

Test Report and analysis

Akos Ferencz

TBK100



TBK100

Engine duration testing

CROPELL ECO INNOVATION Ltd.
6621 Derekegyház, Foltényi Major

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Introduction

TBK100 is a Biofuel with main purpose to replace fossil diesel. It is functioning like Biodiesel as used mainly in compression ignition engines but can be produced with better condition.

Since many years Cropell Eco Innovation Ltd. develops small scaled vegetable oil fueled combined heat and power generators called Crofter MiniPowerStation. These machines are perfectly suited for engine lab testing and measuring of various oil types.

The test were carried out on a Crofter 6131 type equipment as data collecting, preliminary test, and 100 hours duration run.

This report contains the acquired data and analysis.

Tests to be done

No.	Test	Type of data report
	The test runs on an electrically braked bench, the compression ignition engine coupled to a generator which has artificial load on	
1.	The generated power in time, kWh	Test report
2.	Specific fuel consumption, g/kWh	Test report
3.	Thermal balance based on manual records	Thermal diagrams of the data
4.	Cold emission/soot test	Print outs of the emission/soot control device
5.	Warmed up emission/soot test	Print outs of the emission/soot control device
6.	Status control of parts that were in contact with TBK at the end of the run	Test report, photos
7.	Test 1-5. should be carried out with TBK100 and commercially available diesel in 2010 as control.	

The coupled generator of the Crofter CHP was connected with more artificial loads to gain various engine load levels. As the levels were stabilized data were recorded according to the table above. Due to their large volume the raw data are presented as an appendix, the present document describes their analysis mainly.

The samples of TBK100 fuel were produced by the client in 2x50L container.

The control tests were carried out with a commercially available summer diesel with 4,4% biodiesel content. This blended fuel is referred to further on as "Diesel" in this document.

Both fuels were used in their pure form at ambient temperature, non-mixed, settled and unfiltered. The fuel system of the engine was cleaned up at the exchange of fuels, before the measurements were done.

Test bench

The picture below shows the test engine arrangement.



An engine and a generator with 0 workhours were built in for testing purposes.

The tests were carried out in May and June of 2010 at Foltényi Major, the location of Cropell Ltd.

Test equipment data

EQUIPMENTS			
MINICHIP		TYPE	CROFTER 6131
	MAIN PARTS		
	ENGINE		
		ENGINE NO.	NO: 3791
		TYPE	Crofter 61
		IGNITION	compression, prechamber
		POWER	4,5 kW
		ENGINESPEED	650 rpm
		BORE	114,3 mm
		STROKE	139,7 mm
		VOLUME	1433 cm ³
		NO. OF CYLINDERS	1
		COMPRESSION RATIO	18:1
		WEIGHT	365 kg
		COOLING	water
		SPEED REGULATION	weight balance
		FUEL PUMP	plunger type
		INJECTOR	1 hole nozzle, 120 bar
	GENERATOR		
		NO	
		TYPE	ST3
		POWER	3 kW
		ROTATING SPEED	1500 rpm
		WORKING PRINCIPLE	synchronous
		VOLTAGE REGULATION	automatic
		POWER FACTOR	0,83
		EFFICIENCY	0,75
	WATERTANK		
		VOLUME	ca. 200L
		COOLING METHOD	open surface evaporation
		CIRCULATION METHOD	no pump, thermosyphon
		TEMP RECORDING PLACE	inlet from engine
	EXHAUST		
		DIAMETER	6/4 inch tube
		LENGTH	300mm, 1x90° knee
		SILENCER	metal mesh, displaced during emission and soot test
		EMISSION RECORDING PLACE	at 150mm, perpendicular to stream
LOADS			
		PRINCIPLE	induction and ohm
		POWER	various 200W-3000W
RECORDERS			
LOAD			
	POWERMETER		
		NO	500810398
		TYPE	ACTARIS, 3F, C114UR1D
		WORKING PRINCIPLE	analog net meter
		ACCURACY	0,01 kWh
	ENERGY MONITOR		
		NO	9149
		TYPE	ENERGY MONITOR 072006

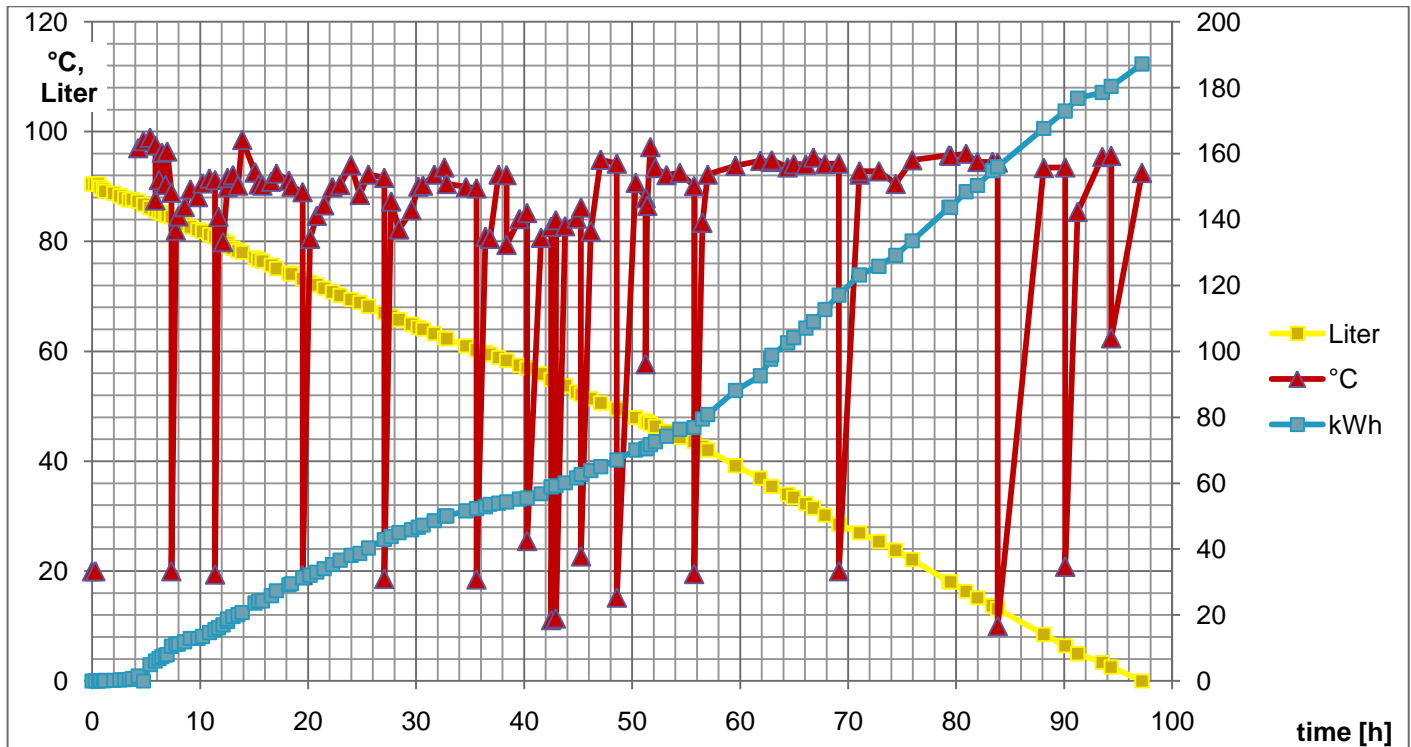
		WORKING PRINCIPLE	digital, power consumption
		ACCURACY	0,01 kWh
	FUEL SCALE		
		NO	WLO742468
		TYPE	Kern&Sohn, DE 150K 50N
		WORKING PRINCIPLE	digital
		ACCURACY	0,01 kg
	WATER TEMP METER		
		NO	n.a.
		TYPE	digital
		WORKING PRINCIPLE	external temp sensor
		ACCURACY	0,1 °C
	EXHAUST TEMP METER		
		NO	0853 6007
		TYPE	Würth Infrared Thermometer
		WORKING PRINCIPLE	infrared temp meter
		ACCURACY	10 °C, 50-350 °C
	EMISSION RECORDER		
		NO	SE0914013
		02 DEVICE NO	A165455
		NOx DEVICE NO	04.13944887.059
		TYPE	Protech, IPEX1
		WORKING PRINCIPLE	exhaust gas analyzer
		ACCURACY	0,001 %vol, 1 ppm
	SOOT RECORDER		
		WORKING PRINCIPLE	white cloth



Test sequence

Normally the recordings were started in the morning and finished by afternoon or in the evening. Therefore the time based temperature diagram starts with the ambient morning temperature.

During the test the average outside temperature was low that may degrade the data gained. However this effect was not counted in the analysis.



The coupled watertank cools by open surface evaporation. Therefore the water temperature was determined by the ambient conditions and not by the engine load, thus we may regard it as constant.

The starting values of every day were recorded with a time stamp of 0 hours and 0 min. Generated power cannot be calculated in these points consequently.

Cold start

Obviously every morning the engine and the fuel were of ambient temperature. Often this temp was around 10°C degree which is regarded as cold start even for Diesel fuel.

Despite of the cold the engine was started at the first compression stroke that corresponds to good cold atomization ability.

No direct measurement was taken about it, but the experiences reflect an objective view.

TBK100 performed well during cold start conditions.

Log book

Data measured were recorded manually during the test in a log book. The log book was converted into an MS Excel table in order to evaluate and document them. A typical part is shown below.

#	dátum é.h.n	idő óra	perc	óra	interval óra	absz. idő óra	üzemanyag kg	fogyás kg	fogyás Liter	absz. Fogyás Liter	átlag terh W	mérő 1F kWh	óraállás 3F kWh	mechanikai kWh	termelt kwh	absz term kWh	fajlagos g/kWh	Tvíz °C	Tkipuf °C	
31	2010.05.10	8:45	0	-		11,38	7,55	-	-	80,83		-	-	-		15,59		19,4	15	
32			19	0,32	0,32	11,70	7,25	0,30	0,33	80,50	38%	0,30	0,54	0,54		16,13	560	84,5	134	
33			44	0,73	0,42	12,12	6,90	0,35	0,39	80,11	47%	0,80	1,43	0,89		17,02	392	79,9	148	
34			9	1,15	0,42	12,53	6,50	0,40	0,44	79,67	58%	1,40	2,50	1,07		18,09	373	89,9	150	
35		10:33	0	-		12,53	6,05	0,45	0,50	79,17		1,80	3,21	0,71		18,81	630	91,6	98	
36			30	0,50	0,50	13,03	5,65	0,40	0,44	78,73	31%	2,20	3,93	0,71		19,52	560	92,1	131	
37			58	0,97	0,47	13,50	5,30	0,35	0,39	78,34	29%	2,55	4,55	0,62		20,15	560	90,2	124	
38			22	1,37	0,40	13,90	5,00	0,30	0,33	78,01	36%	2,90	5,18	0,63		20,77	480	98,5	127	
39			2	33	2,55	1,18	15,08	4,10	0,90	77,02	53%	4,50	8,04	2,86		23,63	315	92,6	151	
40			0	-		15,08	9,55	-	-	77,02		4,50	8,04			23,63		92,6	111	
41			20	0,33	0,33	15,42	9,25	0,30	0,33	76,69	36%	4,80	8,57	0,54		24,17	560	90,4	130	
42			41	0,68	0,35	15,77	9,00	0,25	0,28	76,41	11%	4,90	8,75	0,18		24,34	1400	90,2	107	
43			1	30	1,50	0,82	16,58	8,35	0,65	75,69	42%	5,75	10,27	1,52		25,86	428	90,9	141	
44			1	59	1,98	0,48	17,07	7,80	0,55	0,61	75,08	69%	6,60	11,79	1,52		27,38	362	92,4	167
45			3	8	3,13	1,15	18,22	7,05	0,75	0,83	74,25	36%	7,60	13,57	1,79		29,17	420	91,1	123
46			3	23	3,38	0,25	18,47	6,90	0,15	0,17	74,09	31%	7,80	13,93	0,36		29,52	420	90,0	124
47		17:39	4	24	4,40	1,02	19,48	6,10	0,80	0,88	73,20	40%	8,80	15,71	1,79		31,31	448	89,0	142

The log book has date and time line, and contains all data with their available range.

Next to the records the data table has columns with calculated values like: time interval, absolute test time, consumption [liter], mechanical load, etc.

During the analysis both raw data and calculated values were used for setting diagrams and equations.

The fuel tank of the test equipment has a volume of 10 liter that was often refilled. Therefore the record of fuel weight is not linear but fluctuating. Similarly the testing time record is dashed, every run started with 0 hour and 0 min timestamp.

A single phase plug in Energy meter was used to record the gained power at the beginning of the testing period. However this method appeared instable and after a few testing times it was replaced by an analog net meter with 3 phase capability. Thanks to that the measured power has two record columns in the table without overlap ("mérő 1F", "óraállás 3F"). At the end of the testing period a control run was done in order to compare the two methods: whether they show the same value in the same time interval with the same load. The same value was recorded is this control measurement.

The specific weights of the two fuels differ consequently the same fuel weight correspond to alteration in volume [liter].

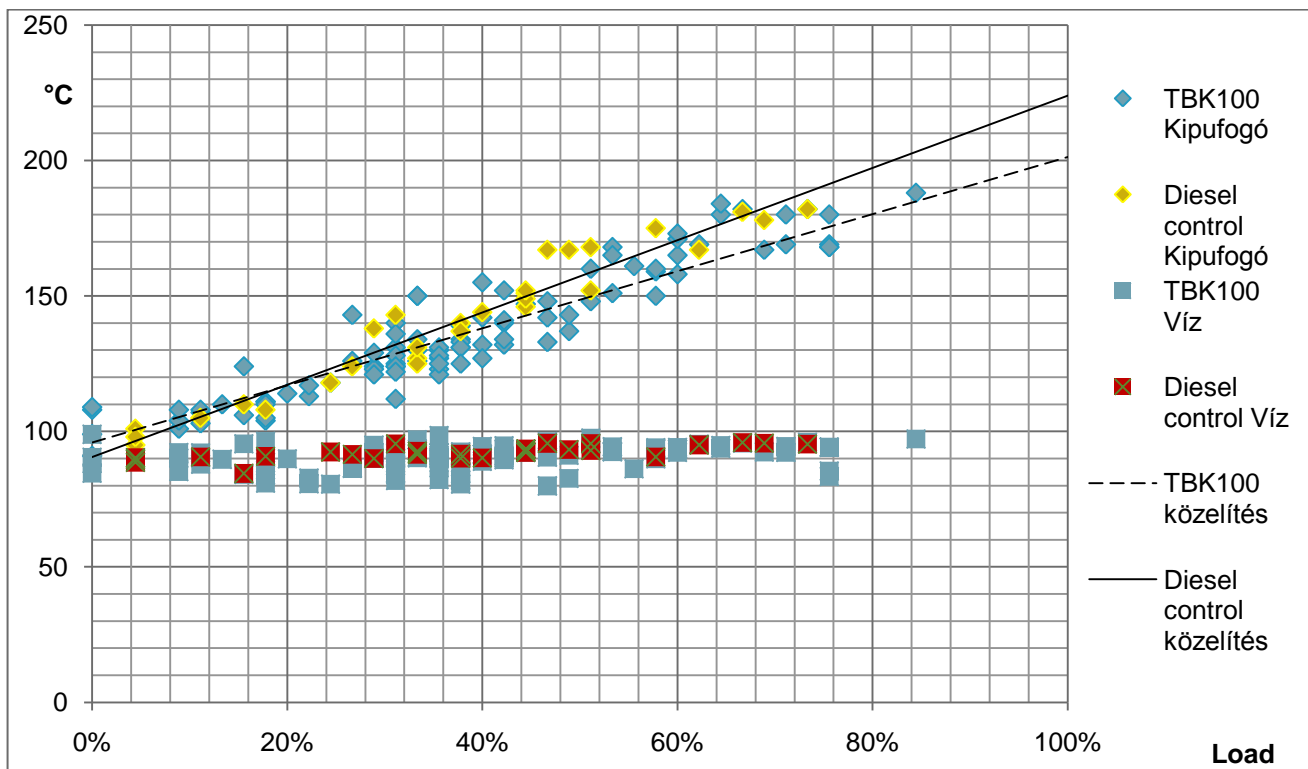
The electric power produced by the generator had an almost constant power factor of 0,8-0,85 for all loads and fuels. Further on according to the data book of the generator it's electrical efficiency is 75%, another constant value for all load and fuel. Therefore we used these values (0,83 és 0,75) as constant failures for the electrical production in order to calculate the real mechanical load of the engine. The result is shown in the column of mechanical load: "mechanikai" [kWh].

The nominal mechanical power of the engine is 4,5 kW. The coupled generator has 3 kW electrical output, calculated with 75% efficiency that equals to 4 kW mechanical load. This load is 80% of the total engine power. Consequently we could not apply higher loads during the test, but this corresponds with the practice.

Thermal balance

The thermal balance of the engine is displayed versus load.

As it was mentioned earlier, due to the cooling method the water temperature can be viewed as constant. This is shown in the diagram as well. The water temperature (“Víz”) level is nearly 95°C in all cases; therefore the thermal balance is represented by the exhaust gas (“Kipufogó”) temperature. This is shown below.



Analysis of the diagram

With the raise of the load the exhaust gas temperature is linearly increasing. The rate of the inclination is nearly the same for both fuels.

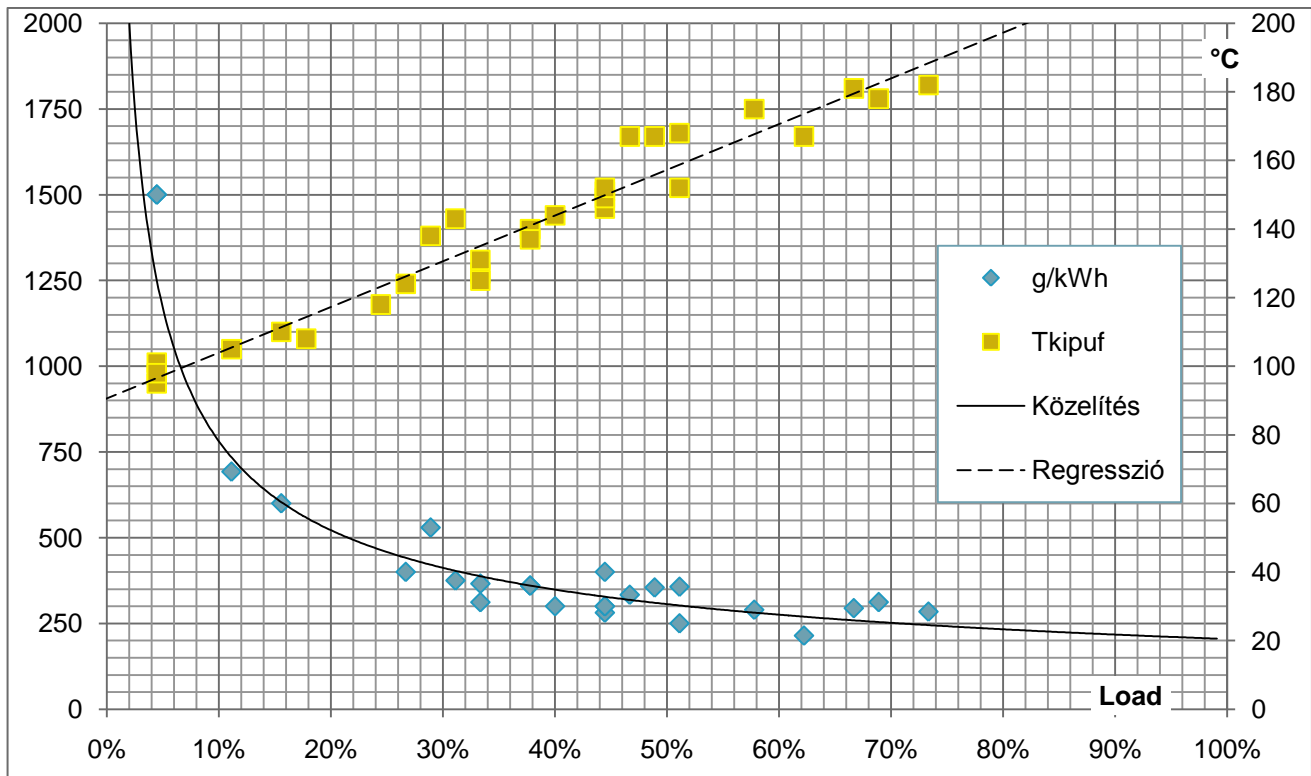
The inclination rate of the diesel is slightly higher that can be explained with the higher HC emission level: the non combusted gases burn in the exhaust causing higher temperature.

The TBK100 and the Diesel fuel have practically the same thermal balance that corresponds to a good burning and therefore proves the adequate performance of the TBK100 in the engine.

Diesel fueled engine characteristics

The engine characteristics are displayed versus the load.

The double scaled diagram has the fuel consumption in g/kWh on the left, while on the right the exhaust temperature in °C (Tkipuf).



Analysis of the diagram

The diesel fuelled engine control test completely fulfilled the expectations. On one hand this proves the correctness of the measurements, on the other gives a perfect base for comparing.

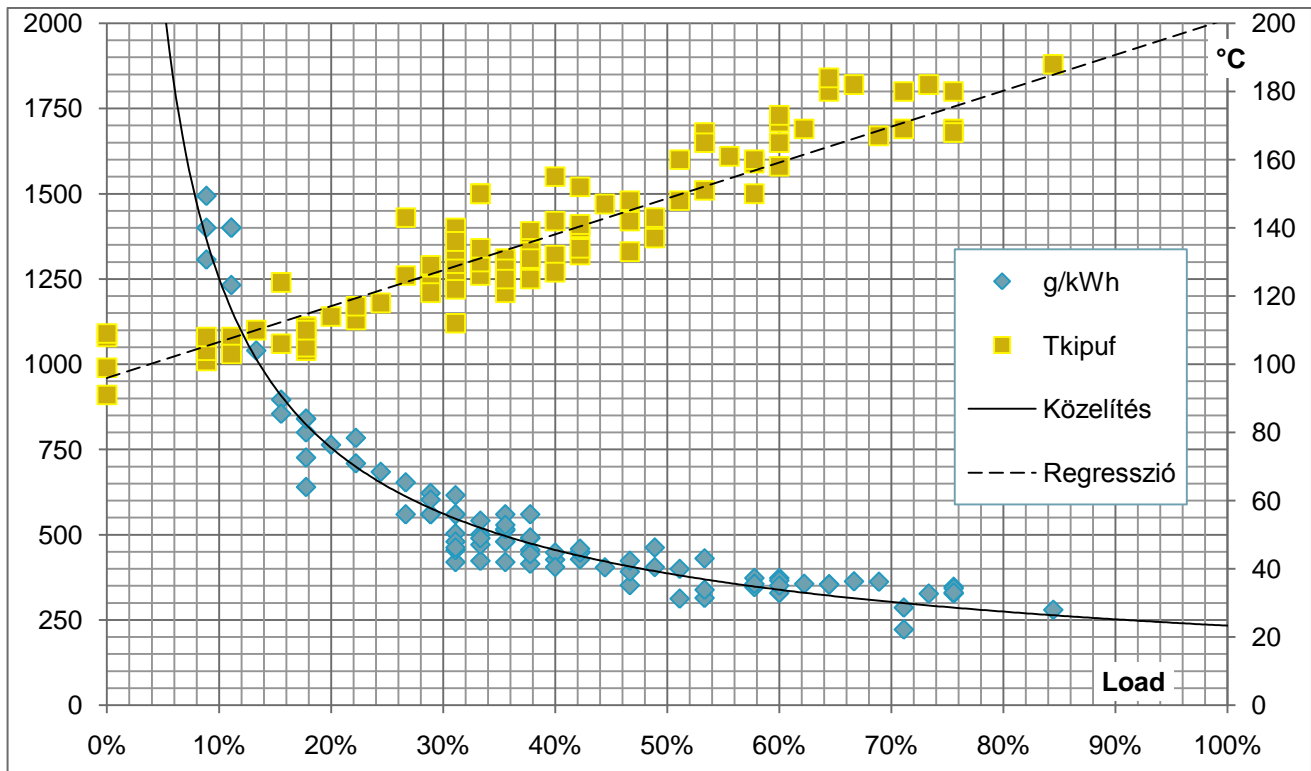
The deviation of the values is small, and the error limit is within 10%.

Consequently the approximation (közéltés) and the regression (Regresszió) can be done with good precision.

TBK100 fueled engine characteristic

The engine characteristics are displayed versus the load.

The double scaled diagram has the fuel consumption in g/kWh on the left, while on the right the exhaust temperature in °C (Tkipuf).



Analysis of the diagram

The diagram complies with the expectation. The load-consumption relation and the exhaust temperature conform to each other. Through the whole load range the data are coherent and correct. The detected behavior is similar to Diesel as the values are close.

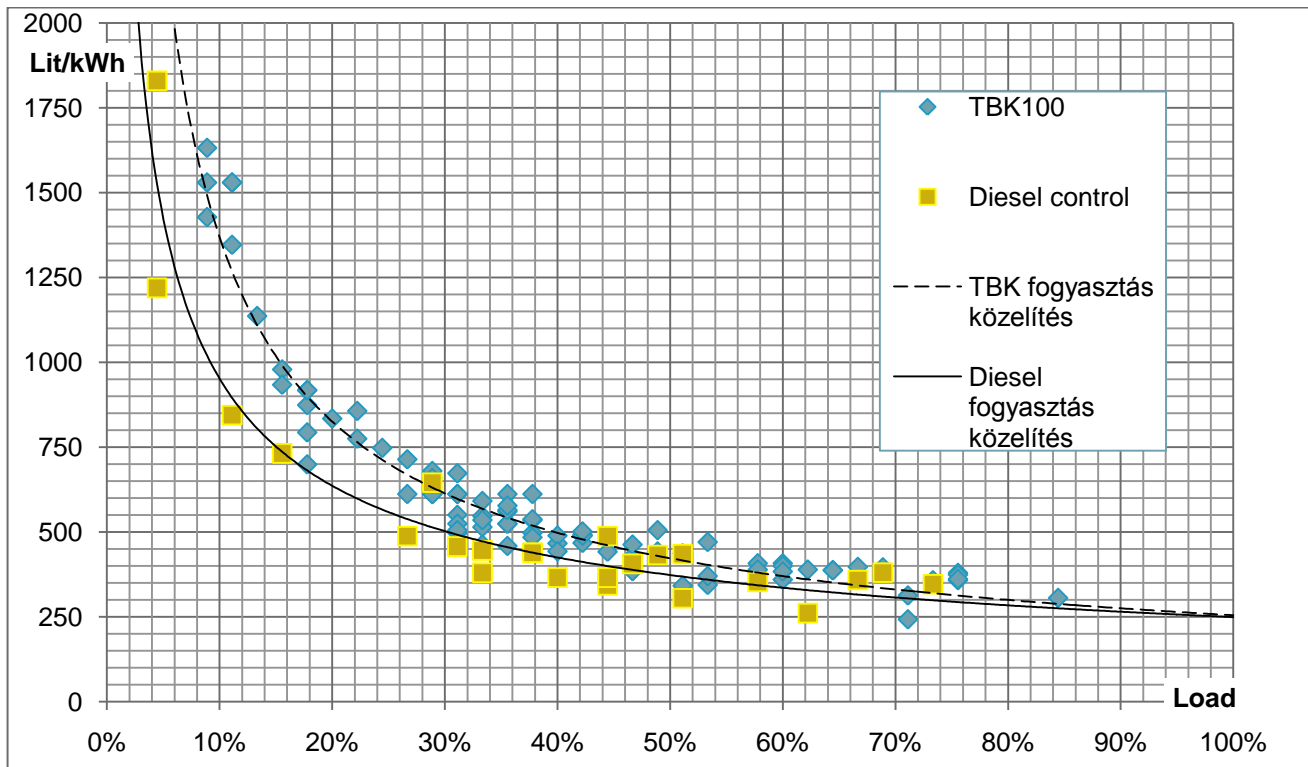
The standard deviation is somewhat higher than that of Diesel. This may have been caused by the severely fluctuating ambient temperature and the recording accuracy.

The error limit is close to 10%, the approximation (Közelítés) can be done correctly.

The TBK100 fuelled engine characteristics were acceptable through the whole load range.

Comparing fuel consumption curves for TBK100 and Diesel

The diagram below shows one of the most important comparing of the test. Hereby the fuel consumption of the test engine is displayed as function of the load.



Analysis of the diagram

The consumption data and the approximation curves (fogyasztás közelítés) lie very close for both fuels. The one for TBK100 is a few percent higher due to the lower calorific value. The diagram is scaled in Liter/kWh, comparing the results in g/kWh is incorrect as their specific weights differ.

TBK100 shows a higher consumption of nearly 20% at partial loads but this load range lies outside of the mainly used area thus is less important.

In practice the load range between 50% and 75% is the most important. TBK100 has between 5% to 10% surplus only. For example, if a vehicle consumes 7,0 Liters Diesel per 100kms, it will take between 7,35 and 7,7 Liters of TBK100.

The TBK100 consumption data are only slightly poorer as compared to Diesel.

Emission test

Test description

The emission test records the amounts of the various exhaust gas components. This mixture was detected by a gas-analyzer. The analyzer can detect 5 components simultaneously with a gas sampler placed into the exhaust pipe. Based on the records we get a detailed picture about the environmental stress at various loads.

The recording was done at colder and warmer engine temp. The colder temp was lower than the operating level, but well higher than the ambient. Between the various load tests the engine was still for approx. 10 min. During this period the water could not be cooled down virtually but only the combustion area. The first measurement was taken as soon as possible after the restart and steady speed. The second was done 2-3 minutes later, when the combustion conditions were stabilized. Consequently for all fuel and load pairs belong two records in the column type diagram on the next page. A small deviation between the colder and warmer data is obvious but not significant.

The recorded data are written on the display of the gas-analyzer, and the snapshot is printed out to a paper roll as a button is pushed. The tested fuel and the load were logged on the paper roll next to every printout. The printed data later were entered into an MS Excel table, and are displayed in the following diagram. Only the raw data are presented with calculated values. The measured range and the unit of the various components are altering. In the table and the diagram the range of the gas-analyzer was followed.

The printouts were digitalized with a scanner and stored electronically as well. The calibrations with their values, software, hardware and device identification parameters are also printed. They are exposed at the upper part of the picture on the left.

The lower part shows one of the records. On this example the Diesel fuel with 50% load after the engine still period (colder combustion chamber) is exposed. The diagram presents the printed data in the related column.

```
PROTECH
IPEX 1

07-06-2010      19:21

GUI Ver. 2.681

Fac.ASN 2.45
SN SE0914013
INF.SW Ver. 5.5H
IS: TE0906080
PEF: 0.535

- Intern. -
- English -

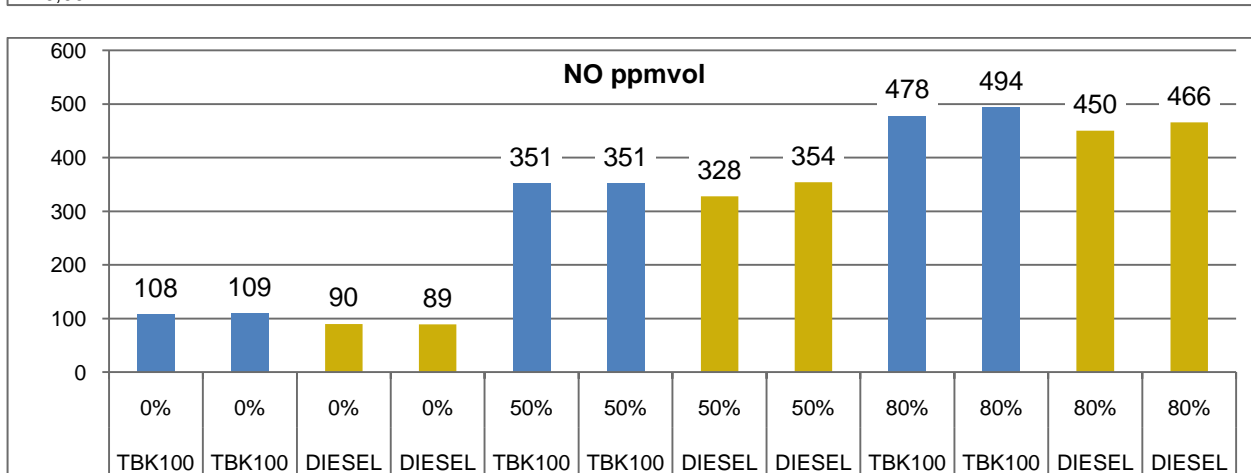
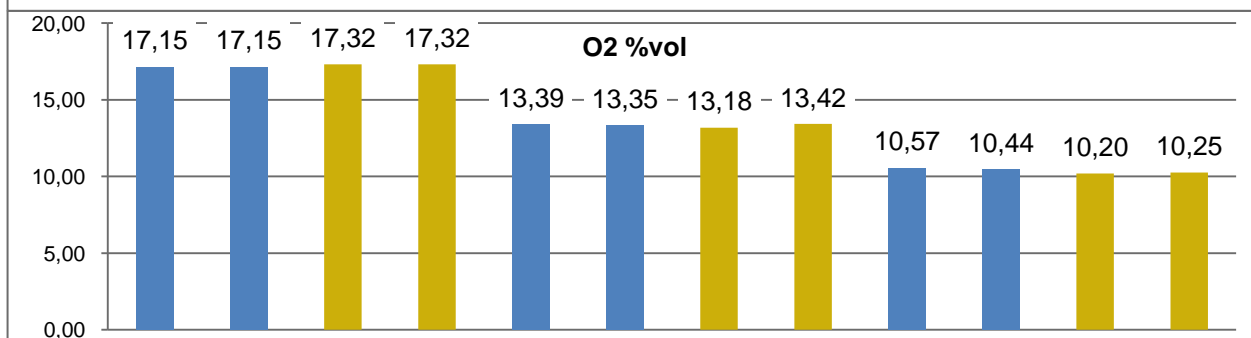
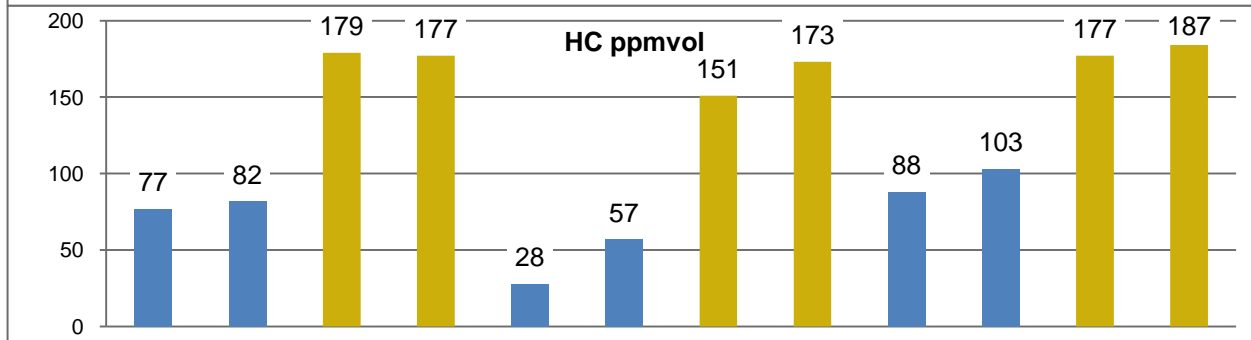
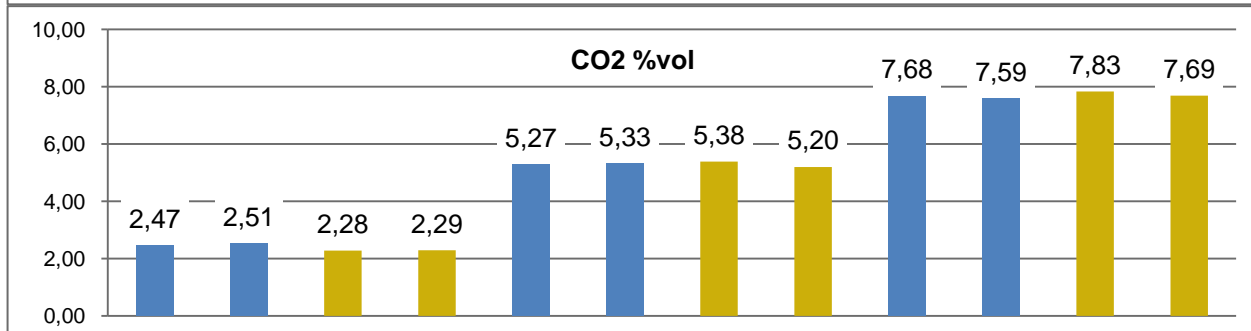
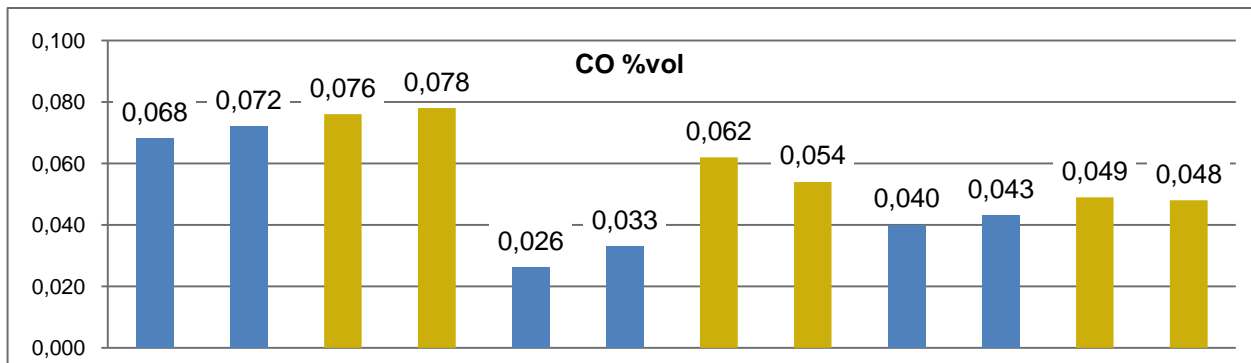
PROTECH
IPEX 1

DIESEL 1500W

07-06-2010      19:30
Make :
Model :
Plate Nr:
Miles : 0

CO : 0.062 %vol
CO2: 5.38 %vol
HC : 151 PPMvol
O2 : 13.18 %vol
NO : 328 PPMvol
Lambda: -----
AFR : -----
RPM : -----
T. Oil: ----- C

Operator :
```



Measurement analysis

The emission records are obvious and well comparable. In the analysis the differences caused by the load rates complies with the technical literature. The values represent a stable, reliable and reproducible result

According to that, the TBK100 produces with lower emission than Diesel for almost all gas components measured. Only in case of the NO it is marginally higher than the control. But if we take into consideration that in case of esterified biodiesel ("FAME") the NO emission is significantly higher, this result can be concluded as very good.

If we take in to account that for the same load rate the engine consumes a slightly more TBK100, and the data are evaluated against the used fuel the results are even better.

In case of the CO (carbon-monoxide) the results are far low, which corresponds to a good burning. The CO emission is quite poisonous therefore a low value is a great advantage.

The CO₂ and O₂ relates to the correct fuel air ratio that shows a similar behavior in all cases.

The HC (hydrocarbon) emission has the greatest advantage of the TBK100 against the Diesel fuel. This poisonous component is significantly lower emitted. Further advantage is that while in case of the Diesel the results are hardly dependant on the load rate, in case of TBK100 the 50% load - that is mainly used in practice - has the lowest value. This may mean one order of magnitude lower emission rate in the everyday usage.

The earlier measured higher exhaust temperature well corresponds with the higher HC emission of the Diesel fuel.

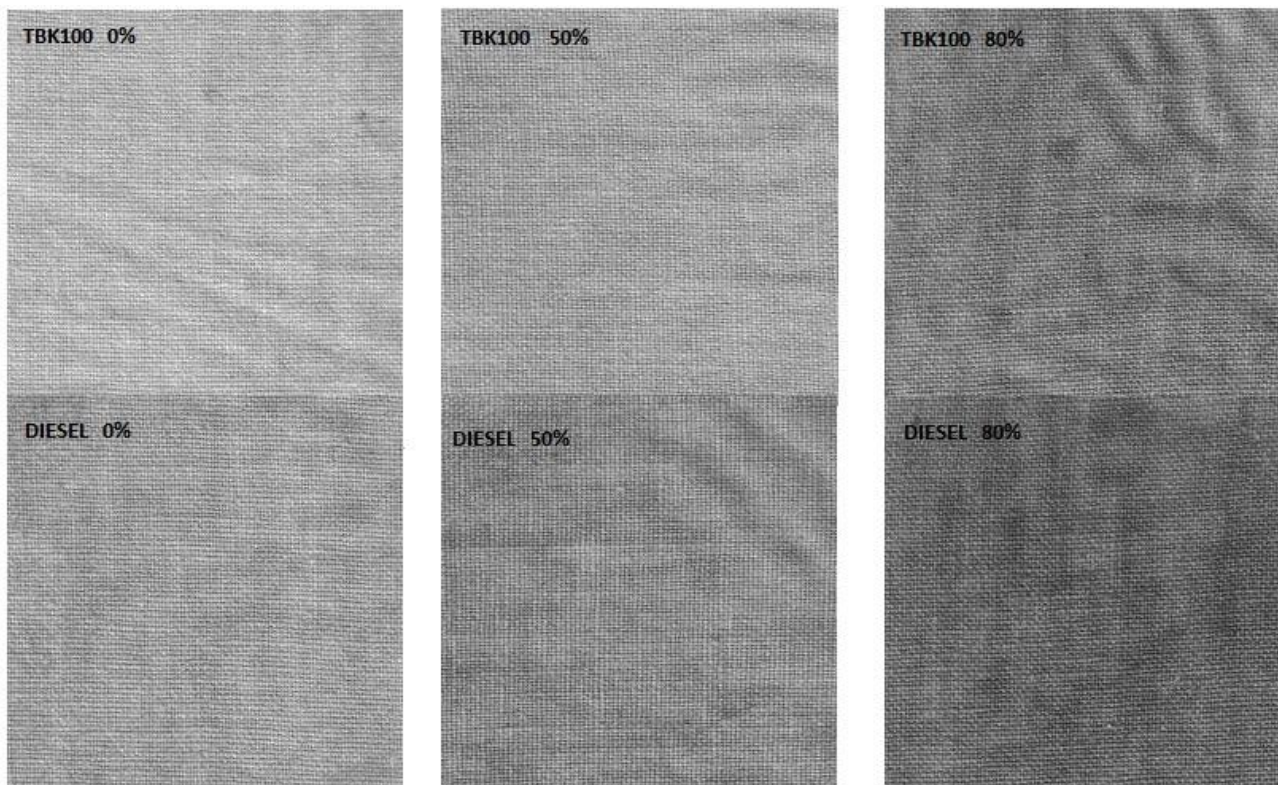
The NO (nitrogen monoxide) emission is marginally, so not significantly higher. In the most used range in practice is the 50%, where the value is lower in one case. Therefore in an average everyday usage, measurable NO emission surplus cannot be acknowledged. This is one of the major advantages as compared to other bio grade esterified fuels.

To summarize the results the TBK100 can be ranked very well in the emission test. In case of CO₂, O₂, NO components the results can be considered equal, but being significantly lower for CO and HC.

Smoke and soot emission

Description of the test

In order to measure the smoke-rate a clean white cloth was held 2-3 cm away from the open end of the exhaust pipe for 60 seconds. This comparing method was used for TBK100 and Diesel fuel as well in 3 load rate: 0%, 50% and 80%. The soot particles contaminated cloth samples were scanned with 150 DPI resolution by a Canon- CanoScan Lide 25 type scanner. Approximately 80% of the contaminated part were cut out of the digitalized pictures and positioned in a comparing view. This is shown below.



Measurement analysis

The test is a comparing method and does not give absolute result.

The soot samples reflect that by increasing the load the smoke rate inclines as well. Further on at the same load rate the TBK100 less contaminated the cloths.

In case of TBK100 fuel the amount of smoke is lower at all load rate compared to Diesel.

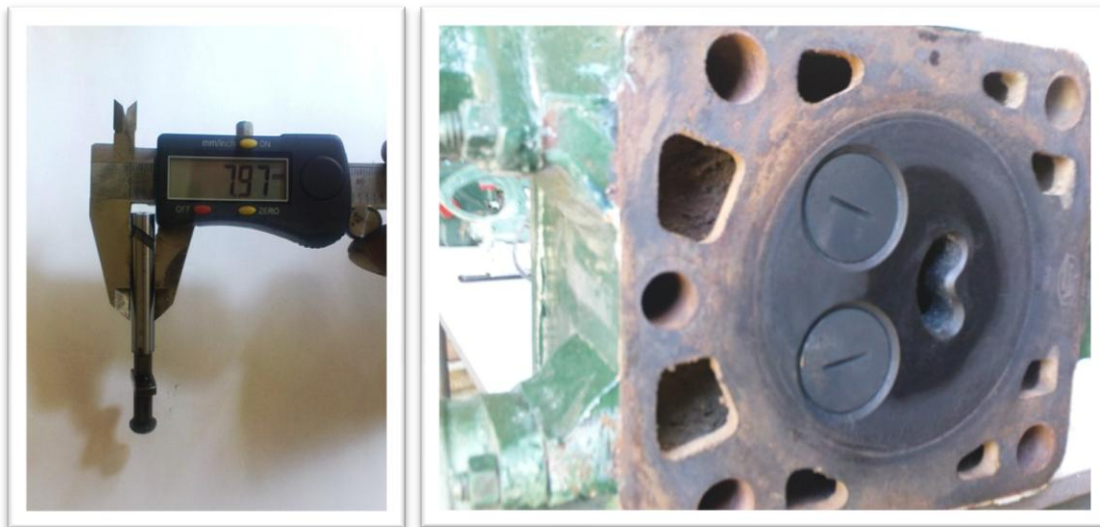
Checking deposits and wear

At the end of TBK100 test those engine parts were dismantled and scrutinized that were exposed to or in contact with the fuel.

In normal cases after the 100 hour test no wear, deposit or altering can be experienced.

The wear was controlled with a digital caliper with 0,01 mm accuracy. Meanwhile the corrosion was checked as well.

On the Crofter test engine there is no plastic or rubber part that in normal case has contact with the fuel except the PVC fuel line.



Evaluation

Examined parts and their evaluation:

PART, MAIN ASSEMBLY	DEPOSIT, ALTERATION, CORROSION	WEAR, WEAR RATE
fuel tank	no	n.a.
fuel tap	no	n.a.
fuel line PVC	no	n.a.
fuel pump	no, not measurable	not measurable
pressure pipe	no	n.a.
interior of injector	no, not measurable	not measurable, nominal values
combustion chamber part of injector	slight soot deposits, same as diesel, not measurable	n.a.
combustion chamber	slight soot deposits, same as diesel, not measurable	not measurable
top of piston	slight soot deposits, same as diesel, not measurable	n.a.
piston rings	same as diesel, not measurable	not measurable, nominal values
lube oil	no	v

The status of the engine was the same that in case of Diesel fuel use: wear, deposit was not measurable.

Summary, conclusion

During this test the TBK100 showed a good behavior in engine usage. It passed all criteria we have checked against. Consequently TBK100 is a good substitute of the Diesel fuel.

In the list below the conclusions of the previous chapters are collected:

- **TBK100 performed well during cold start conditions.**
- **The TBK100 and the Diesel fuel have practically the same thermal balance that corresponds to a good burning and therefore proves the correct utilization of the TBK100 in the engine.**
- **The TBK100 fuelled engine characteristics were acceptable through the whole load range.**
- **The TBK100 consumption data are only a slightly poorer to Diesel.**
- **To summarize the results the TBK100 can be ranked very well in the emission test. In case of CO₂, O₂, NO components the results can be considered equal, but being significantly lower for CO and HC.**
- **In case of TBK100 fuel the amount of smoke is lower at all load rates compared to Diesel.**
- **The status of the engine was the same as in case of Diesel fuel: wear, deposit was not measurable.**

Recommendation

Control measurements are recommended to be done in an accredited engine lab.