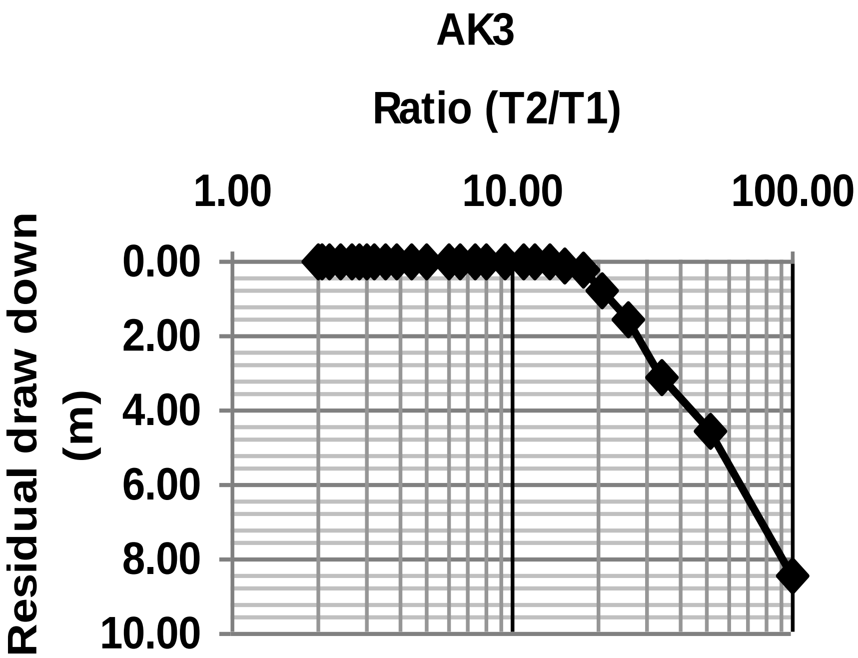

FIG. 4b: Recovery curve for IkotEdemOdo (AK3)

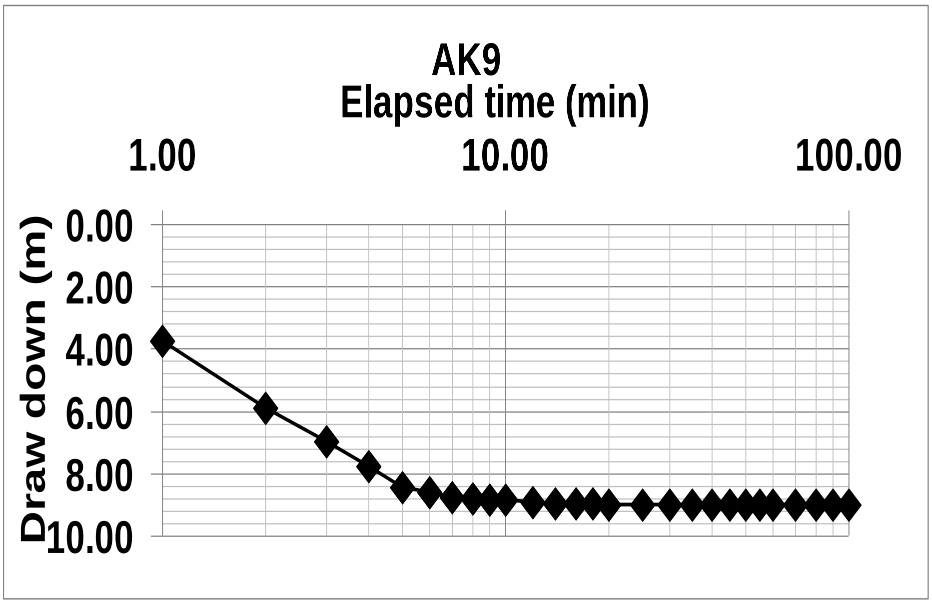

FIG. 4c: Time-drawdown curve for IkotMbakara (AK9)

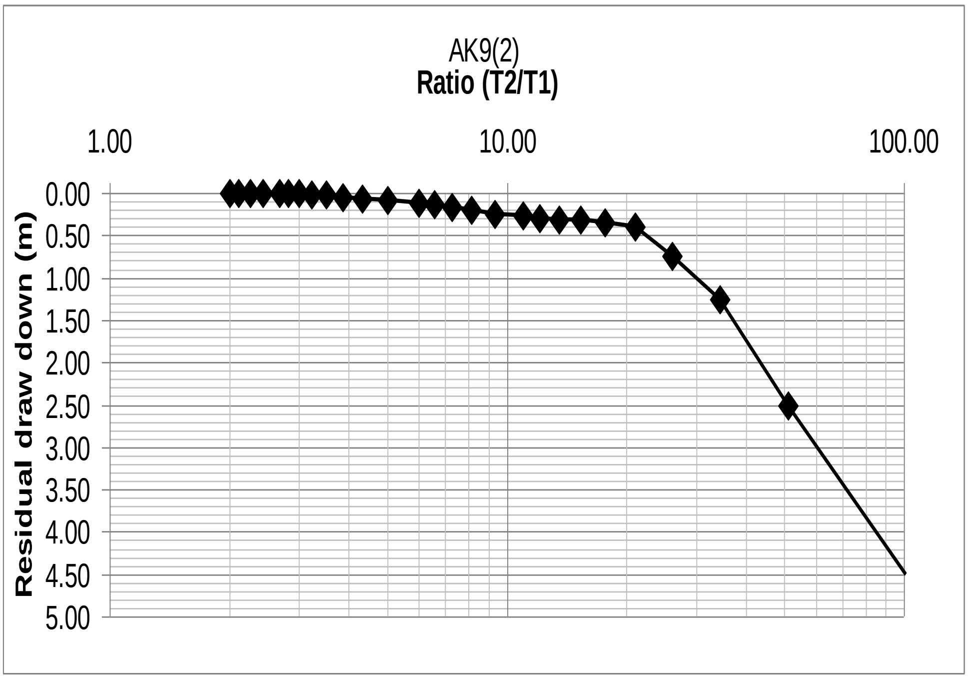

FIG. 4d: Recovery curve for IkotMbakara (AK9)

Pumping Test Results

Bore hole Location:Ikot EdemOdoAkpabuyo L.G.A. AK3

BH Depth 92(m) Screen Level ______ Static W/L 27.8m

Pump Type GROUNDFOS 5HP Pump Setting------ Pumping Rate 120/min

Contractor ____________ Date ____________

CONSTANT RATE / RECOVERY TEST

Elapsed Time	Pumping W/L	Draw Down	Pumping Rate	Recovery Time (T_1)	Total Time (T2)	Ratio T_2/T_1	Water Level	Residual Draw Down
(Min)	(M)	(M)	L/Min	(Min)	(Min)		(M)	(M)
0	32.50	0	1281/min	0	100	0	42.66	10.16
1	35.25	2.75	-	1	101	101	40.90	8.40
2	36.30	3.80	-	2	102	51.0	37.01	4.50
3	13.29	3.79	-	3	103	34.3	35.60	3.10
4	13.68	4.18	-	4	104	26.0	34.10	1.60
5	14.04	4.54	-	5	105	21.0	33.30	0.80
6	14.36	4.86	-	6	106	17.67	32.70	0.20
7	14.81	5.31	-	7	107	15.29	32.60	0.10
8	15.34	5.84	-	8	108	13.50	32.50	0.0
9	15.80	6.30	-	9	109	12.11	32.50	0.0
10	16.23	6.73	-	10	110	11.0	32.50	0.0
12	16.61	7.11	-	12	112	9.33	32.50	0.0
14	17.0	7.50	1281/min	14	114	8.14	32.50	0.0
16	17.7	7.87	-	16	116	7.25	32.50	0.0
18	17.73	8.23	-	18	118	6.56	32.50	0.0
20	18.08	8.58	-	20	120	6.0	32.50	0.0
25	18.12	8.92	-	25	125	5.0	32.50	0.0
30	18.79	9.29	-	30	130	4.33	32.50	0.0
35	18.81	9.31	-	35	135	3.80	32.50	0.0
40	18.82	9.32	-	40	140	3.50	32.50	0.0
45	18.84	9.34	-	45	145	3.22	32.50	0.0
50	18.85	9.35	-	50	150	3.0	32.50	0.0
55	18.87	9.37	-	55	155	2.82	32.50	0.0
60	18.89	9.39	-	60	160	2.67	32.50	0.0
70	18.90	9. 40	-	70	170	2.43	32.50	0.0
80	18.92	9. 42	-	80	180	2.25	32.50	0.0
90	18.93	9. 43	-	90	190	2.11	32.50	0.0
100	18.93	9.43	1281/min	100	200	2.0	32.50	0.0

PUMPING TEST RESULTS

Bore hole Location: IkotOyomEneyoAkpabuyo L.G.A. AK7

BH Depth 64.0(m) Screen Level ______ Static W/L 28.8

Pump Type GROUNDFOS 5HP Pump Setting Pumping Rate 80L/Min

Contractor ____________ Date ____________

CONSTANT RATE				**RECOVERY TEST**				
Elapsed Time	**Pumping W/L**	**Draw Down**	**Pumping Rate**	**Recovery Time (T_1)**	**Total Time (T2)**	**Ratio T_2/T1**	**Water Level**	**Residual Draw Down**
(Min)	(m)	(m)	L/Min	(Min)	(Min)		(m)	(m)
0	28.87	0	80L/min	0	100	0	35.25	6.38
1	31.65	2.78	-	1	101	101	32.06	3.19
2	31.73	2.86	-	2	102	51	31.76	2.89
3	31.81	2.94	-	3	103	34.33	31.59	2.72
4	31.89	3.02	-	4	104	26	31.59	2.72
5	31.91	3.04	-	5	105	21	31.42	2.55
6	31.97	3.10	-	6	106	17.66	31.25	2.38
7	32.05	0.18	-	7	107	15.29	31.10	2.23
8	32.13	3.26	-	8	108	13.5	30.95	2.08
9	32.20	3.33	-	9	109	12.11	30.80	1.93
10	32.25	3.38	-	10	110	11	30.66	1.79
12	32.28	3.41	-	12	112	9.33	30.52	1.65
14	32.44	3.57	-	14	114	8.14	30.38	1.51
16	32.60	3.73	80L/min	16	116	7.25	30.24	1.37
18	32.75	3.88	-	18	118	6.56	30.10	1.23
20	32.86	3.99	-	20	120	6.56	29.96	1.09
25	32.91	4.04	-	25	125	6	29.82	0.95
30	33.16	4.29	-	30	130	4.33	29.68	0.81
35	33.41	4.54	-	35	135	3.86	29.54	0.67
40	33.67	4.80	-	40	140	3.86	29.40	0.53
45	33.92	5.05	-	45	145	3.50	29.26	0.39
50	34.0	5.13	-	50	150	3	28.92	0.05
55	34.17	5.30	-	55	155	2.81	28.92	0.05
60	34.39	5.52	-	60	160	2.66	28.89	0.02
70	34.64	5.77	-	70	170	2.43	28.88	0.01
80	34.85	5.98	-	80	180	2.25	28.87	0
90	25.05	6.18	-	90	190	2.11	28.87	0
100	35.25	6.38	80L/min	100	200	2	28.87	0