A New Quench Boiler for the Ethylene Plant*

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Summary: In order to keep steady operation and to minimize the operating cost of an ethylene plant, Quench System for high temperature effluent gas from a cracking furnace is of primary importance.

Mitsubishi Petrochemical Co., Ltd. and Mitsubishi Heavy Industries, Ltd. have jointly developed a new Quench Boiler (M-TLX) with excellent process and mechanical performances for feedstocks such as Ethane, Naphtha as well as Heavy Gas Oil.

The first commercial units were installed in the Kashima Ethylene Plant of Mitsubishi Petrochemical in June, 1970 and have satisfactorily been operating for more than one year.

M-TLX has actualized an economical quenching technology for various feedstocks, especially for feedstocks heavier than Naphtha.

M-TLX has also actualized a simplified chemical decoking procedure which can be carried out without shut-down of the cracking unit.

It is believed that M-TLX has opened a way to solve operation difficulties of the cracking unit caused by miscellaneous processes and mechanical troubles and to minimize the operating cost because of its steady process performance, mechanical stability and easy maintenance procedure.

1 Introduction

At present, the principal raw materials for ethylene production are Natural Gas in the United States and Naphtha in Europe and Japan. However, it is forecasted that in near future the raw material will be extended to Kerosene and Gas Oil due to the shortage and rise in price of Natural Gas and Naphtha.

In recent ethylene production technology, thermal cracking of hydrocarbons is generally carried out in such a high temperature range from 750 to 900°C. Therefore, in principle, it is required for a quench system to cool down the high temperature cracked gas as quickly as possible to 600°C or lower to prevent undesirable side reactions and to separate each component involved in the cracked gas at the successive separation zone. At the same time it is obviously desirable to recover the heat energy of furnace effluent as high pressure steam from the economical point of view.

In quench technologies hitherto commercialized, an indirect quench boiler was applicable for the cracked gas of Natural Gas and Naphtha in spite of operation difficulties due to coke formation and mechanical troubles, but it is quite difficult to apply an indirect quench boiler for the cracked gas of Gas Oil because of more

deposition of coke on its inside surface.

It was the objective of our joint efforts to develop Mitsubishi Transfer Line Heat Exchanger (M-TLX) which can be applied for cracked gas of Natural Gas, Naphtha as well as Heavy Gas Oil, preventing coke formation and mechanical troubles in a quench boiler and recovering heat energy as high pressure steam.

2 Process Description of M-TLX

2.1 Flow Sequence of Quench System

Fig. 1 shows the schematic flow diagram of M-TLX quench system.

In the cracking furnace, the feed hydrocarbons such as Ethane, Naphtha and Gas Oil are thermally cracked. The thermally cracked gas mixture from the cracking coil is immediately introduced to the indirect quench boiler "M-TLX" and cooled down to the temperature level of 600°C or lower. In this temperature range, essentially all of the reactions such as thermal cracking, polymerization and polycondensation are considered to be terminated.

The effluent gas from M-TLX is furthermore cooled by M-QF (Mitsubishi Quench Fitting) to a temperature level at which cracked gas mixtures are separated into useful products.

Water will be directly injected into the process gas at M-QF for Ethane or Natural Gas cracking, while Quench Oil will be directly injected for Naphtha or Gas Oil cracking. For both cases, thus cooled cracked gas is introduced to the first separation tower where cracked gas is sepa-

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Fig. 1 Process Flow Sequence of M-TLX Quench System

rated from water and components heavier than C_{10} hydrocarbons.

Water or heavier components drawn from the first separation tower will be circulated to the M-QF to be used as a cooling medium. In this recycling system, medium pressure steam can be generated from the hot quench oil.

2.2 Process Description of M-TLX

From the standpoint of process design, it is of primary importance to keep steady operation by minimizing the possible coking troubles.

As the basic process design conditions of M-TLX, the maximum pressure drop across M-TLX after fouling is limited within 0.3 kg/cm^2 to keep optimum cracking pressure in cracking coils.

The optimum outlet gas temperature of M-TLX is determined by properties of feedstocks and cracking severity, but in general tends to become higher for heavier feedstocks and severe cracking conditions.

The lower outlet gas temperature of M-TLX is desirable for the generation of more quantities of high pressure steam in M-TLX but it must be limited to some extent to minimize a harmful coke formation.

So far as the design of steam pressure in the shell side of M-TLX is concerned, any pressure range from 60 to $150 \text{ kg/cm}^2\cdot\text{g}$ can be taken.

And hence, optimum point should be determined so as to give the most economical overall steam system in the ethylene plant.

Author's economic study indicates that the most economical pressure level exists in the range of 80 to $100 \text{ kg/cm}^2\cdot\text{g}$, depending upon local conditions of individual ethylene plant.

3 Mechanical Description of M-TLX

3.1 Construction

Fig. 2 illustrates the construction of M-TLX. M-TLX is a vertical shell and tube type heat

Fig. 2 Construction of M-TLX

exchanger composed of a gas inlet channel, a shell drum, a double tube system with special devices, a gas outlet duct and a steam dome. M-TLX is installed on the top of the furnace structure for a vertical type cracking furnace and on the ground for a horizontal type cracking furnace, and directly connected with cracking coils for both types. The hot cracked gas of 750 to 900°C is fed to the gas inlet channel and goes upward through the cooling tubes. The cooling water is fed to the shell side and high pressure steam of 60 to $130 \text{ kg/cm}^2\cdot\text{g}$ is generated.

It should be noted that mechanical stability is the most important requirement for a Quench Boiler to keep steady operation under these severe operating conditions.

All of the possible emergency conditions, such as failure of boiler feed water or troubles of instruments, are carefully studied and taken into account as design conditions of M-TLX.

In addition to these basic requirements, M-TLX is designed to perform unique chemical decoking procedure which is carried out at 700°C and without existence of any water in shell side.

Many unique constructions in each part and in assembly of them have been developed to satisfy all of these difficult requirements.

3.1.1 Gas Inlet End

The gas inlet end of M-TLX is composed of the gas inlet channel and ring headers which is connected with the shell by an unique double tube system.

This gas inlet end protects the thick shell from direct contact with the hot cracked gas.

The gas inlet channel has multiple gas inlet nozzles which are directly connected with each

cracking coil. In **Fig. 2**, two nozzles are illustrated. This multi-nozzle method eliminates complex and troublesome manifold of cracking coils, and solved such troubles as coking, gas leakage and mechanical failures.

The inside of the gas inlet channel is partially consisted of horizontal flat surface for the capture of coke pieces which are carried from the cracking coils.

For Ethane Cracking, special devices of the inlet gas channel are required to prevent coke formation whose mechanism differs from that of other feedstocks.

3.1.2 Double Tube System of Inlet End

The unique double tube system was newly developed to protect the shell bottom from hot cracked gas and to avoid local thermal stress caused by direct contact of the shell and hot cooling tubes. Double tube system is composed of ring headers, external tubes which have a cooling tube in their inside, and down-comers of cooling water.

External tubes are welded with ring header at the lower end and with the bottom head of shell at the upper side and the upper end of external tubes is opened at the inside of the shell.

Cooling water of the shell can easily circulate through down-comers, ring headers and double tubes by natural circulation.

3.1.3 Cooling Tubes

The cooling tubes are arranged concentrically on ring headers and formed in spiral at the inside of the shell.

The difference of thermal expansion between the shell and tubes caused by their temperature difference is easily released by tubes of spiral form.

3.1.4 Shell

The shell contains a number of cooling tubes of spiral form and a down-comer in the center.

The down-comer facilitates natural circulation of cooling water in the shell and in the double tube section.

3.1.5 Gas Outlet Duct

Cooling tubes which pass the double tube system and the shell are connected to the gas outlet duct. The gas outlet duct has a horizontal gas outlet nozzle and many baffle plates to regulate the flow of the cracked gas.

The level of the horizontal gas outlet nozzle is lower than the upper end of cooling tubes, thus all of coke pieces which are carried from cracking coils can easily flow out and do not accumulate in the gas outlet duct.

3.1.6 Steam Dome

The steam dome contains two types of steam-water separators. One is a baffle type for rough

separation and another is a wire-mesh type for complete elimination of moisture from product steam.

A cyclone type separator can be equipped in the steam dome, when boiler feed water contains considerable amount of steam moisture.

The moisture content in product steam is less than 0.3 wt% and consequently any other drain separator is not required.

3.2 Materials

The materials of each part were carefully studied to satisfy severe design conditions as discussed in chapter 3.1, and it was decided to use materials of high quality as a result of economic studies considering increase of the initial investment and decrease of the maintenance cost in the operation.

Thermally treated 2¼ Cr-1 Mo steel is used for ring headers, the double tube system, cooling tubes, and the gas outlet duct. Incoloy 800 or equivalent is used for the high temperature section of the gas inlet channel. Carbon steel is used for the shell, the steam dome and other pressure parts according to the boiler code to be applied.

3.3 Instrument of M-TLX

Fig. 3 indicates a typical instrumentation system of M-TLX.

Two or three of M-TLXs which are installed on one cracking furnace are connected together through the pressure balance line of shell side and the steam product line. Consequently the pressure of each M-TLX is completely equalized both in the steam side and in the water side by the above mentioned connections. Therefore, a set of M-TLXs installed on one furnace can be treated as one boiler and only one set of instrument equipment is required according to the boiler code.

Water level is controlled by one level controller for a set of M-TLXs which is connected with

Fig. 3 P & I Diagram of M-TLX

boiler feed water control valve.

Also, the steam pressure of the shell side is controlled by one pressure control valve for all of M-TLXs in an ethylene plant.

The quality of boiler water in shell side is observed by an automatic analyser.

3.4 Capacities and Dimensions

The maximum capacity and dimension of M-TLX which can be fabricated are shown on **Table 1** and **2**.

Table 1 Capacities of M-TLX

	Maximum Feed Rate H. C. & STM (t/hr)	Pressure Drop After Fouling (kg/cm ²)
Ethane	19.0	0.3
Naphtha	21.0	0.3
Kerosene	21.0	0.3
Light Gas Oil	21.0	0.3
Heavy Gas Oil	21.0	0.3

Table 2 Dimensions of M-TLX

Inside Diameter	1,370~1,600 ϕ mm
Overall Height	5,100~8,000 mm
Weight	18~40 t

The weight of M-TLX is 18 to 40 tons per one unit according to design pressure of shell side and capacity of M-TLX.

4 Process Performance

4.1 Feedstock

M-TLX can be designed to handle a wide range of feedstocks from Ethane to Heavy Gas Oil.

Table 3 shows typical properties of various feedstocks for which M-TLX has proved the completely successful operation in the proto-type test unit.

Table 3 Typical Properties of Feedstocks

Feedstock	Quality	Specific Gravity	Boiling Point (°C)		
			IBP	50%	EP
Ethane	—	—	—	—	—
Full Range Naphtha	0.70	35	94	175	
Heavy Naphtha	0.74	38	131	198	
Raffinate	0.76	67	104	264	
Kerosene	0.80	166	208	250	
Light Gas Oil	0.83	206	284	367	
Heavy Gas Oil	0.85	220	342	415	

4.2 Process Performance

Fig. 4 shows the typical operation data of M-TLX for Ethane, Full Range Naphtha and Gas Oil as feedstocks.

As clearly shown in **Fig. 4**, the pressure drop across M-TLX and the outlet temperature are

Fig. 4 Typical Operation Data of M-TLX

stabilized within about two weeks after start up and thereafter these parameters are substantially constant throughout the operation period.

These process performances indicate that the coking rate in M-TLX is negligibly small during the stabilized period, promising the steady operation of cracking unit without any coking trouble.

To achieve these unique process performances, it was necessary to investigate the coking mechanism in a Quench System and to know how to avoid the coke formation in Quench System.

In the course of the development work of M-TLX, extensive works on the coking mechanism have been made for various combination of feedstocks and cracking conditions, using an experimental pilot plant and a proto-type test plant with same scale as a commercial use.

It has been clarified through these basic investigations that there exists a quantitative relationship between the rate of the coke formation and properties of feedstocks, cracking conditions as well as quenching conditions.

This relationship obviously leads to noble ideas for suppressing a coke formation, which have been introduced in our M-TLX quench system.

4.3 Decoking Interval

The decoking interval of M-TLX is longer than that of a cracking furnace because of negligibly small coke formation; namely the pressure drop and gas outlet temperature of M-TLX are substantially constant for any feedstock and for any cracking conditions.

Practically speaking, therefore, the decoking of M-TLX is not necessary. When M-TLX is installed, the decoking interval of the cracking unit is determined by the metal skin temperature of cracking coils which almost linearly increase due to the deposition of coke on the inside surface of the cracking coil.

4.4 Recovery of High Pressure Steam

M-TLX can generate high pressure steam from the hot cracked gas, and it is believed that

Table 4 Steam Production Rate

Feedstock	Steam Make	Steam Make
	1 ton of Feedstock (t/hr)	1 ton of Ethylene (t/hr)
Ethane	1.70	0.45
Naphtha	1.40	0.56
Kerosene	1.20	0.55
L. Gas Oil	1.10	0.55
H. Gas Oil	1.00	0.54

Note; above figures are calculated on the basis of the typical cracking conditions and the saturated boiler feed water.

M-TLX is the world's first commercial indirect quench boiler which enables heat recovery as high pressure steam from Gas Oil Cracking.

The steam product ratio versus product ethylene is shown in **Table 4** for various feedstocks.

The steam production ratios are almost constant for various feedstocks and the total quantities of the high pressure steam generated by M-TLX are in balance with or slightly in excess of the steam required for driving the major compressors in an ethylene plant.

5 Decoking Procedure of M-TLX

The most troublesome procedure in the cracking unit of the ethylene plant was the decoking of the cracking coil as well as the indirect quench boiler.

M-TLX has succeeded to simplify the decoking procedure considerably and to shorten the line-off time of cracking unit.

The decoking of the cracking coils and M-TLX is simultaneously carried out by steam and air at 700°C without shut-down of the unit and without labor for mechanical cleaning. The typical decoking procedure of M-TLX, which is named "On Line Decoking" is shown in **Fig. 5**.

The procedure of the On Line Decoking is basically the same as that of usual cracking furnace.

Three tons of steam and about 30 weight per-

Fig. 5 Typical Procedure of on Line Decoking

cent of air which are fed to the inlet end of cracking coils burn the cokes deposited inside the cracking coils and M-TLX at about 700°C, and then, are purged out to the atmosphere at the down stream of M-TLX.

During On Line Decoking period water is completely drained out from the shell side of M-TLX, so that the metal temperature of all the cooling tubes is kept at about 700°C.

All of the coke can be completely removed and M-TLX resumes original clean condition by the On Line Decoking.

The excellent performance of the On Line Decoking has been proved in the proto-type test unit and in the commercial plant.

From our commercial experience, the On Line Decoking of the cracking unit is completed within only 25 hours from on stream to on stream.

By applying this On Line Decoking to the cracking unit, the total stream days of the unit can be increased by about 3 percent through the year.

6 Industrial Application

The first commercial application of M-TLX was 300,000 t/yr Ethylene Plant of Mitsubishi Petrochemical Co., Ltd. which was built in

Table 5 Fabrication Records of M-TLX

Purchaser	Number	Design Pressure (kg/cm ² ·g)	Feedstock	Start Up	Note
Mitsubishi Petrochemical	1	60	Naphtha, Gas Oil	1968	Test Plant
"	1	130	Naphtha	1969	MTC Furnace
"	1	130	Gas Oil	1970	MTC Furnace
"	1	90	Ethane	1970	Selas Furnace
"	28	130	Naphtha	1970	3000,000 t/yr E. Plant
Shindaikyowa Petrochemical	20	130	Naphtha	1971	Lummus Process
Tonen Petrochemical	20	130	Naphtha	1971	300,000 t/yr E. Plant
Mitsubishi Petrochemical	1	15	Ethane	1971	Lummus Process
Maruzen Petrochemical	4	140	Naphtha	1972	300,000 t/yr E. Plant
Idemitsu Petrochemical	1	150	Naphtha, Gas Oil	1972	Esso Process
					Selas Furnace
					Lummus Furnace
					(Extension)
					Test Plant

Kashima of Japan.

The Kashima Plant has been operating since June of 1970, and the performance of M-TLX was perfect as expected. The other commercial experiences are shown in **Table 5**.

7 Conclusions

M-TLX has actualized the economical quenching technology for various feedstocks, especially, for feedstocks heavier than Naphtha.

M-TLX has also actualized the simplified

chemical decoking procedure which can be easily carried out without shut-down of the cracking unit.

It is believed that M-TLX has opened a way to solve operation difficulties of the cracking unit and to minimize the operating cost because of its steady process performance, mechanical stability and easy maintenance procedure.

References

- 1) Japanese Patents, 46-11,208, 46-24,681.
- 2) U. S. Patent, 3,570,458.
- 3) Italian Patents, 864,160, 872,263.