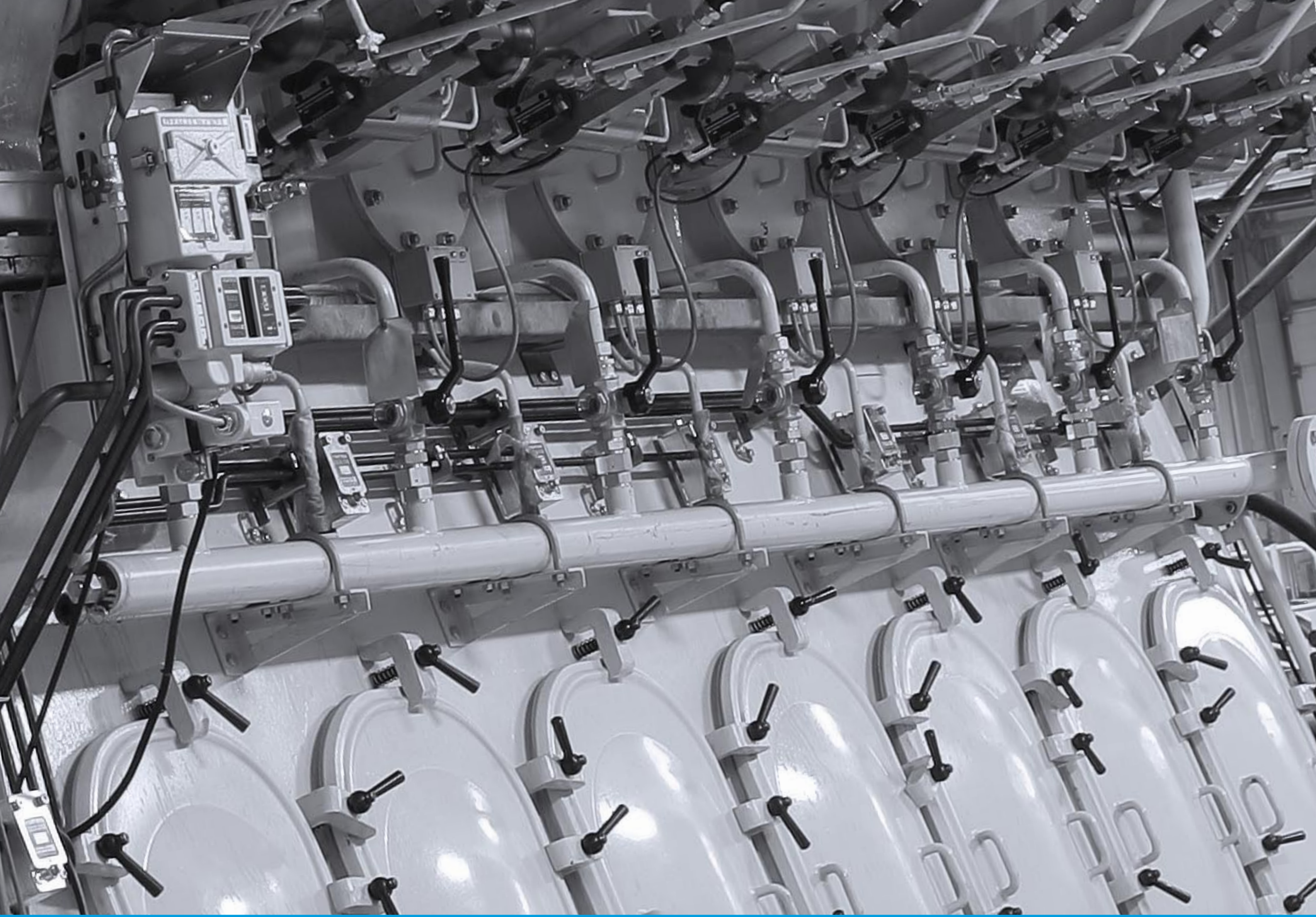

Two-stroke Low Speed Diesel Engines

for Independent Power Producers and Captive Power Plants

MAN Diesel

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Content

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Abstract

In recent years, the stationary diesel engine market for large diesel units has seen an increasing demand for reliable and fuel efficient power plants in the range of 30-250 MW, based on cost effective refinery residuals.

The demand is met by the modern medium speed diesel GenSets and, for the larger units, by the two-stroke low speed crosshead uniflow scavenged diesel engines, the latter capable of burning almost any fuel available on the market, whether liquid or gaseous.

This paper will deal with the service experience gained from two-stroke low speed diesel engines and their fuel capability as well as describe various installation examples.

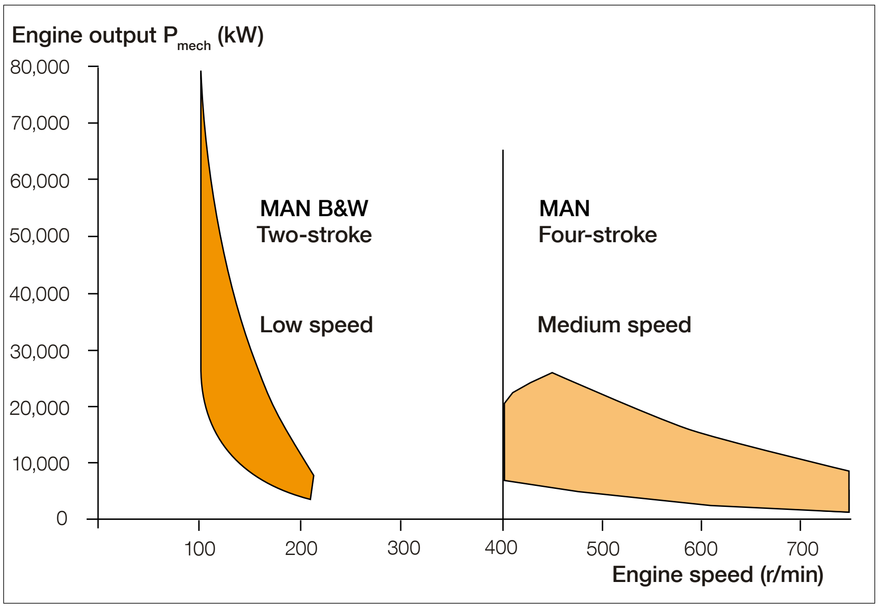

Fig. 1: Engine programme

Preface

Diesel engines for power generation from MAN Diesel are offered in the categories, as shown in Fig. 1:

- MAN high speed and medium speed engines, ranging from 0.5 to 22 MW per unit, from MAN Diesel's companies in Germany, Denmark and France

- MAN B&W two-stroke MC-S engines designed by MAN Diesel, Copenhagen, Denmark. These are low speed engines with unit outputs of up to 80 MW. The engines are built by MAN Diesel's licensees listed in Fig. 2

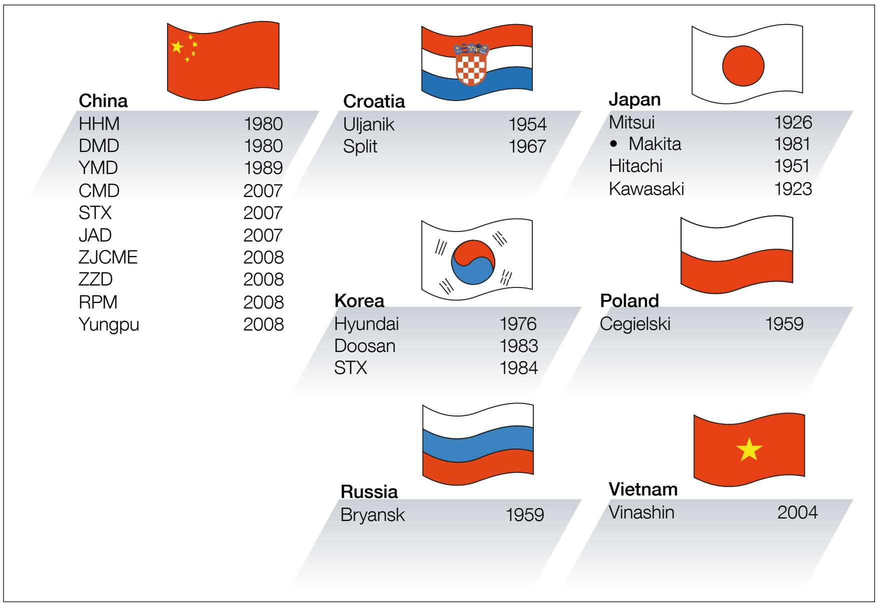

Fig. 2: MAN B&W Diesel two-stroke licensee family

The low speed two-stroke engines match any requirements of medium to large size projects, whether for island utilities or large IPP or captive plants, up to say 250-300 MW.

Low speed engines are particularly suited to digest any fuels with high efficiency and good reliability. Engineers are well-acquainted with the technology through wide experience from the world merchant fleet, which is dominated by MAN B&W low speed two-stroke engines.

The diesel engine and its competitors

Looking at the prime mover options available to the end-user today and comparing their efficiencies, we can see that in the relevant range, say 12-80 MW per unit, see Fig. 3, the two-stroke diesel engine is unrivalled as the most fuel efficient prime mover whether compared with medium speed engines, steam turbines or single-cycle or combined cycle gas turbines.

Diesel engines in stationary applications

The MAN B&W low-speed engines are always matched to the actual climatic conditions of the site with due allowance for seasonal variations. With demanding site conditions, medium speed engines sometimes call for slight derating, however, this is not required for low speed diesel engines in which an acceptable combustion chamber heat load is maintained by a modification of the heat rate of the engine.

A general comparison of deratings, as a function of ambient conditions for the various combustion engines on the market, is shown in Fig. 4, revealing the insensitivity of the low speed diesel engines to ambient conditions when compared with other internal combustion engines. When the various prime movers are compared, differences in the various ISO standards should be considered, see Fig. 5.

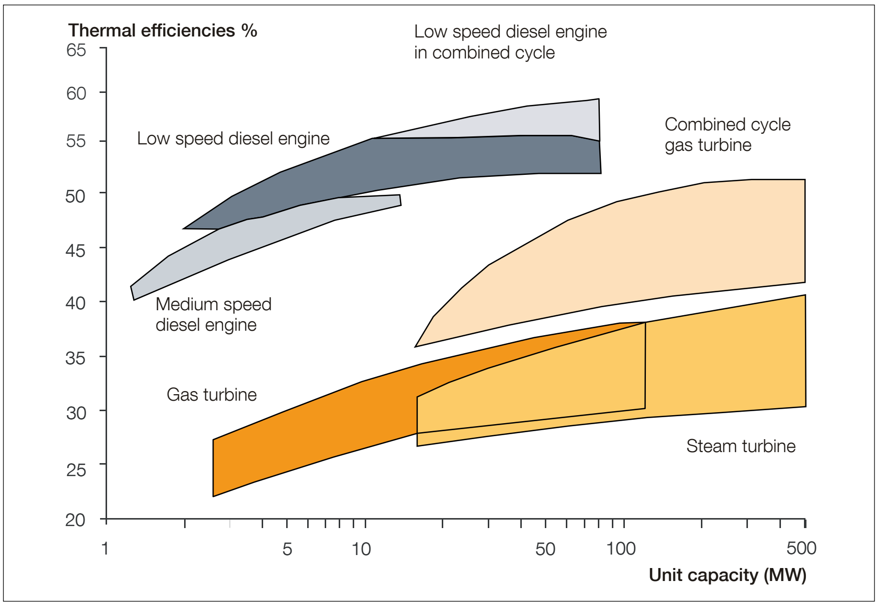

Fig. 3: Power efficiency comparison at ISO 3046

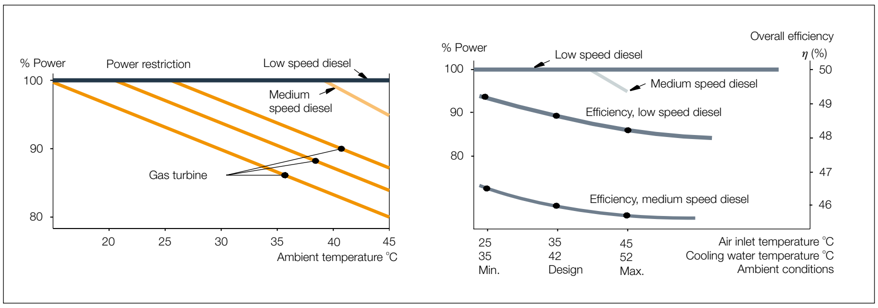

Fig. 4: Influence of ambient conditions on rating of internal combustion engines

		Gas turbines ISO 3977	Diesel engines ISO 3046
Air temperature	°C	15	25
Coolant temperature	°C	15 *)	25
Barometric pressure	mbar	1013	1000
Relative humidity	%	60	60

*) if applicable

Fig. 5: Comparison of ISO conditions

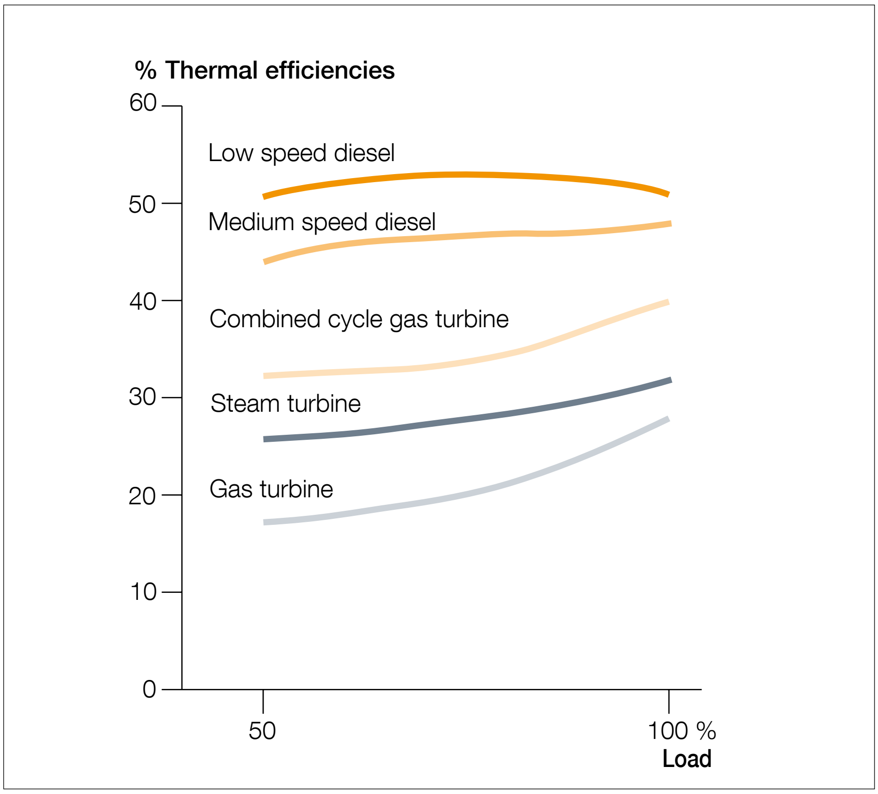

Fig. 6: Typical part load efficiencies of prime movers, ISO 3046

Load Flexibility

To cater for load variation in plants, say up to 300 MW, it is quite common to install a number of equally-sized units. The load fluctuations called for by users are then managed by sequential starting and stopping of the units.

This configuration and running principle is very often seen with the traditional gas turbines, because of their poor part-load efficiency behaviour.

As shown in Fig. 6, the efficiency of diesel engines, and especially of two-stroke low speed diesel engines, is almost independent of load over a wide load range. Furthermore, low load running without any limitation is possible down to approx. 10% of the site specified Maximum Continuous Rating (MCR), and the engines are able to run at 10% overload for one hour every 12 consecutive hours. It is therefore fully feasible to install the largest two-stroke diesel units applicable, i.e. as few units as possible for a given plant size, thereby shortening plant construction time, reducing the space requirement, as well as reducing first cost, running cost and maintenance load, while still ensuring high efficiency and reliability, irrespective of the plant running programme.

Fuel Linkage

As most diesel plants are installed in areas which depend on liquid fuels with scarce and unstable supplies of high quality fuels, it is of paramount importance for the feasibility of a project that the acceptance range in the guiding fuel oil specifications of the various prime movers is considered at a very early stage. Fig. 7 shows the difference in fuels that can be used in gas turbines and diesel engines in general.

Due to the global climate changes and the various international agreements on CO_2 emissions, the past few years have shown an increased interest in the use of various liquid biofuels of animal or vegetable origin.

Fig. 8 shows the Guiding Biofuel Specification for MAN B&W two-stroke low speed diesel engines. The first MAN B&W two-stroke low speed engine, an MAN B&W 7L35MC-S running on crude palm oil, see Fig. 9, was commissioned by MAN Diesel's Polish licensee H. Cegielski – Poznan S.A. in Brake, Germany, at the beginning of 2009, see Fig. 10.

Designation		Diesel engines CIMAC-H55	Gas turbines ASTM 2880
Density at 15 °C	kg/$_3$	1010	876
Kinematic viscosity at 100 °C	cSt	55	50
Flash point	°C	≥ 60	66
Carbon residue	% (mm)	22	0.35***
Ash	% (mm)	0.15	0.03
Water	% (mm)	1.0	1.0**
Sulphur	% (mm)	5.0	1.0
Vanadium	ppm (mm)	600	0.5-2
Aluminium + Silicon	mg/kg	80	(10)
API gravity (min)	°API	*	35
Sodium plus potassium	ppm (mm)	200	1
Calsium	ppm (mm)	200	1
Lead	ppm (mm)	10	10

*) experience, no limittations in official specificationa
**) incl. sediment
*** on 10% destillatiion

Fig. 7: Diesel engine and gas turbine liquid fuel specication

Fuel flexibility

Most power plants built today are based on the use of one or two fuels. Such fuels are typically natural gas or light fuels for gas turbines, coal or heavy fuel for steam turbines and diesel oil, heavy fuel oil or natural gas for diesel engines.

The two-stroke low speed diesel engines of MAN B&W design are able to run on virtually any commercially available liquid or gaseous fuel.

Fig. 7 shows a typical guiding fuel oil specification of today for such engines. The basic data are dictated by the logistics of the marine market, which require that the fuel can be transported to the ship. This requirement does not, in principle, apply to stationary plants which can be placed close to the source of energy and connected to it by a pipe which is heated by waste heat from the engine.

Various types of refinery waste can thus be used in low speed diesel engines.
Such fuel oil specifications are normally quoted by the majority of diesel engine designers on the market, regardless of the number of strokes. Nevertheless, in this connection, it should be noted that most medium speed designers specify a maximum design temperature of HFO at injection in the range of 130-150°C, resulting in a maximum fuel viscosity of 700 cSt at 50°C.

For the two-stroke engines of MAN B&W design, the maximum design temperature of the fuel preheating is 250˚C, corresponding to a specific fuel viscosity of approx. 70,000 cSt at 50˚C, i.e. a factor of 100 in admissible fuel viscosity.

Designation		
Density at 15 °C	kg/m^3	1010
Kinematic viscosity at 100 °C 2)	cSt	55
Flash point	° C	> 60
Carbon residue	% (m/m)	22
Ash	% (m/m)	0.15
Water	% (m/m)	1.0
Sulphur 3)	% (m/m)	5.0
Vanadium	ppm (m/m)	600
Aluminium + Silicon	mg/kg	80
Sodium plus potassium	ppm (m/m)	200
Calcium	ppm (m/m)	200
Lead	ppm (m/m)	10
TAN (Total Acid Number)	mg KOH/g 4)	< 25
SAN (Strong Acid Number)	mg KOH/g	0

1) Maximum values valid at inlet to centrifuge plant
2) Pre-heating down to 15 cSt at engine inlet flange is to be ensured
3) Iodine, phosphorus and sulphur content according to agreement with emission controls maker
4) TBO of engine fuel systems to be adjusted according to actual value and experience

Fig. 8: Two stroke guiding biofuel specification for MAN B&W two-stroke low speed diesel engines 1)

Fig. 10: PBB GmbH, Brake, Germany

Fig. 9: MAN B&W 7L35MC-S engine

Fuel No	A	B	C	D	E	F	G	H	Units
Viscosity	3.8	84	85	141	198	255	470	520	cSt/50°C
Density	968	995	970	993	938	977	985	983	kg/m³ at 15°C
Flash point	98	84	80	103	100	106	90	95	°C
Conradson Carbon	0.3	17.2	12.1	13.3	9.4	14.5	16.8	14.8	% weight
Asphalt	0.78	15.1	8.9	9.2	3.7	10.0	11.3	12.8	% weight
Sulphur	0.10	2.72	1.16	0.91	0.83	0.87	0.90	1.18	% weight
Water	0.01	0.01	0.01	0.00	0.01	0.02	0.02	0.01	% weight
Ash	0.00	0.065	0.025	0.03	0.03	0.025	0.03	0.035	% weight
Aluminium	-	-	-	-	-	-	-	-	mg/kg
Vanadium	0	220	20	23	12	17	24	45	mg/kg
Sodium	0	27	23	24	25	40	35	22	mg/kg
CCAI	912	874	849	866	807	843	844	841	-

Fuel No	I	J	K	L	M	N	O	Units
Viscosity	560	690	710	800	1200	50,000	-	cSt/50°C
Density	1,010	1,008	1,030	935	998	1,040	1.01	kg/m³ at 15°C
Flash point	90	79	84	>40	80	>60	>70	°C
Conradson Carbon	17.3	22.1	24.7	9.4	14,1	24.2	11.7	% weight
Asphalt	14.6	19.3	29.0	1.02	12	-	-	% weight
Sulphur	2.22	3.52	3.30	0.37	4	4.8	2.8	% weight
Water	0.00	0.00	0.00	-	0,65	0.05	-	% weight
Ash	0.04	0.07	0.09	0.043	-	0.035	0.18	% weight
Aluminium	-	-	-	-	12	2.0	1	mg/kg
Vanadium	122	300	370	415	312	149	-	mg/kg
Sodium	22	24	50	9	-	-	-	mg/kg
CCAI	868	864	885	-	-	-	-	-

Fig. 11: Examples of liquid fuels burned in MAN B&W two-stroke low-speed engines

Composition	Units	Natural gas types			VOC fuel types		
CH_4	vol.%	88.5	91.1	26.1	–	–	–
C_2H_6	vol.%	4.6	4.7	2.5	1.1	6.3	–
C_3H_8	vol.%	5.4	1.7	0.1	–	–	–
C_4H_{10}	vol.%	1.5	1.4	–	23.9	5.0	6.1
C_{5+}	vol.%				6.5	88.7	93.9
CO_2	vol.%	–	0.5	–	–	–	–
N_2	vol.%	–	0.6	7.3	–	–	–
Molar mass	kg/mol	18.83	17.98	35.20			
Lower calorific value	kJ/kg	49170	48390	7060			
Lower calorific value	kJ/Nm^3	41460	38930	11120			
Density:							
at 25 °C/ 1 bar abs	kg/m^3	0.76	0.73	1.43			
at 25 °C/ 200 bar abs	kg/m^3	194	179	487			

Fig. 12: Examples of gaseous fuels burned in MAN B&W two-stroke low-speed engines

Fig. 11 shows examples of liquid fuels burned or tested successfully in MAN B&W two-stroke low speed diesel engines. Fig. 12 shows the similar data for gaseous fuels.

Fig. 13 shows the fuel flexibility of the MAN B&W ME-GI-S type high-pressure gas injection, dual fuel, two-stroke engines, which are able to burn both liquid and gaseous fuel in almost any ratio without influencing their power rating or efficiency.

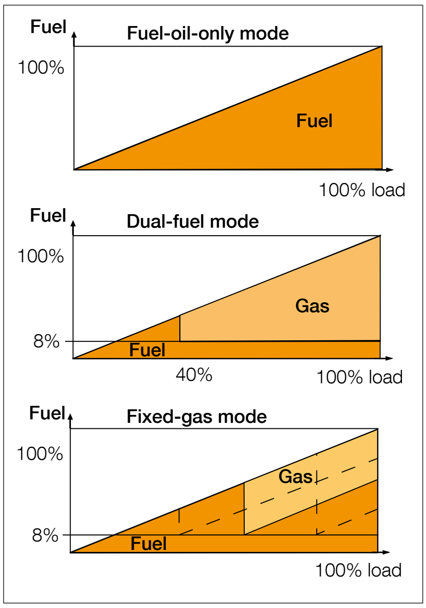

Fig. 13: Fuel type mode

Emissions

In response to the increasing demand for environmental protection, the plants – based on MAN B&W low speed engines – can be delivered with internal and external controls to comply with virtually any emission restriction requirements, including the World Bank Guidelines for diesel-driven plants.

Two-stroke Engine Driven Plants

An example of a 40 MW medium-load high-injection pressure two-stroke crosshead diesel engine plant is the Chiba plant in Tokyo, see Fig. 14, built by MAN Diesel's Japanese licensee Mitsui Engineering Shipbuilding Co., Ltd. This plant is based on an MAN B&W12K80MC-GI-S engine, generating 40 MW at 102.9 rpm at an ISO efficiency of 49.3%. The plant is equipped with an extensive SCR (Selective Catalyst Reactor) control of NO_x emissions in order to fulfil the local NO_x limit of 13 mg/Nm^3.

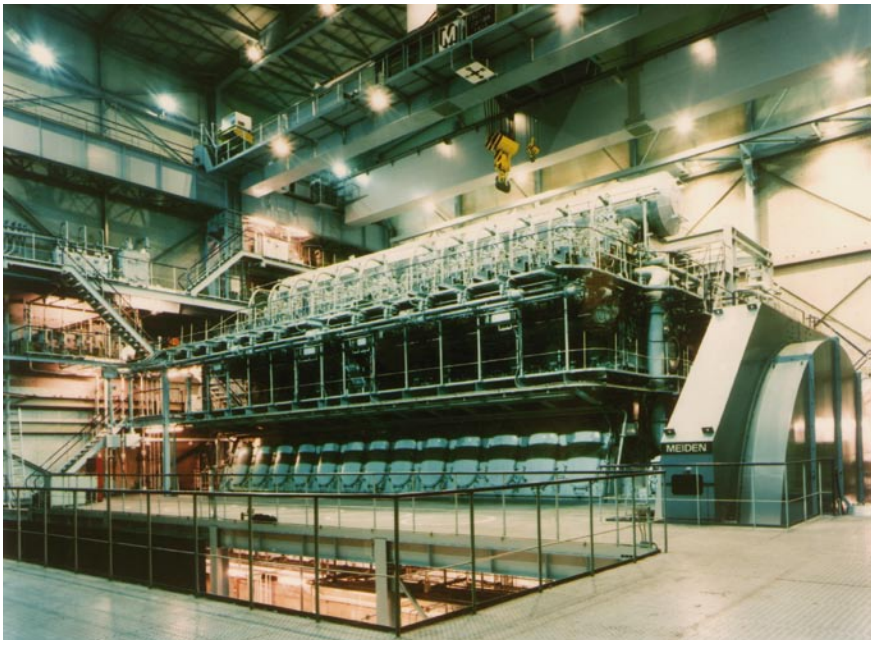

Fig. 14: Chiba 12K80MC-GI-S 40 MW

The Cheju Plants

Another example of a plant with highly sophisticated emission controls incorporated is the Korea Midland Power Plant at the Cheju Island in Korea, see Fig. 15.

Fig. 15: Korea Midland Power, Buk Cheju

Fig. 16: MAN B&W 12K80MC-S at Buk Cheju, Korea Midland Power

Emission limits:
SO_x < 50 ppm at 4% O_2, dry gas
NO_x < 250 ppm at 13% O_2, dry gas
PM < 30mg/Sm^3 at 4% O_2, dry gas

Fig. 17: Local environmental legislation at Buk Cheju, Korea

This 40 MW plant supplied by MAN Diesel's Korean licensee Doosan Engine Co., Ltd. is based on a single MAN B&W 12K80MC-S engine, developing 42 MW at 109.1 rpm (Fig. 16).

In order to fulfil the local environmental legislation, see Fig. 17, the plant is equipped with SCR for NO_x emission control, electrostatic filter for particle emission control and flue gas desulphurisation plant for control of SO_x emissions, see Fig. 15.

The plant is now extended with one more identical unit from the same supplier.

On the same island, at Nam Cheju, four MAN B&W 7K60MC-S engines have been installed since 1990. From the beginning, these engines have been equipped with electrostatic precipitators and in order to follow-up on the latest environmental legislation, they have been retrofitted with SCRs for NO_x control some years ago, see Fig. 18.

Fig. 18: MAN B&W 7K60MC-S at Nam Cheju before and after retrofit of SCR

The Chennai Plant

Today, if a power plant project is to be successful, it is not enough that it is environmentally friendly with regard to emissions. It must also be environmentally friendly in terms of the economical use of scarce resources, such as fuel oil and cooling water.

When the cooling water resources are limited, radiator coolers or cooling towers are often used. While radiator coolers can be used in areas where water is simply non-existent, their disadvantage is the high consumption of electrical power. Therefore, cooling towers are normally preferred if sufficient water for direct raw water cooling is not available.

The disadvantage of cooling towers is that they have a some consumption of water.

At the GMR plant, this problem has been solved by MAN B&W's licensee Hyundai Heavy Industries Co., Ltd. in connection with the order they have obtained for a 200 MW plant consisting of four 50 MW units of the MAN B&W 12K90MC-S type for the GMR Vasavi Group in Chennai (former Madras), India, Fig. 19.

The plant is built in combination with a sewage treatment plant that produces the water required for the cooling towers, see Fig. 20. This pilot combination of a sewage treatment plant and a two-stroke low speed diesel plant is therefore interesting for coming projects, not only in the area in question, but also in other countries.

Fig. 19: 200MW GMR plant at Chennai Power

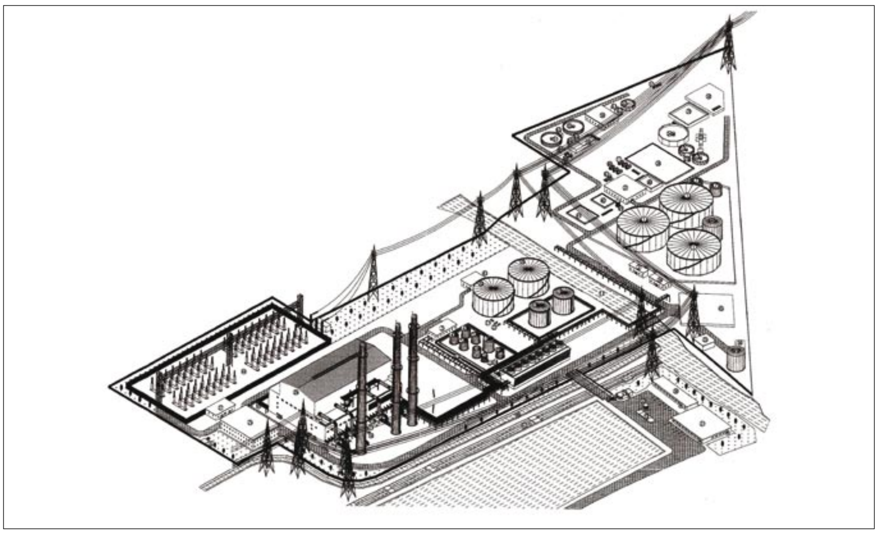

Fig. 20: GMR Power Plant, layout

Conclusion

As shown, the two-stroke low speed diesel engines of MAN B&W design are a viable option to be investigated and chosen by owners anywhere where reliable fuel-efficient diesel plants are required, especially if the fuel is of a poor quality and available in scarce amounts.

The future development of such engines will be dictated by the market, in particular by the future fuel oil prices and qualities, and the trend seems to point in the direction of even more efficient, ever larger and more environmentally friendly units.

MAN Diesel
Teglholmsgade 41
2450 Copenhagen SV, Denmark
Phone +45 33 85 11 00
Fax +45 33 85 10 30
mandiesel-cph@mandiesel.com
www.mandiesel.com

MAN Diesel SE
Business Unit Power Plants
Stadtbachstr. 1, D-86153 Augsburg
Phone +49-821-3223897
Fax +49-821-3221460
powerplant@mandiesel.com
www.mandiesel.com

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