Regression Analysis on Main Dimensions of Existing Tug Engine Power

Stephen Chidozie Duru, Alexander Okpara
Department of Marine/Mechanical Engineering,
Niger Delta University ,Amassoma, Bayelsa State, Nigeria

Abstract

Regression analysis on the principal dimensional data collected from 387 different tug boats resulted in the 42 reliable equations for the design of tugboats. These regression equations published here are based on main engine power of existing tugboats. Microsoft EXCEL software is used for the numerous regression analysis from which these equations were selected basing on their Coefficient of regression values R^2 being greater than 0.85. An example of the application of these equations for the prediction of the main dimensions of a projected tugboat is demonstrated in this work for the design of a new tugboat of main engine power of 2720hp. This method can be used to predict the size of a new or used tugboat for purchase by porspective vessel owner.

Keyword: *Tugboat, main-power, regression, formulas, dimensions.*

I. INTRODUCTION

The initial extimation of a projected Tugboat design main dimensions can be obtained from the regression analysis of similar existing tug boat parameters. The regression analysis offered in this paper is for this purpose. It is based on the main power of tugboats parameters collected from existing world tugboats published in the internate.

The principle offererd in this paper is that the main power value for the new intended design is the input substituted in the derived equations to predict the required expected dimensional parameters of the projected tugboat. The parameters computed are preliminary and are subject to more rigorous hydrodynamic computations to obtain the optimum and complete design of the tugboat.

II. LITERATURE REVIEW

Tugboats exist in types and sizes. They are subdivided mainly by their propulsive machinery type and arrangments as well as their towing capabilities , (Howard Collins (1994), Jaroslaw Artyszuk(2013), Robert G. Allen (2016), and others.

Tugs are heavy duty equipment in which the main power is maximizes with respct to their form or dimensional size to achieve optimum thrust power or bollard pull. The reason for minimization of the form size is to reduce the resistance of the hull so as to achieve a maximized tow rope or push power of the vessels.

Publications on tugboat design design parameters are available , Roach (1954), Prabhat Kumar.P (1992), D.G.M. Watson (1998), and others . The equations in these older publications are derived basing on the dimensional and ship stability parameters. These authorities derive the main parameters of the tug firstly and then optimize it by systematic parametric changes and to main power, tow force and speed basing on hydrodynamics propulsive computaions [].

IIII. MATERIAL AND METHOD

The data for the regression analysis are obtained from Marintimesale Inc(2016), Damen Trading and chartering(2016), Marcon International Inc(2016), references. The data occupy so many pages hence a short form is of it is shown in Table 1. The mathematical model of regression formula fitted to the data were linear and none linear function. These are function of these types

linear $Y = mX + c$. 1
power $Y = mX^c$. 2
Exponential $Y = m \ln(X) + c$ 3
Polynomial $Y = aX^n + aX^{n-1} + .. + aX^{1-} + +c$. 4

Where Y is the variable depicting the geometrical dimension of the tugboat.

X is the main engine power P of the tugboats

m, c, and n are constants determined by the regreesion analysis.

These are well known mathematical procedues Montgomery (2002), and others. The Micrsoft EXCEL add in software has software for these procedues and are used for the regression analysis in this work.

The author formulated the system of dependent variables, for example LB, L/B, B/D, BD, P/L, PB, $(\sqrt{L})/D$, TL, TL^2 and so on and then correlated them with the respective main power P (hp). The existing tugboat variables of L, B, D, T, were also correlated with P but only B correlated well with tug main engine power P.

Where:

L = length of the Tug Boat (m)
B = breadth of the tugboat(m)
D = depth of the tugboat(m)
T = Draft of the tugboat(m)
P = Tug main engine power (hp)
Numerous regression correlation were made between different formulated variables and the main power but only those reliable formulas with correlation coefficient R^2 greater than 0.85 are selected and published in this paper.

IV. RESULT AND DISCUSSION

Table 2 show the resulting equations from this work. Fig. 1 to Fig 30 show the diagram for the regression. The various correlation coefficient R^2 are shown in the table and on each diagrams. In Table 2 the maximum power range P_{max}(hp) and the number of data points N for each regression are shown so as to show the limits the regression equations can be validly useful. The total number of equations are forty two (42 equations). Obviously the range of P in most of the equations cover the likely main power for the present and future design of different types and sizes of tugboat.
If, for example, a prospective tug owner specify that he wants to acquire a tug boat of main power P of 2720hp for CAT5312 DI-TA/B running at 1600rpm. Refering to Table 3 ,by substituting P = 2720hp in equation : eq2 and eq6 will give two L(m) values; eq4 and eq5 will give two B(m) values; eq 17,18, 19, and eq20 will give four values of D(m); eq 26, 27, 28, as well as eq31 will give the values of T(m). The mean of this respective values resulted in a prediction of the dimension of the tugboat as:
L = 30.48m, B = 9.19m, D = 4.35m and T = 3.62m for P = 2720hp. Table 3 show this calculation done with EXCEL worksheet. The other equations in Table 2 that are not applied in Table 3 can also be used to predict the parametric dimensions of tugboats especially in an optiminisation model.

V. CONCLUSION

The owners or operators of Tugboats mostly specify the main power as one of the technical and commercial measure for ascertaining the value of the tugboat especially in Nigeria. This paper focuses on the determination of the dimensional parameters (L, B, D, T in meters) of the tug as a function of the main propulsive power P (hp).

Data of modern 387 different tug boats were collected and analysed using linear and none-linear regression analysis software of Micrsoft EXCEL add in which resulted in 42 equations selected from many others published hereunder. These equations are selected basing on their correlation coefficient ranging from 0.85 to 0.99. The maximum range of validity with respect to main engine power as well as the number of data points for each respective regression formula is presented in Table 2. Fig 1 to 20 show thw scatter diagram and the respective regression equations. presented. A brief example using owners requirement of 2720hp for the main power was used to substitute on some of the formulas to predict the main dimensions of the projected tugboat.
The 42 formulas will give the designer the possibility to predeict many sets of dimensions for the main engine power from which the optimum set of projected tug dimensions emerges. This can be done by the application of linear algebra or other optimization techniques.

REFERENCES

[1] Howard Collins (1994), An International Classification of Ships by Type (ICST(94)); Department of Trade, London, June, 1994.
[2] Jaroslaw Artyszuk(2013), Types and Power of Habour Tugs – The Latest Trends, Prace Naukowe Politechniki, Warsaw, pg 9 - 20 April, 2013
[3] Robert G. Allen (2016), The Design of Modern Tugboats, Tugboat Features, Pacific Maritime USA www.pacmar.com
[4] Roach (1954), Tugboat Design, Transactions of Society of Naval Architects and Marine Engineers (SNAME), Pg 1-56,1954
[5] Robert Taggart (1980), Ship Design and Construction, Society of Naval Architects and Marine Engineers (SNAME) USA, Pg 10-12, 69-72,1980
[6] Prabhat Kumar.P (1992), Computer-Aided Preliminary Design of Tugs, PRADS '92, University of New Castle Upon Tyne, England 18 – 22 May, 1992.
[7] D.G.M. Watson (1998), Practical Ship Design, Elservier Ocean Engineering Book series Volume I, Pg 7 to 77, 1998
[8] Marintimesale Inc(2016), Tudboats for Sale, www. Maritimesale.com.
[9] Damen Trading and chartering(2016), Damen Stan Tugs for sale, www.damen.com
[10] Marcon International Inc(2016), Vessels sales, www.marcon.com
[11] Douglas C. Montgomery, George C. Runger(2002) Applied Statistics and Probability for Engineers, John Wiley and Sons, Inc, USA Pp 372 – 467. 2002

Table 1 A collection of the principal dimension of modern Tugboat

	NAME/ID	BUILT/CLASS	BUILT	LAO	B	D	T	ME(HP)
1	140807-VN		2012	36.600	10.500	4.600	3.300	4800.000
2	120233-VW			36.020	10.600	4.800	3.600	5200.000
3	121111-VN		2012	37.700	10.400	4.800	3.650	5200.000
4	Sea Eagle	Turkish/BV		32.500	11.700	5.600	4.300	5632.292
5	140421-VW	Singapore/ABS	2006	29.000	9.000	4.250	3.500	3200.000
6	MR NICK	USA	1979	30.328	9.449	5.182	4.420	2000.000
7	140234 VN	KOREA	2012	36.900	10.000	4.500	3.400	4500.000
8	151223 VT	ITALY	2005	14.910	5.000	1.800	1.200	500.000
9	140321 VT	USA	1979	15.240	6.100	2.260	1.710	600.000
10	140113 VW	SPAIN	2011	16.000	5.500	2.800	2.150	780.000
11	150419 VT	USA	1989	16.640	6.100	2.320	1.980	900.000
12	120109 VW	US		18.290	6.100	2.400	2.010	405.000
13	151118 VN	ITALY	1986	19.000	5.370	2.750	2.280	577.000
14	Wendeanna	USA	1952	19.812	5.700	1.768	1.524	800.000
15	130718-VN	ISTANBUL /RINA	2011	19.950	7.000	3.200	2.200	1200.000
16	151222 VN	SINGAPORE	1983	21.500	6.800	3.340	2.600	900.000
17	151150 VT	TURKEY/BV	2015	22.000	7.700	3.700	2.200	600.000
18	BEN FOSS		1980	23.712	7.995	3.344	2.949	1700.000
19	SMS F		2007	24.988	7.570	3.490	3.466	1658.000
20	121063-VO	SPAIN /RINA	1982	25.000	8.400	4.360	4.200	2030.000
21	160524-VW	SPAIN	1968	25.860	6.400	3.050	3.000	825.000
22	151131-VO	MALAY/NKK		26.000	8.000	3.650	3.000	1650.000
23	STAN2608	DAMEN	1999	26.150	7.950	4.050	3.450	2720.000
24	ARI CRUZ	USA /ABS	1995	26.152	8.687	3.048	2.515	1248.000
25	140220 VN	HOLLAND/GL	1978	26.300	8.800	3.600	2.800	1716.000
26	ESTAURUS	CHINA/NKK	1997	26.448	7.965	3.466	3.192	1240.000
27	121068-VO	MALAY	2012	27.000	9.000	4.100	3.485	2000.000
28	OLIKTOK	USA/ABS	1982	27.432	9.754	3.414	2.591	2110.000
29	Pt Barrow	USA/ABS	1982	27.432	9.754	3.414	2.591	2110.000
30	denizcilik(uL)	Turkish /RINA	2009	27.432	9.144	4.039	4.000	3300.000
31	140725-VN			27.890	8.170	4.270	3.970	2100.000
32	120304-VM	SINGAPORE/NKK	2012	28.500	8.500	3.800	3.000	1440.000
33	121108 VW	ITALI /RINA	1985	28.550	6.560	3.820	3.140	1520.000
34	141043-VO	/ABS		29.100	9.000	4.250	3.500	2400.000
35	AMERICA	ITALY	1972	29.148	7.315	4.499	3.956	2100.000
36	160108 VO	FRANCE /GL	1976	29.200	8.500	4.150	3.500	1500.000
37	160422-VN	RUSSIA	1988	29.300	8.300	4.300	3.400	1604.000

Table 1. Continued

S/N	NAME/ID NO	BUILT/ CLASS	BUILT	LAO	B	D	T	ME(HP)
38	160422-VN	RUSSIA	1988	29.300	8.300	4.300	3.400	1604.000
39	RELIANCE	USA /ABS	2007	29.870	10.973	5.232	4.699	5000.000
40	141129 VO	/RINA	2012	30.000	9.000	4.000	3.000	2060.000
41	140409 VO	NS	2009	30.220	9.000	4.380	3.680	2400.000
42	Sandusky	USA	1980	30.480	9.754	3.800	3.353	3000.000
43	Island Brave	USA	1944	30.480	7.620	3.800	3.353	2600.000
44	atlantic	USA/ ABS		30.988	10.998	5.588	4.597	5364.000
45	T W Ocean 15	Indonesia /LR	2005	31.000	9.000	4.500	3.500	3000.000
46	141207-VO	SPAIN	2002	31.210	8.410	4.510	4.000	1716.000
47	TITO NERI S	ITALY/RINA	1985	31.272	8.230	4.237	3.627	2068.000
48	DEFENDER	USA /ABS	1998	31.521	11.278	5.486	4.267	3900.000
59	150825 VA NG	BV	2014	31.650	9.140	4.200	3.650	3200.000
50	challenger	USA /ABS	2003	31.699	10.973	4.877	4.115	4200.000
51	new tug	CHINA/ BV	2000	31.791	9.601	4.145	3.109	3200.000
52	120917-VO	/LR	2012	31.990	11.600	5.810	5.370	5364.000
53	ENTERPRISE	USA /ABS	1999	32.004	10.363	5.029	4.877	4400.000
54	WEATHERLY	USA /ABS	2012	32.004	11.582	5.385	5.232	4720.000
55	140412-VO	MALAY /NS	2011	32.100	9.000	4.200	3.680	3200.000
56	140408-VO	/NS	2014	32.400	9.150	4.480	3.680	3200.000
57	141125-VO	UK	2014	32.600	9.000	4.300	4.050	2500.000
58	140802 VN	CHINA	2009	33.000	10.000	4.500	4.100	4000.000
59	140240VO	INDONESIA	1982	33.520	7.920	3.200	2.400	1273.000
60	140804 VN	CHINA	2013	33.980	10.000			
61	140413-VO	CHINA/ BV					3.650	3200.000
				35.000	11.500	5.620	4.800	5150.000
375	Leslie Foss	USA /ABS	1970	36.576	9.449	4.542	4.115	3000.000
376	141137-VA		2007	37.000	10.600	4.950	4.000	3200.000
377	Coastal Sun	USA	2006	37.186	10.363	5.334	4.572	4400.000
378	432236Boatson		1978	37.200	10.840	4.900	4.300	3500.000
379	432236EA	AFRCA/ IRE	1978	37.300	10.840	4.900	4.300	3500.000
380	150721-VO	KUWAIT	1984	37.600	9.200	4.200	3.600	2000.000
381	Garibaldo	CHINA/LR		37.990	10.997	4.999	3.810	4960.000
382	Thunderer Tnd	Holland/BV	1977	41.392	10.485	5.304	4.389	4460.000
383	Pathfinder	USA	1970	41.514	11.125	5.852	4.115	5750.000
384	SUIATTIEUS	USA/ABS	1965	37.088	9.144	5.273	5.273	3070.000
385	Melvin E L	USA/ABS	1973	38.100	9.754	5.486	5.455	3900.000

Table 2 Tugboat design formulas as a function of main power capacity.

N	Max. P(hp)	R^2	Formula	Eq. no
91	22000	0.851	$L^{0.5}/D^2 = 21.815P^{-0.543}$	1
293	22000	0.881	$P/L = 6E-11P^3 - 2E-06P^3 + 0.0326P + 15.254$	2
123	8400	0.851	$B = 2E-08P^2 + 0.0008P + 6.407$	3
293	22000	0.954	$P/B = 2E-10P^3 - 7E-06P^2 + 0.1113P + 41.919$	4
280	22000	0.994	$PB = 0.0007P^2 + 7.8453P - 1455.5$	5
280	22000	0.992	$PL = 0.0032P^2 + 22.913P - 2060.4$	6
280	7200	0.995	$PLB = 0.0971P^2 - 105.4P + 245478$	7
278	7200	0.8533	$LB = 1.3787P^{0.6732}$	8
280	22000	0.947	$LB^2 = 7E-05P^2 + 0.4397P + 713.27$	9
280	22000	0.944	$BL^2 = 0.0003P^2 + 1.1559P + 2711$	10
93	22000	0.919	$LD^2 = 9E-06P^2 + 0.211P - 20.988$	11
93	22000	0.881	$LD^2 = 0.3572P - 347.95$	12
156	8400	0.933	$PLD = 0.038P^2 + 19.079$	13
156	8400	0.972	$PLD = 0.428P^{1.7255}$	14
82	22000	0.935	$DL^2 = -E-08P^3 + 0.0004P^2 - 0.1064P + 650.5$	15
152	8400	0.926	$P/D = 0.0.1412P + 222.01$	16
152	8400	0.933	$P/D = 5.015P^{0.6117}$	17
152	8400	0.944	$P/D = -9E-06P^2 + 0.2083P + 136.92$	18
156	8400	0.985	$PD = 0.0004P^2 + 3.682 - 940.16$	19
156	8400	0.986	$PD = 0.202P^{1.3863}$	20
93	22000	0.931	$BD^2 = 1E-06P^2 + 0.0645P - 2.9418$	21
93	22000	0.913	$BD^2 = 0.0891P - 58.05$	22
86	8400	0.889	$DB^2 = 7E-09P^3 - 6E-05P^2 + 0.2914P - 69.227$	23
156	8400	0.968	$PBD = 0.0083P^2 + 17.351P + 1$	24
156	8400	0.980	$PBD = 0.1647P^{1.6927}$	25
92	22000	0.881	$T = -6E-08P^2 + 0.0092P + 9.4702$	26
92	22000	0.966	$PT = 0.1793P^{1.3797}$	27
92	22000	0.938	$PT = 7.2182P - 9209$	28
92	22000	0.989	$PLT = 0.0331P^2 + 20.167P$	29
92	22000	0.904	$TL^2 = -9E-09P^3 + 0.0003P^2 + 0.1255P + 970$	30
92	22000	0.878	$P/T = 4E-10P^3 - 1E-05P^2 + 0.2576P + 160.75$	31
92	22000	0.913	$LT^2 = 5E-06P^2 + 0.1575P - 13.555$	32
92	22000	0.884	$LT^2 = 0.2524P - 219.99$	33
92	22000	0.993	$PBT = 0.0075P^2 - 15.047P$	34
93	22000	0.904	$BT = -9E-08P^2 + 0.0098P + 8.3702$	35
92	22000	0.992	$PDT = 0.0032P^2 + 8.4954P$	36
152	8400	0.877	$LBD = 2E-08P^3 - 0.0002P^2 + 1.0917P - 362.24$	37
152	8400	0.887	$LBD = 0.3424P^{1.0349}$	38
156	2200	0.951	$PLBD = 0.3483P^{2.0412}$	39
156	2200	0.994	$PLBD = 1E-05P^3 + 0.6937P^2 - 938.1P$	40
92	22000	0.947	$PLBT = 7E-05P^3 - 0.2581P^2 + 1219.5P$	41
92	22000	0.946	$PLBT = 0.4807P^{1.9695}$	42

Table 3 Calculation of principal dimension of tugboat with main power P = 2720hp.

Substitute	**P (hp) = 2720 hp**	**(in Table 2) for:**
Equation (2)	P/L = 90.33662 hp/m	Then, L = 30.109m
Equation (6)	PL = 83937.84 hpm	Then, L = 30.859m
	Then, Mean of L	**= 30.484m**
Equation (4)	P/B =296.8909 hp/m	Then, B = 9.162m
Equation (5)	PB = 25062.6 hpm	Then, B = 9.214m
	Then, Mean of B	**= 9.188m**
Equation (16)	P/D =606.074 hp/m	Then, D = 4.488m
Equation (17)	P/D =632.6984 hp/m	Then, D = 4.299m
Equation (18)	P/D =636.6384 hp/m	Then, D = 4.272m
eq uation (19)	PD =12034.24 hpm	Then, D = 4.424m
eq uation (20)	PD =11659.88 hpm	Then, D = 4.287m
	Then, Mean of D	**= 4.354m**
Equation (27)	PT = 9823.246 hpm	Then, T = 3.611 m
Equation (28)	PT =10424.5 hpm	Then, T = 3.832 m
Equation (31)	P/T =795.4875 hp/m	Then, T = 3.419 m
	Then, Mean of T = 3.621104	
Therefore, the projected tub boat design when the power of the main engine is expected to be 2720hp could have the prdicted dimension of length overall L = 30.48m, Breath B = 9.19m, depth D = 4.35m and draft T = 3.62m as prelimanary principal dimensions from the piont of veiw of current existing tugboat design regression analysisn equation used in this table.		

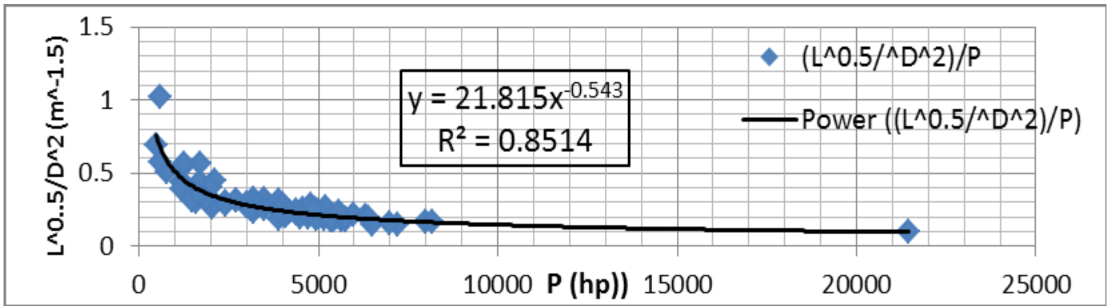

Fig 1. Correlation of $\sqrt{L}/D^2$ variable with power P.

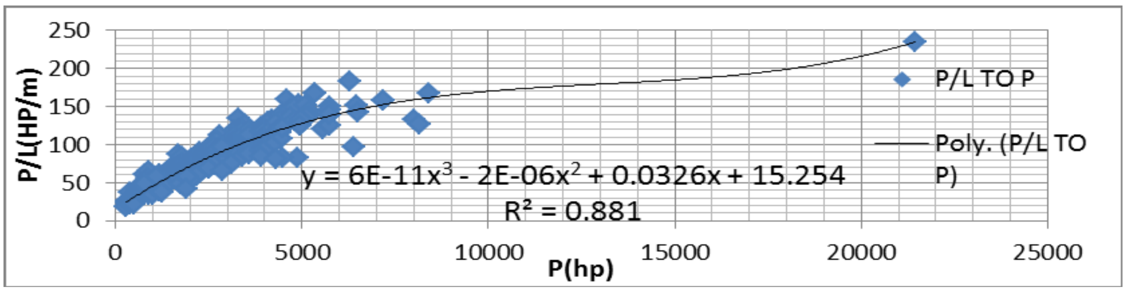

Fig 2. Correlation of P/L variable with power P.

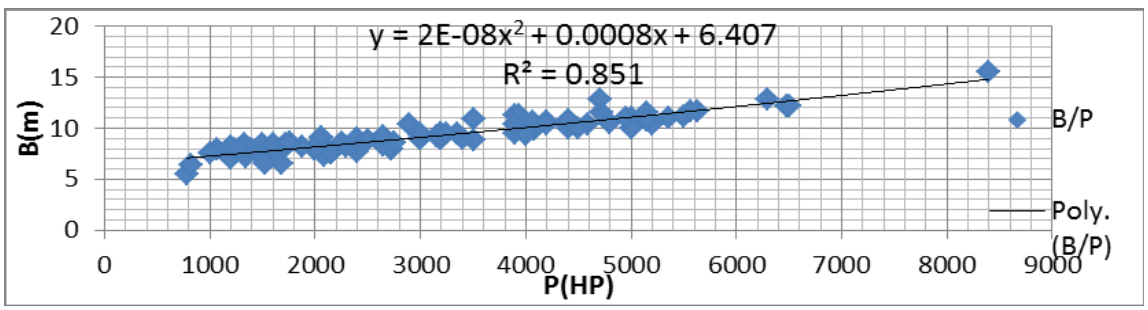

Fig 3. Correlation of B variable with power P.

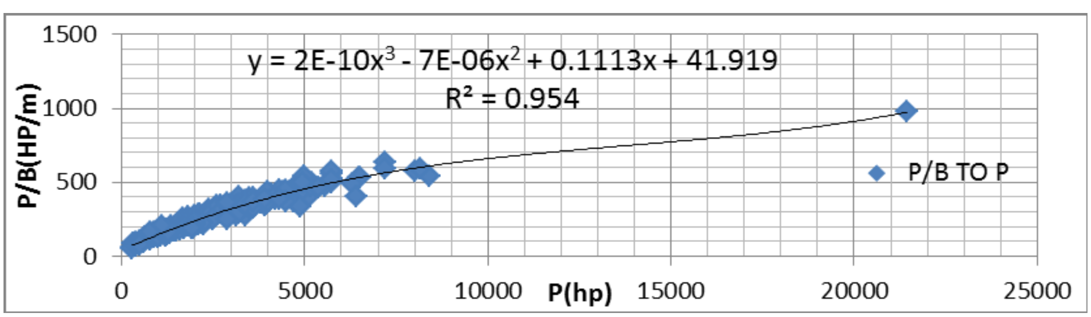

Fig 4. Correlation of P/B variable with power P.

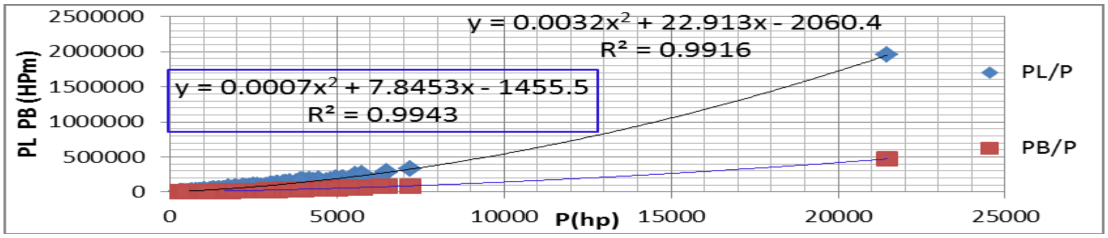

Fig 5. Correlation of PL and PB variables with power P.

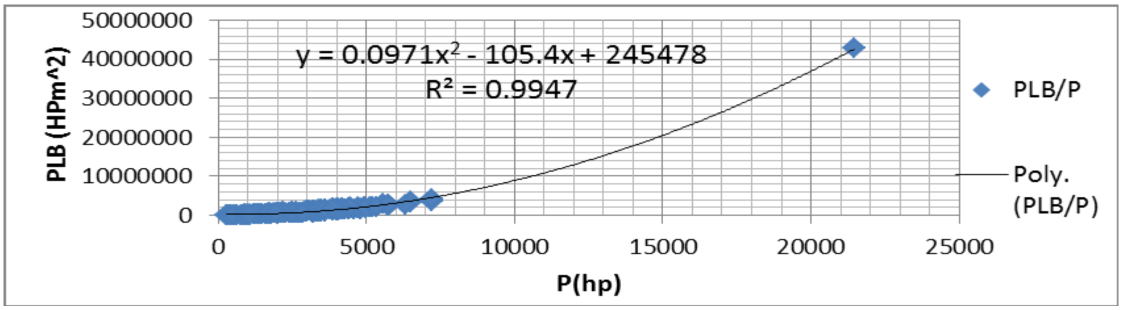

Fig 6. Correlation of PLB variable with power P.

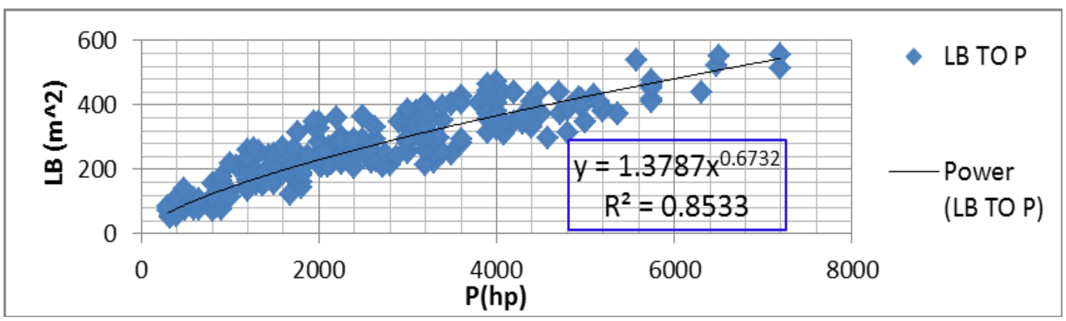

Fig 7. Correlation of LB variable with power P.

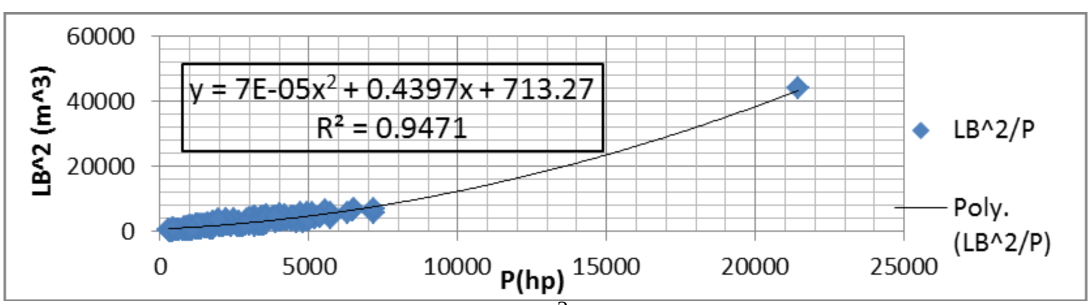

Fig 8. Correlation of LB^2 variable with power P

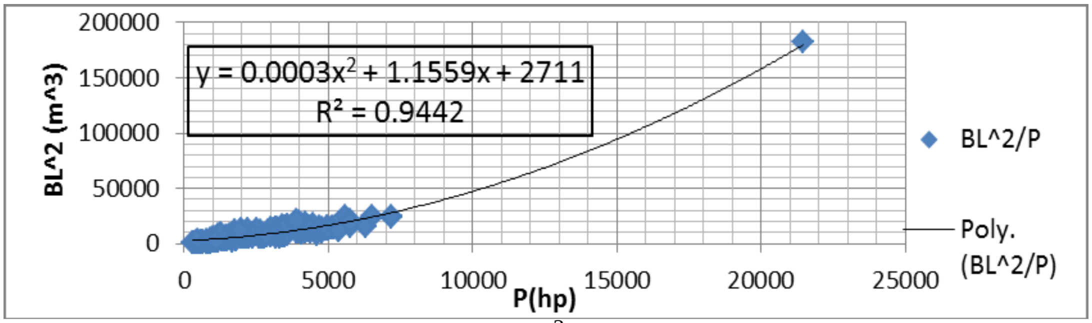

Fig 9. Correlation of BL^2 variable with power P.

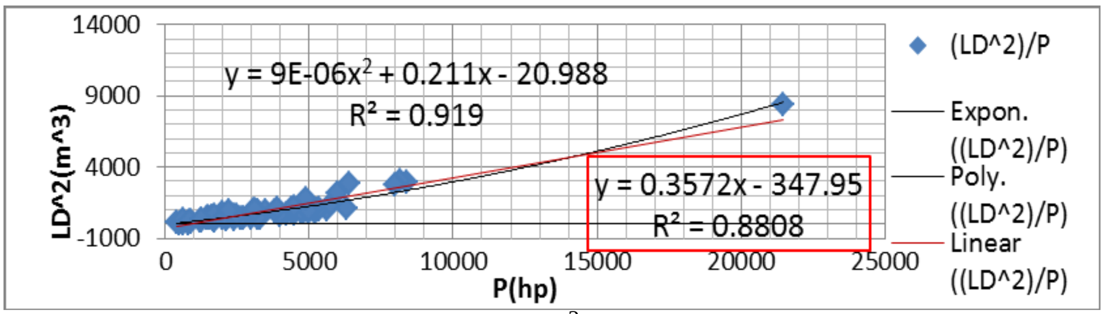

Fig 10. Correlation of LD^2 variable with power P.

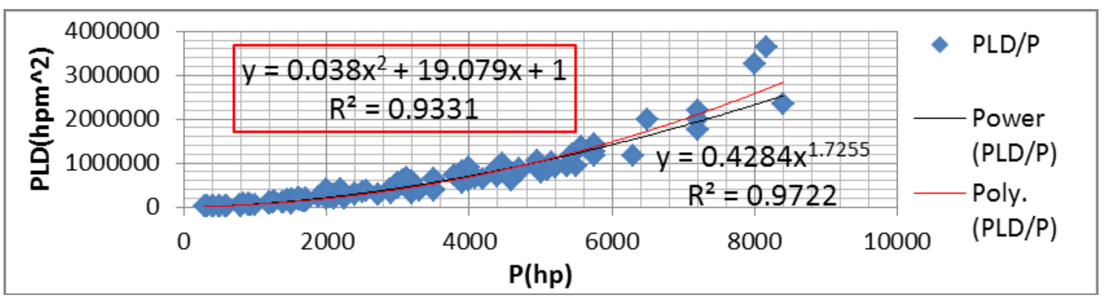

Fig 11. Correlation of PLD variable with power P.

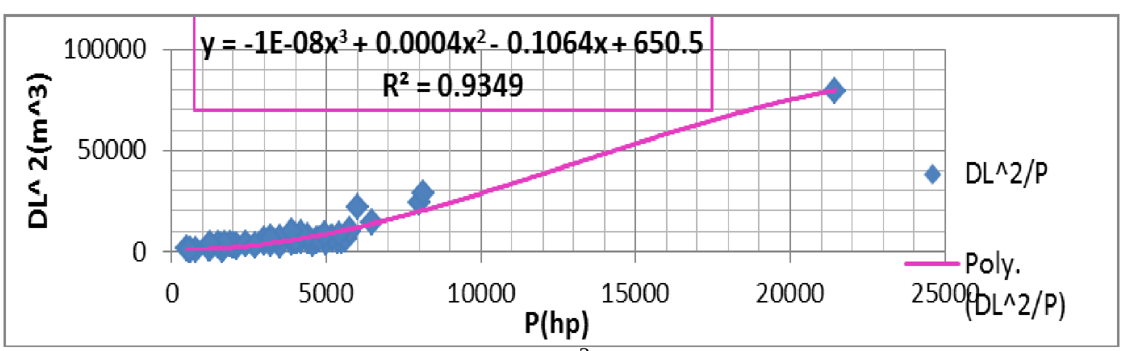

Fig 12. Correlation of DL^2 variable with power P.

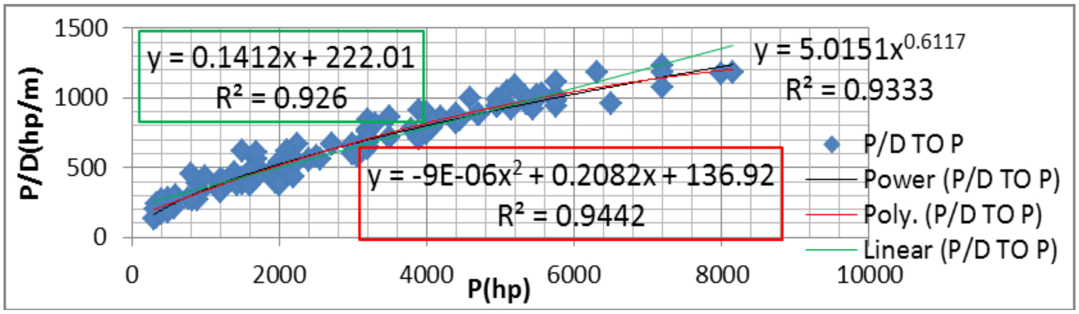

Fig 13. Correlation of P/D variable with power P.

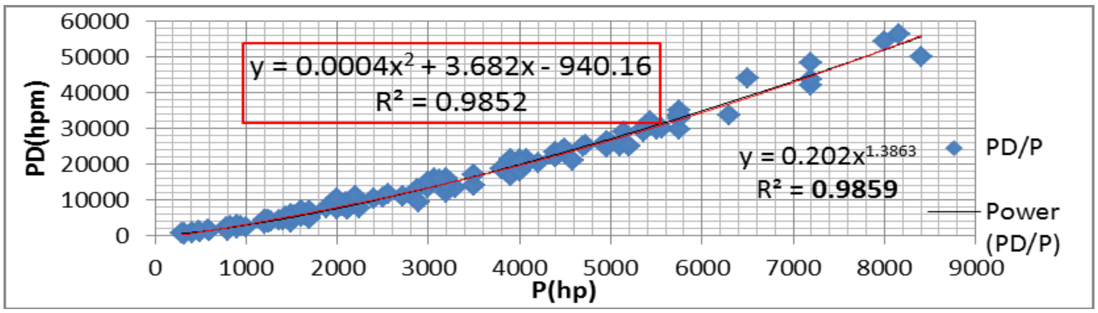

Fig 14. Correlation of PD variable with power P.

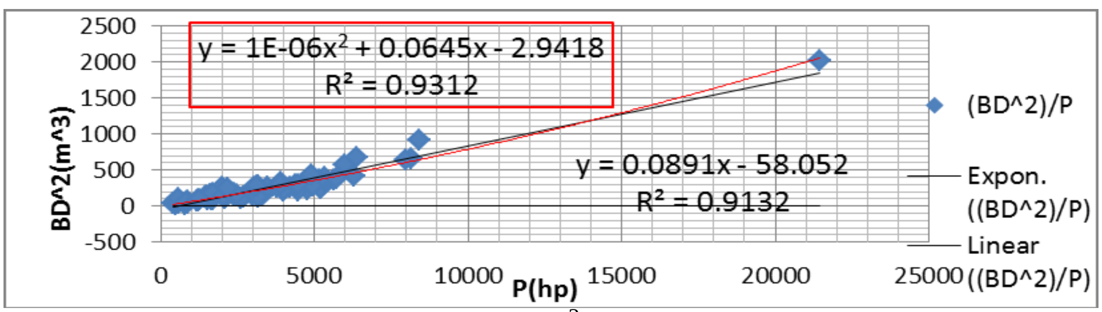

Fig 15. Correlation of BD^2 variable with power P.

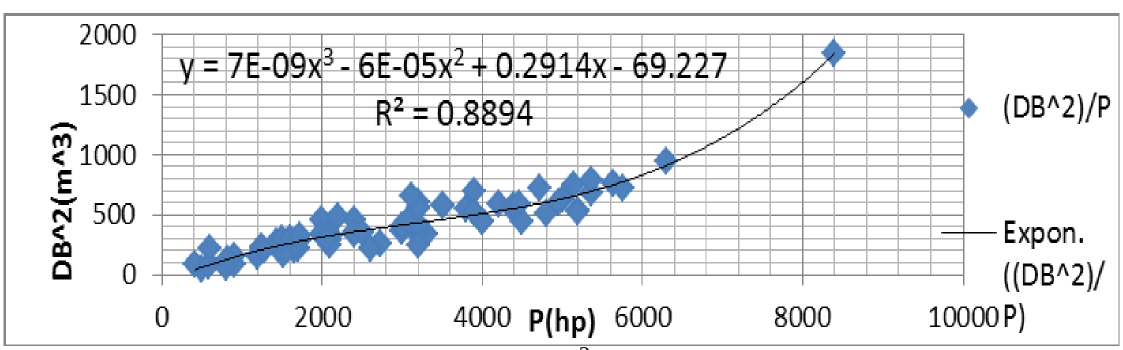

Fig 16. Correlation of DB^2 variable with power P.

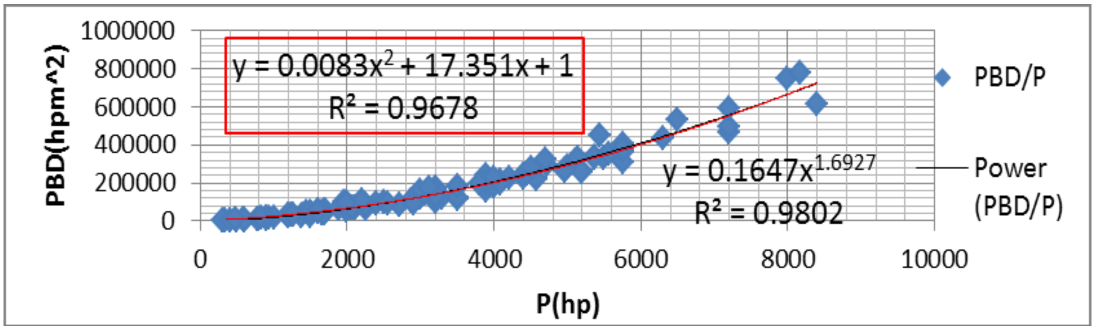

Fig 17. Correlation of PBD variable with power P.

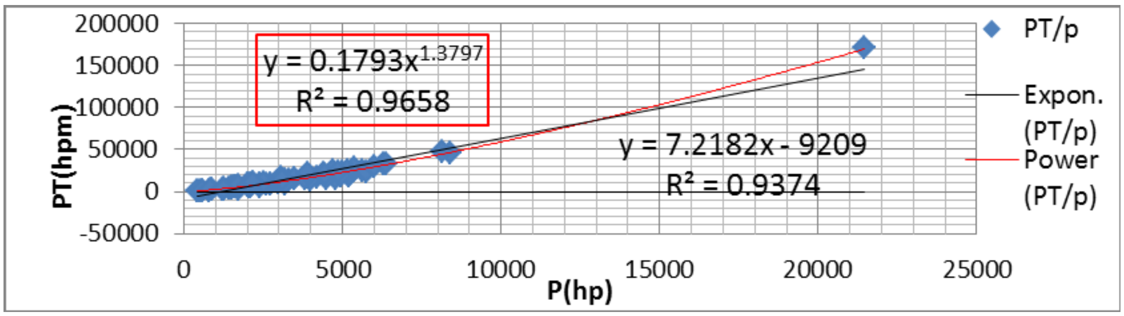

Fig 18. Correlation of PT variables with power P.

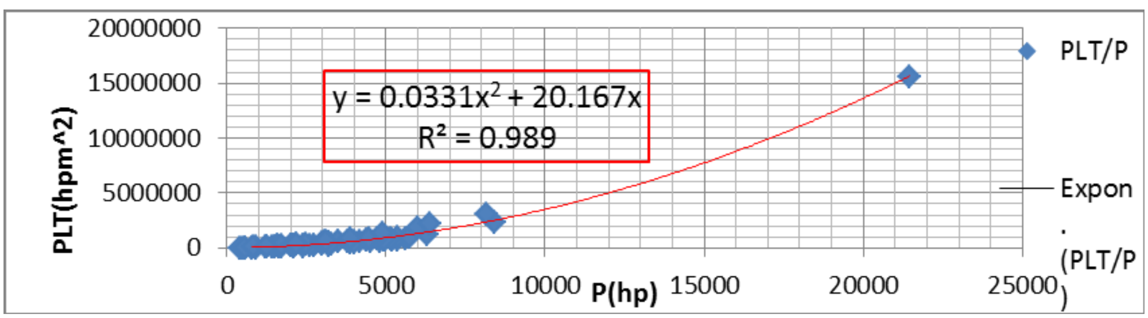

Fig 19. Correlation of PLT variable with power P.

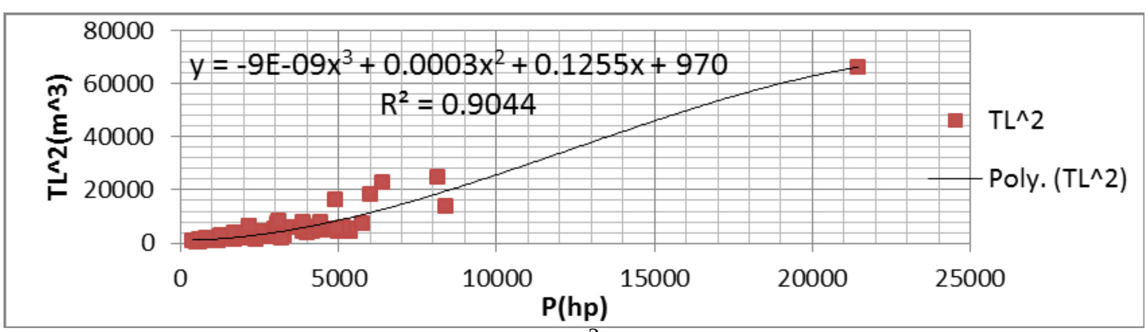

Fig 20. Correlation of TL^2 variable with power P.

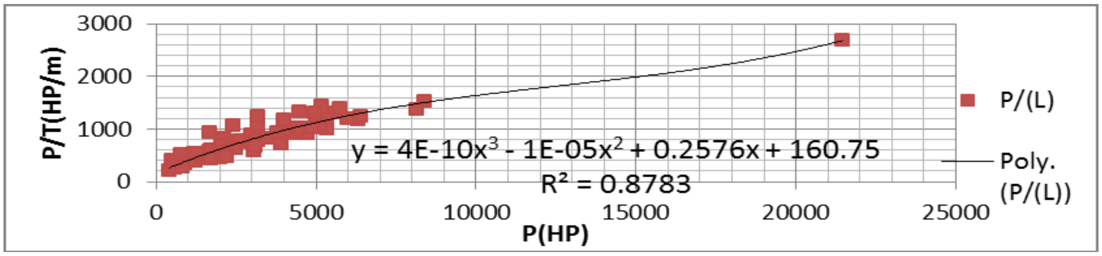

Fig 21. Correlation of P/T variable with power P.

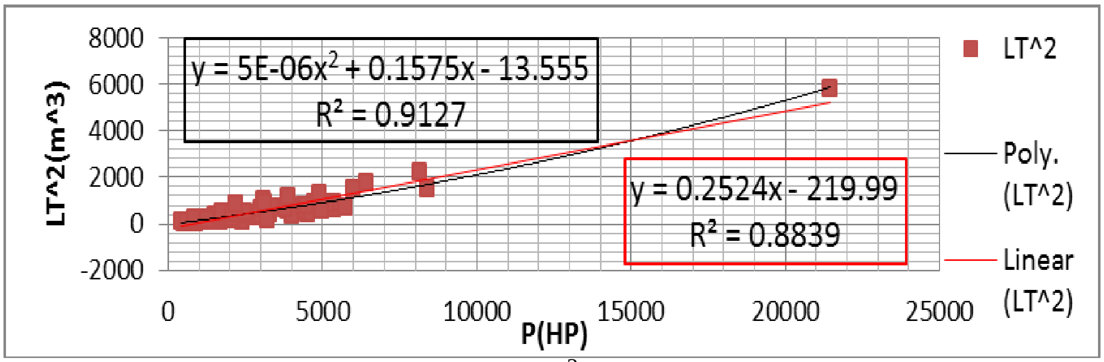

Fig 22. Correlation of LT^2 variable with power P.

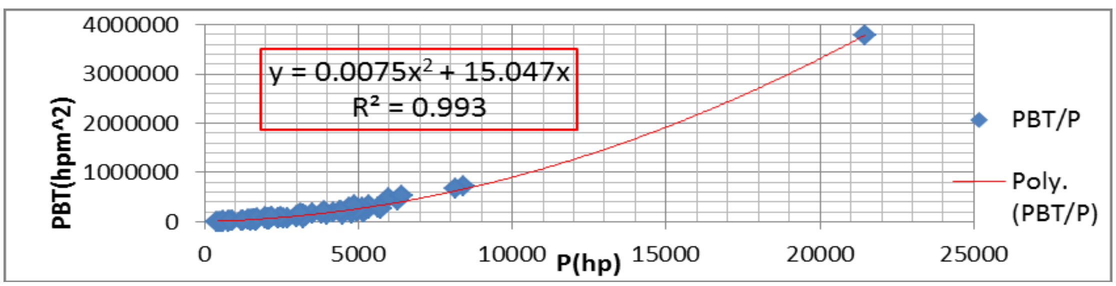

Fig 23. Correlation of PBT variable with power P.

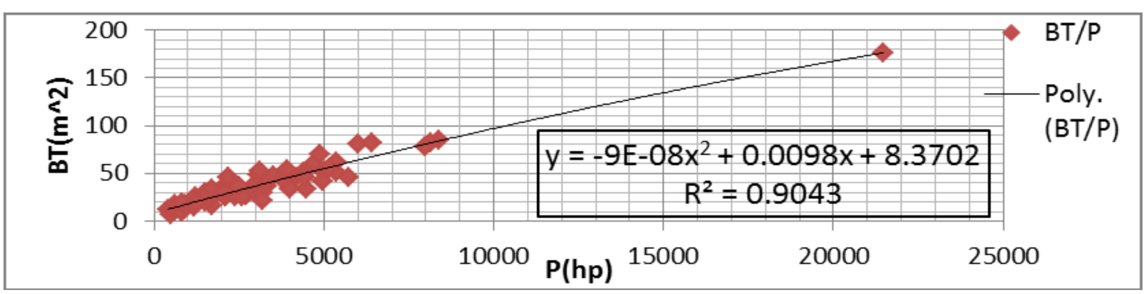

Fig 24. Correlation of BT variable with power P.

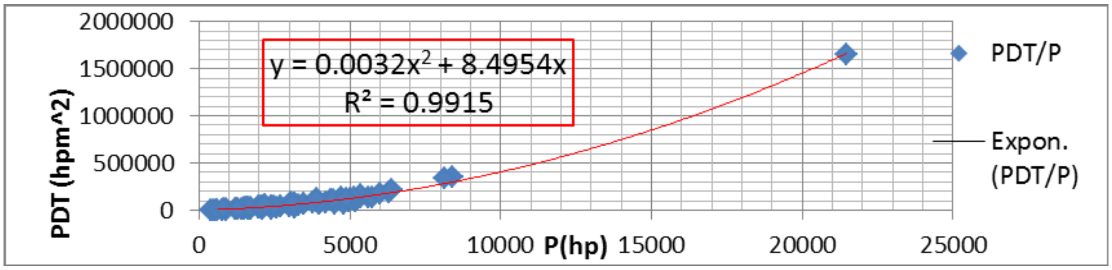

Fig 25. Correlation of PDT variable with power P.

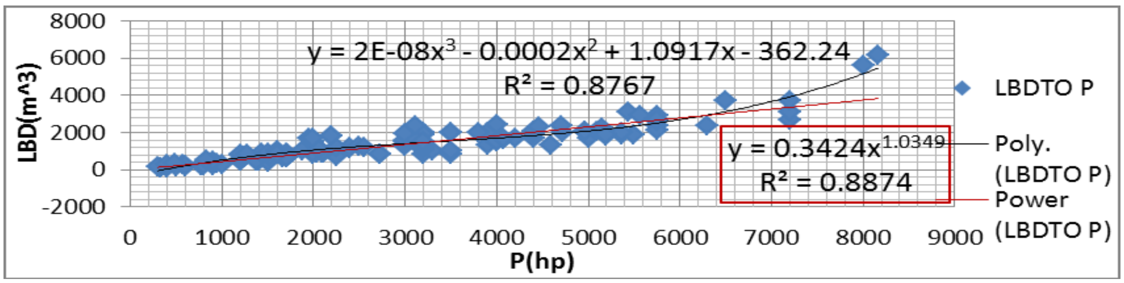

Fig 26. Correlation of LBD variable with power P.

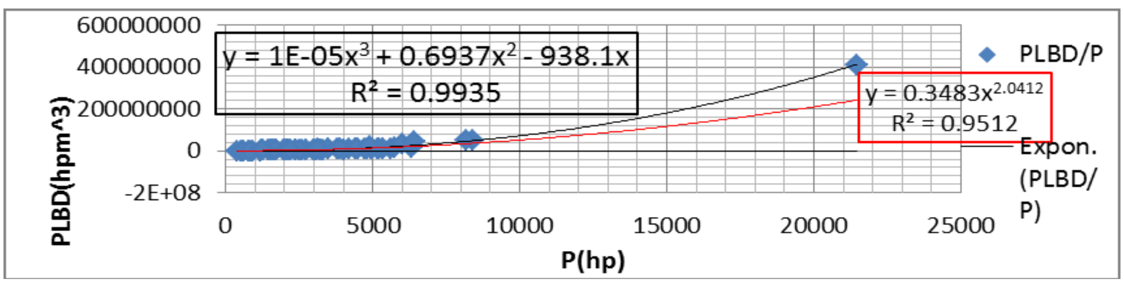

Fig 27. Correlation of PLBD variable with power P.

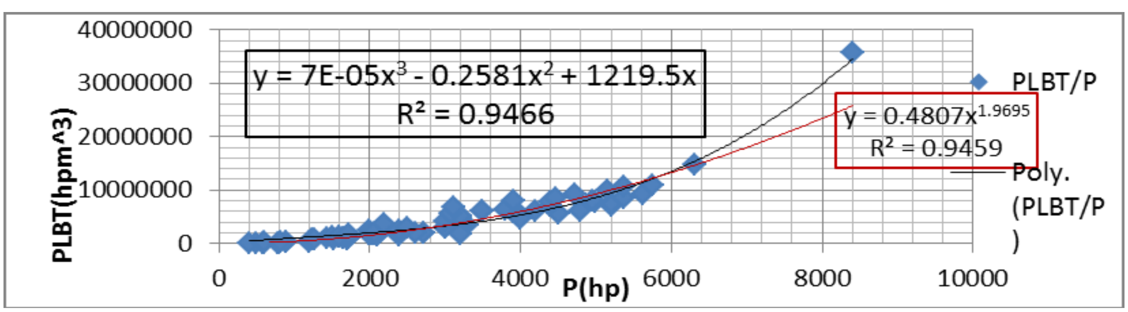

Fig 28. Correlation of PLBT variables with power P.