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Performance Evaluation of Different Small Engines for Agricultural and Fishery Machinery Application

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ABSTRACT

The enactment of the Agriculture and Fisheries Mechanization Law of 2013 increased the demand for the testing and evaluation of small engines in the Philippines. This is in line with the promotion of agricultural mechanization in the Philippines as the country's response to the growing concerns in food production. This study sought to evaluate and compare the performance of small engines tested by the Agricultural Machinery Testing and Evaluation Center (AMTEC) from 1986 to 2019 with the minimum requirements set forth in PAES 116: 2001 (Small Engine-Specifications). A total of 778 engines were analyzed in the study through AMTEC test data: 258 gasoline engines, 157 air-cooled diesel engines, and 363 water-cooled diesel engines. The performance of the small engines were evaluated using four parameters, namely: maximum power at varying load (MBP), percent rated continuous power at rated speed (CBP), noise level (NL), and specific fuel consumption (SFC). Results showed that the average overall engine performance based on the MBP and the NL of both varying and continuous running tests were within the standards. In the performance evaluation scheme analysis, only 317 small engines attained more than the minimum ratings. Diesel water-cooled engines yielded the highest count which complied with the standards in PAES 116: 2001. To further the discussion on the study, analysis of the engine performance can be done in terms of assigning weights on specific parameters and using other different statistical tools such as the Analytic Hierarchy Process (AHP) or Multi Criteria Decision Analysis (MCDA). Other parameters in PAES 116:2001 may also be considered for the development of other evaluation schemes.

***Keywords**: small engine, percent rated maximum power, percent rated continuous power, noise level (NL), specific fuel consumption, agricultural mechanization, AMTEC, PAES 116*

INTRODUCTION

The Philippines has been actively promoting farm mechanization at a national level in response to the increasing demand in food production. The use of agricultural machinery may help in easing the labor and workloads of farmers during various farm operations and increase the capacity and efficiency in agricultural production. Moreover, agricultural mechanization allows a more precise application of inputs and reduces postharvest losses. According to Dela Cruz and Bobier (2013), several indicators used in assessing the level of mechanization of a country include (a) power/unit land (hp/ha), (b) number of tractors/unit land, and (c) mechanical power as a percentage of total power from human, draft animals, and machines.

Although the law on Agriculture and Fisheries Mechanization (AFMech Law or R.A. 10601) was enacted in 2013, mechanization in the Philippines is still only at 3 hp/ha from the 0.75hp/ha in 2010 despite the approved law (Simeon, 2016). The available farm power in the country is mostly concentrated in rice and corn where seventy seven percent (77%) was supplied by mechanical power, six percent (6%) from human power, and seventeen percent (17%) from draft animals (Dela Cruz and Bobier, 2013). Moreover, the study also showed that the major source of the total mechanical power came from prime movers (engines and motors) which could provide a mechanization level of 0.87 hp/ha. Several problems arise in promoting and acquiring sustainable mechanization in the Philippines such as low farm gate prices, high cost of machines, and the lack or inadequate structures to support mechanization such as irrigation structures and farm roads. Moreover, irregular, and small-sized farms common in the Philippines make it inefficient and difficult to maneuver the machines for operations. (Suministrado, 2013; Bautista, et al. 2017).

With the enactment of the RA10601 or "AFMech Law", the Agricultural Machinery testing and Evaluation Center (AMTEC) was designated as the premier and reference testing center of the agricultural and fisheries machineries in the country (Agricultural Machinery Testing and Evaluation Center (AMTEC, n.d.). Over a thousand agricultural machineries such as engines, tractors, pumps, and postharvest machineries were tested and evaluated with the result being published by AMTEC (Resurreccion, et al., 2008). AMTEC has tested more than 2, 350 agricultural and fishery machinery by the end of 2013.

Though there are several machines tested and evaluated by AMTEC, copies of test reports are only available to the one or agency who requested the test. To make all these test data available to everybody, it should be published in other forms such as Test Data Bulletin, compilation, etc. In these publications, it is necessary to compile all important data with well-defined parameters, tables, graphical charts, and categories. It is also necessary to present a less technical and simplified report for consumers and clients that does not have the technical background in evaluating and analyzing the data published by AMTEC. Moreover, with some proper compilations and less technical data, clients, consumers, and researchers can easily understand the methods done in testing and evaluating agricultural and fishery tools and products. Their understanding and eventual feedback on tested products will help in improving the methods done on the research and testing facility at AMTEC.

The study aimed to evaluate the performance of small engines tested by AMTEC from 1986 to 2019.

Specifically, the study aimed to compare and evaluate engine performance based on PAES 116:2001 (Small Engine-Specifications). Furthermore, to validate and apply the existing performance evaluation scheme (Resureccion, et al, 2008) using the data generated from the study. This study may also help AMTEC and other official governing departments recommend pending drafts in updating the standards set on PAES. According to PAES 010-1:2005, standards should be reviewed at regular intervals and revised if deemed necessary. With agricultural machinery being rapidly developed, the current standards may start to get outdated since the existing standards on PAES were developed more than 10-20 years ago.

MATERIALS AND METHODS

Performance Requirements

A total of 845 test report data on small engines from 1986 to 2019 tested and evaluated by AMTEC were obtained and consolidated. Trends and distribution on the small engines were done based on the brand, manufacturer, and country of origin over the past 34 years. The data trends and distribution consisted of the actual test results on percent rated maximum power at varying load, percent rated continuous power at rated speed, noise level, and specific fuel consumption. Moreover, actual performance of the small engines was compared with the standard set in PAES 116:2001 (Table 1) to determine if the engine was within the minimum requirements. As the minimum performance requirement for specific fuel consumption (SFC) is unavailable in PAES 116, the thermal efficiency of small engines was converted to corresponding SFC. The thermal efficiency of 20-25% for gasoline and 24-30% for diesel were then used as reference.

Performance Rating Scheme

A total of four parameters were chosen in evaluating the performance of the small engine. The rationalized criteria of the four parameters for the performance rating of small engines was based on the AMTEC Performance Rating System adopted from the study conducted by Resurreccion, et al (2008).

The criteria for the performance rating of small engines were based on the minimum standard performance specifications stated in PAES 116 and is presented in Table 2. As for the minimum requirement for the SFC, these were based on the lecture notes from Agricultural and Biosystems Power Engineering by Fajardo (n.d.). A rating scale from 2 to 10 was used with 10 being the highest and 2 as the lowest. The final rating points were computed by dividing the total rating points by the number of parameters used.

A final rating point of 6 and above means that the small engine meets the minimum standard performance specifications whereas a score of below 6 means that it fails to meet the minimum requirements. It can be noted that the parameters used have equal weights on the final rating achieved regardless of whether the engine was within the minimum standards set in PAES 116.

RESULTS AND DISCUSSIONS

Small Engine Performance (1995-2019)

The general data from AMTEC consisted of the performances of small engines from 1986 to 2019. Regular and marine engines (engines without mufflers; fishery application) tested were classified and separated. Some analyses were specifically targeted for the data starting from 1995 to 2019 to account for the full throttle setting instructed in PAES 117 to see if the measured data were “within” or “below” the standards set in PAES 116-117.

In terms of maximum and continuous brake power, 73.52% (517 out of 778) and 53.60% (417 out of 778) of the small engines tested was within the standards set in PAES 116:2001, respectively (Table 3) whereas 25.32% (197 out of 778) and 45.50% (354 out of 778) was below the standards, respectively. Nine (9) test reports had no power rating data in varying load tests and seven (7) test reports during the continuous running test. For the noise level during the varying load tests, 52.06% (405 out of 778) of small engines was within the standards set in PAES and about 59% (459 out of 778) under continuous running test (Table 4). About 46.14% (359 out of 778) and 38.82% (302 out of 778) of the engines tested was below the standards set in PAES for varying and continuous running tests, respectively. In the varying load test, 7 reports had no noise level data and 7 were non-readable, while in continuous running test, 15 had no noise level data and 2 were non-readable.

Table 1. Minimum performance requirements for small engines in accordance with PAES 116.

PARAMETER	MINIMUM REQUIREMENT
Percent rated maximum power at varying load (%)	80
Percent rated continuous power at rated speed (%)	80
Noise level (dB)	92

Table 2. Criteria for the performance rating of small engines.

PARAMETER	MINIMUM REQUIREMENT	RANGE OF VALUES	RATING POINTS
Percent rated maximum power at varying load	80	90% and higher	10
		85% to <90%	8
		80% to < 85%	6
		75% to <80%	4
		75% and lower	2
Percent rated continuous power at rated speed	80	90% and higher	10
		85% to <90%	8
		80% to < 85%	6
		75% to <80%	4
		75% and lower	2
Noise level (dB)	92	88.0 and below	10
		88.1 to 90.0	8
		90.1 to 92.0	6
		92.1 to 94	4
		94.1 and above	2
Specific fuel consumption (g/kW-h)	Diesel (@24-30%; 328-263)	<197	10
		197 to <263	8
		263 to <329	6
		329 to <395	4
		>395	2
	(Gasoline) (@20-25%; 389-310)	<231	10
		232 to <310	8
		310 to <389	6
		389 to < 468	4
		>468	2

Table 3. Summary of engine performance based on PAES 116:2001 for engines tested by AMTEC from 1995-2019.

PAES STANDARD	MAXIMUM BRAKE POWER	CONTINUOUS BRAKE POWER
Within PAES Standard	572	417
Below PAES Standard	197	354
No Data	9	7
Total	778	778

Table 4. Summary of noise level performance of engines tested by AMTEC from 1995-2019.

PAES STANDARD	VARYING LOAD TEST	CONTINUOUS RUNNING TEST
Within PAES Standard	405	459
Below PAES Standard	359	302
No Data	7	15
Not Readable	7	2
Total	778	778

Performance of Gasoline Engines

Majority of the gasoline engines tested were manufactured in China (39.92% or 103 out of 258) followed by Japan (17.83% or 59 out of 258), and USA (14.73% or 46 out of 258) (Figure 1). A total of 47 different brands were observed during the period and the average horsepower measured was 9 hp (6.71 kW). The minimum and maximum horsepower observed were 3.5 hp (2.61 kW) and 18 hp (13.42 kW), respectively.

Out of the 258 gasoline engines tested, most of the engines tested was below the maximum and continuous brake power standard set in PAES 116:2001 (Table 5). About 51.55% (133 out of 258) and 69.38% (179 out of 258) of the gasoline engines tested was below PAES standard for varying load and continuous running tests, respectively. Whereas only 47.29% (122 out of 258) and 29.46% (76 out of 258) was within the set standard, respectively. Three (3) test reports had no data regarding the power rating for both tests.

In terms of noise level measurements, the majority of the gasoline engines tested was within the standards set by PAES 116:2001 (Table 6). For varying load tests, 58.14% (150 out of 258) of the engines tested had at least 80% of the rated maximum output power and 60.85% (157 out of 258) for the continuous running test. About 40.7% (105 out of 258) and 37.6% (97 out of 258) was below the PAES standard.

Performance of Air-cooled Diesel Engine

A total of 157 air-cooled diesel engines were tested by AMTEC from 1995-2019 with 61 different brands observed. Majority of the engines tested were

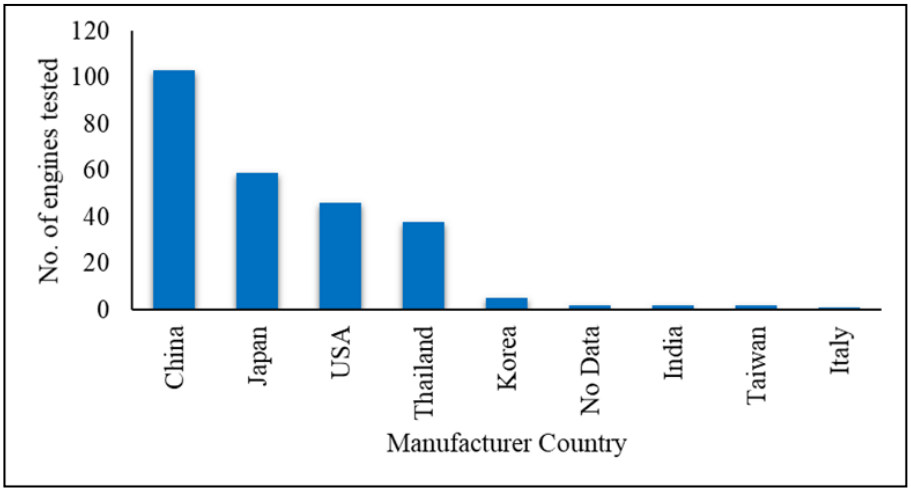

Figure 1. Gasoline engines tested by AMTEC based on manufacturer country from 1995-2019.

Table 5. Summary of engine performance of gasoline engines tested by AMTEC from 1995-2019.

PAES STANDARD	MAXIMUM BRAKE POWER	CONTINUOUS BRAKE POWER
Within PAES Standard	122	76
Below PAES Standard	133	179
No Data	3	3
Total	258	258

Table 6. Summary of noise level performance of gasoline engines tested by AMTEC from 1995-2019.

PAES STANDARD	VARYING LOAD TEST	CONTINUOUS RUNNING TEST
Within PAES Standard	150	157
Below PAES Standard	105	97
No Data	2	3
Not Readable	1	1
Total	258	258

manufactured in China (94 out of 157) followed by Italy (21 out of 157), and Germany (18 out of 157) (Figure 2). The average horsepower measured for air -cooled diesel engines was 10.0 hp (7.46 kW) with minimum and maximum horsepower or 4.0 hp (2.98 kW) and 26 hp (19.39 kW), respectively.

The engine performance of the air-cooled diesel engines for maximum brake power and noise level can be seen in Table 7 and Table 8. For the maximum brake power, 76.43% (120 out of 157) and 54.78% (86 out of 157) was within the standard set in PAES 116:2001 for varying load and continuous running tests, respectively.

Whereas 21.02% (33 out of 157) and 45.22% (71 out of 157) was below the standard set in PAES, respectively. In terms of noise level performance, the majority of the air-cooled diesel engines performed below the standard set in PAES of not more than 92 dB. During varying load tests, 59.87% (94 out of 157) was below the standards set in PAES and 51.59% (81 out of 157) during continuous running tests. Only 38.22% (60 out of 157) and 47.13% (74 out of 157) of the engines tested performed within the PAES.

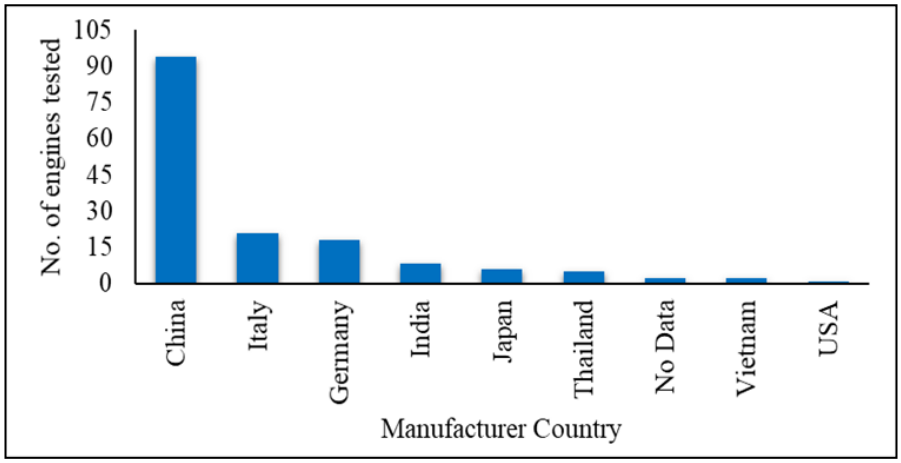

Figure 2. Number of air-cooled diesel engines tested by AMTEC based on manufacturer country from 1995-2019.

Performance of Water-cooled Diesel Engine

Majority of the engines tested fby AMTEC from 1995-2019 were water-cooled diesel engines with 363 test reports and around 68 different brands. Most of the engines were manufactured in China (93 out of 363) followed by Thailand (82 out of 363), and Vietnam (58 out of 363) (Figure 3). The average horsepower measured was 10 hp (7.46 kW) and the minimum and maximum horsepower observed were 5 hp (3.73 kW) and 26 hp (19.39 kW), respectively.

For the maximum and continuous brake performance, most of the engines tested was within the performance requirement of at least 80% of the

Table 7. Summary of engine performance of air-cooled diesel engines tested by AMTEC from 1995-2019.

PAES STANDARD	MAXIMUM BRAKE POWER	CONTINUOUS BRAKE POWER
Within PAES Standard	120	86
Below PAES Standard	33	71
No Data	4	---
Total	157	157

Table 8. Summary of noise level performance of air-cooled diesel engines by AMTEC from 1995-2019.

PAES STANDARD	VARYING LOAD TEST	CONTINUOUS RUNNING TEST
Within PAES Standard	60	74
Below PAES Standard	94	81
No Data	2	2
Not Readable	1	---
Total	157	157

rated maximum output power both in varying load test (90.91% or 330 out of 363) and continuous running test (70.25% or 255 out of 363) (Table 9). Only 8.54% (31 out of 363) and 28.65% (104 out of 363) of small engines tested was below the standards set in PAES under varying load tests and continuous running tests, respectively. As for the noise level, 53.72% (195 out of 363) and 62.81% (228 out of 363) of small engines tested performed within the standards set of below 92dB whereas 44.08% (160 out of 363) and 34.16% (124 out of 363) was below the standards set by PAES for varying load and continuous running tests, respectively (Table 10).

General Statistics for Engines Tested from 1995-2019

Out of 778 small engine AMTEC test reports from 1995-2019, there are 590 unique engines tested, and 762 engines tested were easy to start. Table 11 shows the overall performance of the engines tested from 1995-2019 based on minimum, maximum, and average values.

On the average, the engine performance based on the maximum and continuous brake power and the noise level of both varying load test and continuous running test were within the standard set in PAES 116:2001 of at least 80% of the rated maximum output power and not more than 92 dB of the noise emitted by the engine.

Performance Evaluation Scheme

The previous study conducted by Resurreccion, et.al. (2008) developed rationalized criteria for the performance rating of agricultural machinery. The performance evaluation scheme or point system established in the study of Resurreccion, et.al.

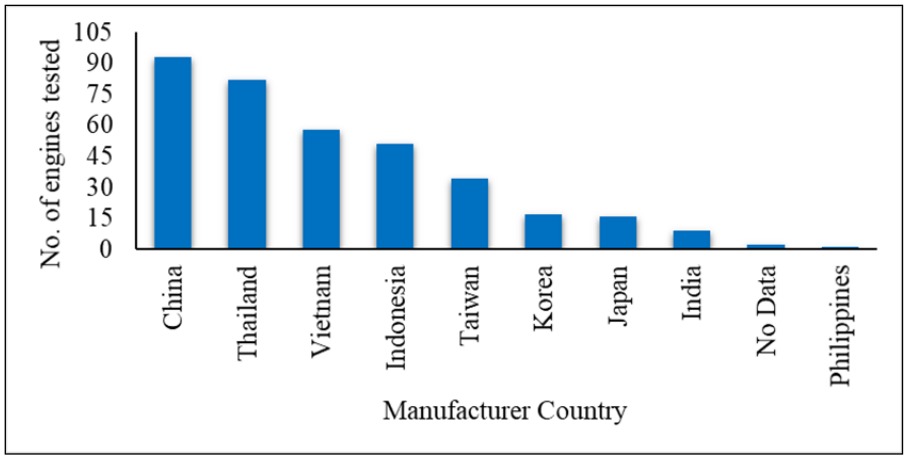

Figure 3. Number of water-cooled diesel engines tested by AMTEC based on manufacturer country from 1995-2019.

Table 9. Summary of engine performance for water-cooled diesel engines tested by AMTEC from 1995-2001.

PAES STANDARD	MAXIMUM BRAKE POWER	CONTINUOUS BRAKE POWER
Within PAES Standard	330	255
Below PAES Standard	31	104
No Data	2	4
Total	363	363

Table 10. Summary of noise level performance of water-cooled diesel engines tested by AMTEC from 1995-2019.

PAES STANDARD	VARYING LOAD TEST	CONTINUOUS RUNNING TEST
Within PAES Standard	195	228
Below PAES Standard	160	124
No Data	3	10
Not Readable	5	1
Total	363	363

(2008) was adopted and evaluated using the data generated in the study. The performance evaluation scheme was set by allocating different rating points on different parameters such as specific fuel consumption, power ratings, and noise level of small engines.

Table 12 showed the test report counts for each rating point based on power ratings, SFC, and noise level. For varying load tests, 46.29% (356 out of 769) of all small engines except for those test reports with No Data and Not Readable earned the highest point in terms of maximum brake power whereas the majority of the engines has a rating point of 6 (27.05%, 208 out of 769) and 2 (27.7%, 213 out of 769) in terms of continuous brake power.

Under varying load tests, the majority of the engines' SFC has a rating of 2 (52.8%, 405 out of 767) as well as its noise level performance (33.2%, 256 out of 771). As for the continuous running test, the majority of the engines has a rating of 6 (41.68%, 318 out of 763) and a rating of 10 (27%, 206 out of 763) for the noise level performance. Overall, the majority of the engines performed within the rating score of 6 and above except for SFC at varying load test where 72.75% (553 out of 767) of all the engines tested earned a rating score of below 6 (Table 13).

After assigning the rating points of the small engine based on its performance, the average weighting of the six parameters was computed to determine the number of test reports that was within the minimum and above minimum rating points regardless of whether the engine performance was within the standard set in PAES 116. The result of the weighted average of the engine performance can be seen in Table 14. Majority of the engines was below the minimum requirement (57.51% or 429 out of 746 small engines).

Whereas only 34.85% (260 out of 746) and 7.64% (57 out of 746) was above and within the minimum requirement, respectively. Out of the 317 small engines with minimum and above minimum ratings, the type of engine based on the cooling system was determined and is summarized in Table 15. Diesel water-cooled engines have the highest total number of engines (61.83% or 196 out of 317) that was within the minimum and above minimum rating points regardless of whether the engine satisfied the standard set in PAES 116.

Table 11. Summary of the overall engine performance from 1995-2019 based on AMTEC test.

OVERALL	MIN	MAX	AVE
Ratio of maximum output power to rated power (varying load test), %	44.00	139.70	87.80
SFC (varying load test), g/kW-h	185.70	2041.10	512.53
Noise emitted (varying load test), dB	76.50	107.50	91.99
Ratio of maximum output power to rated power (continuous running test), %	9.12	124.65	77.89
SFC (continuous running test), g/kW-h	2.83	1811.70	362.64
Noise emitted (continuous running test), dB	3.40	109.20	90.83

Table 12. Number of engines per rating points based on its performance based on AMTEC test.

RATING POINTS	VARYING LOAD TEST			CONTINUOUS RUNNING TEST		
	Maximum Brake Power	SFC	Noise Level	Continuous Brake Power	SFC	Noise Level
10	356	1	149	69	13	206
8	98	45	111	140	115	124
6	118	168	145	208	318	129
4	83	148	110	139	182	117
2	114	405	256	213	135	187
No Data	9	5	7	9	14	15
Not readable	---	6	---	---	1	---

continuous running tests. As for water-cooled diesel engines, 363 samples were observed. Most of the engines tested was within the maximum power standards set in PAES as well as for the noise level.

In the performance evaluation scheme analysis, the majority of the engines performed within the rating score of 6 and above except for SFC at varying load tests. Moreover, only 317 small engines was within the minimum and above minimum ratings. In terms of type of engines based on cooling systems, diesel water-cooled engines have the highest total number of engines regardless of whether the engine satisfies the standard set in PAES 116. Moreover, diesel water-cooled engines also had the highest count of engines that satisfy the standards set in PAES 116.

RECOMMENDATION

Based on the evaluated performance rating scheme, further analysis of the engine performance can be done in terms of assigning weights on specific parameters (i.e., output power at rated speed, noise level, and specific fuel consumption). The use of different statistical analysis such as the Analytic Hierarchy Process (AHP) or Multi Criteria Decision Analysis (MCDA) can be useful tools in expanding the limitations of the study.

Further calibrations can be made in terms of weight percentages of specific parameters used in the study. Moreover, development of evaluation scheme/ system may consider other different parameters in the standards set in PAES.

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