DUAL FUEL (NATURAL GAS/DIESEL) MARINE INSTALLATIONS

DESIGNED & PREPARED BY:
M.D.A. MARINE DESIGN ASSOCIATES LTD.

COPY

U.S. DEPARTMENT OF TRANSPORTATION MARITIME ADMINISTRATION

WORKSHOP ON ALTERNATIVE FUELS FOR FERRIES & OTHER VESSELS

AT

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M.D.A. MARINE DESIGN ASSOCIATES LTD.
#307 - 1625 Oak Bay Avenue
Victoria, British Columbia
V8R 1B1 CANADA

Phone: (250) 384-4191
Fax: (250) 381-1143
E-Mail: info@marinedesign.net
Internet: http://www.marinedesign.net

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First of all I would like to thank Danny Gore and his associates in the Maritime Administration of the US Department of Transportation for inviting me to be here at this workshop and trust my paper on marine dual fuel installations is informative and of interest to you all.

"K" CLASS DUAL FUELED FERRIES – M.V. "KLATAWA"

M.D.A.'s experience with dual fuel (natural gas/diesel) marine installations began in September 1984 with a contract from the British Columbia Ministry of Transportation and Highways to prepare a design package to convert their existing 13 year old twin screw vehicle/passenger ferry the M.V. "KLATAWA" from diesel powered main engines to dual fuel powered engines. This conversion would permit the main engines to operate either on dual fuel (natural gas/diesel) or diesel alone, the latter in the event natural gas was not available for whatever reason.

Since this ferry was certificated by the Canadian Coast Guard Ship Safety, now called Transport Canada Marine Safety Branch, it was necessary to submit the conversion design to this Regulatory Body for approval. Initially, Marine Safety were very hesitant to give approval since there were no rules within the Canada Shipping Act that applied to the use of natural gas aboard a vessel, never mind a passenger ferry. However as the design progressed and their concerns were addressed, specifically the ability to shut off the supply of natural gas in an emergency and have the main engines instantly revert to diesel fuel only, Marine Safety Branch became extremely helpful in the design development.

The conversion design package prepared by M.D.A. included calculations to determine the volume of natural gas required to operate the vessel on a 80% / 20% natural gas/diesel mixture under 85% engine load. After establishing the ferry's route pattern and convenient times for natural gas refueling, the number of on-board natural gas storage cylinders was established. In the M.V. "KLATAWA's" case, refueling was scheduled for every 4½ hours and the number of on-board natural gas cylinders comprised 8 in number. These were of aluminum fibreglass composite construction, each 1,100 standard cubic feet (s.c.f.) capacity at 3,000 p.s.i. pressure and able to be drawn down to a pressure of 400 p.s.i.

With the engine rooms on the KLATAWA located on the Main Deck, one port for'd and one starboard aft, it was decided for safety purposes to retain the on-board natural gas piping supply system above deck in two (2) separate systems one (1) P and one (1) S including the storage of the natural gas cylinders within steel shelters partially open to the weather on the outboard sides only and entranced by a single steel door.

Drawings and documentation in the conversion dual fuel design package prepared by M.D.A. and submitted to Transport Canada, Marine Safety Branch for approval were: -

- General Arrangement Outline of Natural Gas System
- Gas Piping System Arrangement
- Gas Cylinder Compartment – Structure
- Ventilation System Supply & Exhaust Trunks
- Specification
- Operating Manual – Preliminary

The ferry M.V. "KLATAWA" was successfully converted to operate on dual fuel (natural gas/diesel) in 1985 and on December 16th of that year, the vessel was awarded a Passenger Certificate by Transport Canada, Marine Safety Branch, to operate in this capacity. **With the award of this certificate, the M.V. "KLATAWA" became the first vehicle/passenger vessel in the world licensed to operate on dual fuel (natural gas/diesel).**

The conversion of the M.V. "KLATAWA" to a dual fuel (natural gas/diesel) operation can be broken down into three main activities: -

1. conversion of the main engines, with additions of carburetors and natural gas controls;

2. installation of on-board natural gas storage tanks, piping and safety features; and

3. development of the shore based natural gas compressor station comprising the compressor, inter-coolers, a self-contained radiator for the inter-coolers and compressed gas bottle storage.

1. **Main Engine Conversion** for this project was not complex. The converted units were four-stroke, turbo-charged, fresh water after-cooled Caterpillar diesel engines. Other than the addition of gas regulators, a carburetor and a modified Woodward governor, the engine is a standard 3406-B with the timing retarded only by two degrees.

   These engines can run either on dual fuel (i.e. natural gas/diesel) or on diesel fuel only at all times. Even at high compression ratios, temperatures are too low to spontaneously ignite the natural gas and, therefore, diesel fuel injection is used as a source of ignition.

Originally the engines were set up for a 80% / 20% natural gas/diesel mixture at 85% load but to-date, now operate on a 91% / 9% natural gas/diesel ratio at 85% load and a 35% / 65% natural gas/diesel ratio at an idle speed of 750 r.p.m.

2. **On-board Natural Gas Installation System** was carefully planned, designed and installed to meet all safety requirements and licensing conditions. As already stated the ferry was fitted with two (2) completely independent natural gas storage/supply systems, one (1) for each engine. Also there was no piping below the main deck nor cross connections between the separate banks of cylinders or main engines. (Following approval from Lloyds Register of Shipping and Transport Canada, Marine Safety Branch in 1998 for underdeck natural gas supply systems, the two (2) independent gas supply systems were cross connected underdeck.)

Safety features incorporated into the on-board natural gas system included: -

a) safety valves and vents and a breakaway connection built into the natural gas system to ensure system integrity in the event of an unplanned disconnection during fueling;

b) above deck installation of all natural gas storage cylinders, piping and connections;

c) "gas-tight" cylinder storage compartments inboard while being fully ventilated outboard;

d) ventilation holes in the cylinder containment shelters to prevent any gas pocket buildup;

e) fully approved natural gas storage cylinders (U.S. D.O.T. and C.T.C.), each fitted with two isolating valves and two bursting discs (failure pressure 3,600 p.s.i. (24.82 MPa) which, if activated, will ensure any escaping gas is vented overboard and upwards; *N.B. natural gas, being lighter than air will always move upwards when being released into the atmosphere);*

f) two independent natural gas storage and supply systems (one per engine) with no cross connections between the separate banks of cylinders or engines. *(Note: this is now changed with the system cross-connected under deck);*

g) controls to ensure automatic changeover from dual fuel to diesel fuel only if any of the following main engine malfunctions occur: -
- incorrect gas pressure;
- engine overload;
- low control air pressure;
- engine revolutions fall below 600 r.p.m.; or
- gas leakage at 40% lower explosive limit (L.E.L.);

h) gas detectors in each main engine room, in each cylinder storage space and in the battery space which are connected to gas alarms both in the wheelhouse and the machinery space;

i) a first level warning at 20% L.E.L. activates a flashing light and a horn in the wheelhouse and control station to alert the crew of a leak;

j) a second level warning signal at 40% L.E.L. automatically activates the remote controlled main gas valve at the cylinders to a closed position, thereby cutting off the natural gas supply and at which time the engines revert to diesel fuel;

k) a sprinkler deluge system within each gas cylinder storage compartment which, when actuated, will keep the gas cool in the event of a fire and assist in overboard disbursement in the case of a leak or discharge *(N.B. the system is automatically activated upon registration of a 40% level alarm);*

l) nitrogen introduction into the crankcase of the main engines in the eventuality of a crankcase explosion or an engine room fire; and

m) fixed $C.O._2$ smothering systems in each engine room which are manually operated from outside in the event of fire;

n) revised fire and safety drills;
o) preparation of a "Crew Safety Manual";
p) preparation of a "Damage Control Manual";
q) preparation of a "Gas Equipment Maintenance Manual and Plan"'

r) a training programme carried out for all ship and shore staff ... with special emphasis on engineering staff training;

s) a six month interval between pressure testing of gas line flexible connection;

t) inspection of one main engine after six months (approximately 3,000 hours) of operation;

u) an emergency shut off valve between the compressor station and the vessel which activates in any emergency (eg. a burst line, an electrical failure or a breakaway);

v) electrical and emergency shutdown controls for the shore side compressor;

3. **The Shore Installation** is comprised of a three-stage compressor, inter-coolers, a self-contained radiator, a cascade of fifty bottles and electrical, operating and emergency controls which are all housed in a 20'-0" long trailer "natural gas storage facility". Connections to the BC Gas (Utility) trunk pipeline and from the storage facility to dockside are also integral components of the shore installation. A pumping station is also provided for Ministry natural gas propelled vehicles.

Natural gas is supplied via the trunk pipeline at 120 p.s.i. (873 KPa). It is then compressed through three stages to a working pressure of 3,600 p.s.i. (24.9 MPa). Following compression, the gas is stored in fifty (50) 520 cubic foot (14.7 cubic meter) steel cylinders which provide a total storage capacity of 26,000 cubic feet (736.2 cubic meters) at 3,600 p.s.i. (24.8 MPa) on shore. The bottles are connected in groups of three and piped to a main manifold which connects to the ferry containment system.

The design of this compressed gas station allows for a "quick fill" of the KLATAWA's cylinders, with a full charge design time of three to four minutes. From the shore cylinders the compressed gas passes through isolating valves, non-return valves and pressure regulators to a hose connection. At the end of the hose the gas passes through a "breakaway disconnect" to the shipboard bunker connection station. Refueling follows a Transport Canada, Marine Safety Branch, approved procedure and is carried out under the supervision of the vessel's Chief Engineer.

The Ministry's cost in 1985 to convert the M.V. "KLATAWA" to a dual fuel operation was $347,000, this including development of shore side facilities. From the Ministry's records, annual fuel savings are over $58,000 and taking into consideration the main engines extended refit period at 30,000 hours, the Ministry calculate cumulative savings of $541,600 in 1990 dollars from the period 1990 to 1995.

M.V. "KULLEET" CONVERSION

With the success of the dual fuel operation on the M.V. "KLATAWA", her sister ferry M.V. "KULLEET", which operates on the same route, was similarly converted to dual fuel operation in 1988. In addition to the main engine conversion, the genset engines were also converted to dual fuel on a 75% / 25% mixture of natural gas/diesel whilst the hot air furnace was modified to 100% natural gas. These latter modification were installed in the M.V. "KLATAWA" in 1990 during her first refit following conversion in 1985.

Unlike the M.V. "KLATAWA" whose main engines were first opened up at 30,000 hours and found to be in first class condition, the main engines in the M.V. "KULLEET" ran to 60,000 hours before requiring overhaul. This is four times longer than the average diesel fueled engine and roughly equates to running a highway truck 2.4 million kilometres between overhauls. Quite impressive, when you consider the cost of the "KULLEET" dual fuel conversion to be $97,000 (no additional shore facilities were required).

Taking into consideration the higher natural gas/diesel mixing ratios, 91% / 9% for the main engines, the dual fuel generator engines and the natural gas fired hot air furnace, cumulative savings of $848,000 in 1990 dollars was calculated from the period 1990 to 1995.

Since conversion of the "KLATAWA" and "KULLEET", a variety of environmental benefits beyond the expected one of cleaner exhaust emissions have been realized. These are summarized as follows: -

- main engine noise reduction;
- fuel spill risk reduction; and
- reduced lubricating oil for disposal.

1. **Engine Noise Reduction.** When either the "KLATAWA" or the "KULLEET" are operating on diesel fuel, engine noise is noticeable. Under natural gas propulsion, the diesel "knock" disappears and explosions in the cylinder are softer. The quieter operation is an important advantage to passengers, crew and nearby businesses alike.

2. **The Risk of Fuel Spills** are reduced due to the design and operation of these ferries. Should an accident now occur, spillage would be less than half what it would have been before conversion because a full load of diesel is now 6,000 litres while it was 14,000 litres previously. During an accident, natural gas would be effectively vented overboard and upwards. Importantly. Since fuel spill risk is highest during bunkering, the "KLATAWA" and "KULLEET" are now operating with a much lower risk since bunkering takes place only every 14 days, compared to a 3-day cycle before conversion.

3. **A Reduction in the Amount of Lubrication Oil Used** on the dual fuel operations means that less lube oil needs to be disposed of. This reduces the pollution caused by disposal or recycling and the costs involved. In fact, with lube oil changes now every 700 hours compared to every 160 hours before conversion, less than one quarter of this waste pollutant now needs to be recycled.

M.V. "OMINECA PRINCESS"

Following the successful operation of these ferries on dual fuel, M.D.A. then prepared dual fuel conversion design plans on another Highway vehicle/passenger ferry, the M.V. "OMINECA PRINCESS". This is a conventional twin screw vessel with main engines and generator sets located below deck in a common engine room. As such, the natural gas piping and storage cylinders were also located below deck. The dual fuel conversion design is now approved by Transport Canada, Marine Safety Branch and the vessel awaits conversion once a 16 kilometre natural gas feeder pipeline ashore has been installed.

CENTURY CLASS FERRIES

The largest ferry for dual fuel conversion design completed by M.D.A. was on the Century Class Ferries for the British Columbia Ferry Corporation. One of these ferries has been completed and is in operation on a diesel fuel mode only but the remaining two (2) ferries, one (1) of which is scheduled to begin construction next year, are proposed to operate on dual fuel. These vessels are of 100 car/600 passenger capacity powered by four main engines each 1,400 HP and two 400 KW gensets located in a common underdeck Engine Room amidships. The natural gas supply piping and natural gas storage cylinders are also below deck, the cylinders stored in a gas storage compartment on centreline in a void compartment. Initially, the Owner wished a total natural gas operation rather than dual fuel, as proposed by M.D.A. but both Lloyds Register of Shipping and Transport Canada, Marine Safety Branch were averse to the total natural gas method unless there was a standby propulsion system operable on diesel. The cost of this standby system being prohibitive, the Owners elected for the dual fuel system. The dual fuel conversion design package is now approved by Transport Canada, Marine Safety Branch and also by Lloyds Register of Shipping, London head office, this approval being a first by an International Classification Society for the use of dual fuel aboard a passenger vessel.

The estimated annual fuel and maintenance cost savings operating on dual fuel is in excess of $100,000.00.

M.V. "OSPREY 2000"

This is the latest and newest vehicle/passenger ferry for the Ministry of Transportation and Highways. Preliminary designed by M.DA. it is an 80 car, 250 passenger capacity vessel with a 15 knots service speed for operation on the Kootenay Lake in the Interior of British Columbia. The ferry is powered by four (4) Caterpillar Model 3512B DITA Electronic engines and two (2) Caterpillar Model 3306TA, 190 KW generators. M.D.A. prepared the dual fuel conversion design drawings for the vessel and these were approved by Transport Canada, Marine Safety Branch.

The ferry is double ended and operates on a Roll On/Roll Off arrangement with vehicular traffic accommodated on the open Main Deck. Passenger and crew accommodation are located on both sides of the vessel in a 2 tier deckhouse arrangement over which a wheelhouse is centred atop a cross over structure.

The onboard natural gas installation when completed will comprise a gas bunkering system on the forward Main Deck, port side with compressed natural gas supply piping then led below deck to the gas storage bottles located in a module within a gas storage compartment on centreline entranced either end through an air lock compartment. The gas storage bottles, six (6) in number have a combined natural gas capacity of 55,000 standard cubic feet at 2,400 p.s.i. and take approximately eight (8) minutes to refill during bunkering. Originally on the "KLATAWA" and "KULLEET" such natural gas refueling could only be performed when all passengers and vehicular traffic were off the vessel. Following M.D.A.'s request to Transport Canada, Marine Safety Branch in 1997, that due to the location and height of the refueling station away from passengers and traffic and that any escaped natural gas would only rise due to its density, refueling of the natural gas system did not represent a hazard to the travelling public and as such could be carried out whilst loading and discharging of vehicle and passengers. This was agreed to by Transport, Marine Safety Branch.

Returning to the onboard natural gas system, the natural gas supply is then regulated down from the 2,400 p.s.i. within the gas bottles to 100 p.s.i. Following this the natural gas supply piping was then led through the tunnel walkway on centre line to the forward and aft Engine Rooms and at which time the gas pressure was regulated down to 40 p.s.i. pressure. Within the Engine Rooms the natural gas supply piping was then led to each of the main engines, and genset engines.

The safety features previously described in the KLATAWA will also be incorporated into the onboard natural gas system aboard the "OSPREY 2000".

It should be noted this natural gas system was to have been installed during the construction of the vessel but due to the Ministry's fixed time delivery of the ferry and penalty for late delivery, it was determined the dual fuel system be retro fitted over this winter season.

In addition to these dual fuel designs, M.D.A. have completed a number of Financial/Feasibility studies to determine the cost effectiveness on the implementation of dual fuel (natural gas/diesel) aboard various vessels. These provide the Owner with the estimated capital costs to convert their vessel(s) to a dual fuel system and which then plotted against a range of diesel prices can assist the Owner in determining the return on his initial investment.

M.D.A. VIEWS OF FUTURE DEVELOPMENT OF MARINE DUAL-FUEL SYSTEMS

Following the successful conversion of the ferry vessel "KLATAWA" in 1985 and "KULLEET" in 1988 to dual fuel operation and their proven fuel and maintenance savings, M.D.A. stood back awaiting further dual fuel conversion designs. With the exception of further orders from the British Columbia Ministry of Transportation and Highways and the BC Ferry corporation, there was very little interest expressed elsewhere although several feasibility studies were prepared for other parties, these usually occurring when diesel fuel prices were high.

Paul Jensen of Energy Conversions, whose son Scott is here to-day as one of the Panel Members, will testify that following their successful conversion of a Burlington National Railway engine to operate on LNG in 1985, further orders did not ensue until years later and these were orders generally relevant to the offshore oil industry.

Today, with the concerns of the greenhouse effects and damage to the ozone layer, Governments world wide have begun to recognize that something has to be done to reduce present day emissions whether it be from factories, cars, buses, or marine vessels. The automobile industry and engine manufacturers are already working on this pollution problem and the latest engines built to-day are more fuel efficient and environmentally friendly with noticeable reduced emissions. However, more need be done in other industries including that of the marine industry and it is the considered opinion of M.D.A. that this will happen here first of all in the State of California and from experience, will carry on to the remainder of the United States and the world. M.D.A. trust the exhaust emission levels set by the State are reasonable and achievable.

Pertaining to the Private Sector of the Marine Industry cost incentives must be made to the Owners to convert their vessels to operate on dual fuel (natural gas/diesel) since there is a capital cost outlay at the beginning. Such incentives would be seen to be governmental whether it be from the Federal or State coffers or a combination of both. Such incentive may be in cash or in a form of tax credit.

With regards the technical aspects in the future development of marine dual fuel systems, M.D.A. would suspect an increase in the use of Liquified Natural Gas (LNG) aboard dual fuel vessels as was incorporated in the recently built Norwegian ferry and the ferries in Virginia. It was also used by Dr. Brett in his conversion of the workboat MERV 1 in 1988. The main benefit of an LNG system is its ability to store a large volume of gas in a smaller containment system with a possible lesser weight than that of compressed natural gas (CNG) as was used in the "KLATAWA" and "KULLEET". In the case of the latter two (2) vessels there was no ready availability of LNG at that time, and it was considered that Transport Canada, Marine Safety Branch would be more amenable to the use of CNG aboard the ferries than LNG. M.D.A. are presently entering into a study with the BC Ferry Corporation to examine the use of LNG as a dual fuel aboard their ferries.

Aside from the natural gas form aboard the vessel whether LNG or CNG, M.D.A. foresee the use of dual fuel (natural gas/diesel) being expanded from ferry systems into tugboats, feeder and vessels, and coastal cruise ships when in port.

M.D.A. would note that all the equipment necessary for dual fuel conversion is readily available off the shelf here in North America. Also although there are few engine manufacturers in North America building dual fuel (natural gas/diesel) engines, there are a number of smaller competent engineering companies cable of retro-fitting these engines to operate on dual fuel (natural gas/diesel).

In closing, M.D.A. feel optimistic that the age of dual fuel (natural gas/diesel) is about to dawn and become a standard method of propulsion.

Thank you for your interest and attention.