MIXING ELEMENT RADIANT TUBE (MERT) OFFERS NEW CONCEPT FOR ETHYLENE STEAM CRACKING PROCESS

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ABSTRACT

Mixing Element Radiant Tube (MERT) is a centrifugal cast cracking tube with a spiral element protuberate inside of it. The concept of the mixing the feed gas is introduced in the ethylene steam cracking technology for the first time. The mixing the feed gas in the tube appears to afford homogeneity in gas temperature which provides minimizing under and over cracking and consequently maximizing proper cracking volume. This means that higher yield of ethylene and/or propylene with lower coking rate can be expected. Moreover, effective heating with breaking boundary film by mixing flow provides reducing tube metal temperatures which result in extending tube life. The concept of MERT and its verification test is described.

INTRODUCTION

In a petrochemical industry, olefins such as ethylene or propylene is produced from hydrocarbon by thermal cracking process. In the process, cracking tubes are used in several types of coils. The feed gas ,typically naphtha or ethane and steam gas, flows inside of the cracking tube at high velocity. The tube is heated at high temperature from the outside of the tube - within a pyrolysis furnace. During the passage of the feed gas throughout the coils, it is thermally cracked into ethylene, propylene, and so on (see Fig. 1).

There have been a lot of developments in ethylene pyrolysis furnace to increase capacity, improve yield and thermal efficiency and reduce downtime for maintenance and decoking along with material developments (1)(2) and improvement in tube size and shape(3).

MERT or mixing element radiant tube , is a centrifugal cast cracking tube with a spiral mixing element on the inside diameter(see Fig.2), and provides new concept for improving steam cracking process.

By the mixing of the feed gas:

1. Homogeneous heating can be achieved.
2. The feed gas flow inside of the tube, can be effectively heated thus breaking the boundary film which act as an insulator effecting heat transfer at the metal gas interface.

Homogeneous heating of the feed gas inside the tube can minimize both under and over cracking as well as maximizing proper cracking volume. Therefore it is reasonable to assume that a) ethylene and/or propylene yield can be increased and b) coking can be reduced.

In order to verify the effect of the mixing element, computational fluid dynamic (CFD) analysis was applied to both smooth tube (Bare Tube) and MERT using hot air. As shown in Fig. 3, homogeneous heating of the gas inside of the tube can be expected in MERT. The advantage of homogeneous heating of the feed gas is illustrated in Fig. 4.

Effective heating can provide an energy saving and reduce tube metal temperature which is normally related to coking rate. Therefore tube life can be extended, run length can be extended because of lower coking rate, and firing can be increased as much as the temperature drop as well as production increase without sacrificing tube life.

Based on this new concept of cracking tube, MERT was developed to apply to commercial ethylene cracker.

The material used for MERT is KHR45A(43Ni-31Cr-Nb,Si,Ti) which is superior grade of conventional HP alloys for the mother tube and KHR45A mod. for the element. The element in the MERT is well integrated to the mother tube, and has excellent properties of carburization resistance, thermal shock resistance, and anti-coking.

This paper mainly described the performance of the MERT both in pilot test plant and commercial plant.

EXPERIMENTAL

Experimental 1

In general, internal protrusions in the cracking tube have been considered a cause of coking due to stagnation of the feed gas where over cracking might occur(4). The MERT element is designed in a spiral shape to produce a "swirl flow", thus eliminating stagnation of the feed gas(see Fig. 5). The visualization tests were performed to confirm the "swirl flow" in each tube size and element angle(see Fig. 6).

In the design of the element, pressure drop (delta P) and heat transfer coefficient should be taken into account. As shown in Fig. 7, the heat transfer coefficient and pressure drop was measured by air test. The air supplied from a blower is controlled in the flow rate by the air damper. And the tests were carried out within the range of the Reynolds Number between $2.5x10^4$ and $2x10^5$. The heat was supplied from hot water or well controlled electric heater from outside of the pipe. Inlet temperature and outlet temperature were measured by thermocouples. Then the heat transfer coefficients of the boundary film were calculated.
In the same way, the pressure drop was measured from the measurement of the pressure difference between inlet and outlet pressure.
These measurements were performed on both bare pipe and MERT in each test.
The pressure drop and boundary film heat transfer coefficient depend on both element angle and fluid velocity. In order to apply MERT technology practically in an ethylene furnace, these data should be made available.

Experimental 2

In order to verify the concept of MERT described in Fig. 4, pilot plant tests were performed.
As shown in Fig. 8, the tube used in this test was 2 inch O.D. and 1.5 inch I.D. and 3.6 M in length. The element angle in MERT was 30° and element height was 2.5mm. The furnace used in this test had electric heater separated in three zone which were independently controlled. The feed gas flows from top to bottom. The composition of the naphtha used is shown in Table 1. The steam to feed ratio was 0.5 for naphtha and 0.3 for ethane respectively. The system of the pilot plant was quite similar to that of commercial plant.
The product was immediately quenched just after the outlet of the tube and the product yield was analized by G.C. The coking amount was measured by the analysis of CO and CO_2 as well as the measurement of the temperature during de-coking.

Experimental 3

In order to verify the performance of the MERT tubes, they are testing in commercial plants. Fig. 9 shows an example of the result of U coil furnace. The MERT tubes were installed in one quadrant of the furnace in two types of modes, applied MERT to both inlet and outlet tubes and to only outlet.
The pressure drop , Tube Metal Temperature(TMT), and feed increase was measured throughout the run length.

RESULTS AND DISCUSSIONS

The heat transfer coefficient of MERT is ,however it is depend on tube size, the element angle and height, and velocity of the gas, normally 20 to 50 % higher than that of smooth tube (Bare tube) while its increasing of heat transfer area is only around 1%.
So it is expected that TMT must be lower than that of bare tube under the same firing condition.
In the pilot plant test using naphtha as a feedstock, when the temperature was adjusted at the same TMT, the feed rate of the MERT could be increased by 40%. And under the same TMT, coking rate of MERT was about 50% lower than that of bare tube. Moreover both ethylene and propylene yield was increased by MERT(see Table 2 - test 1).
When the feed rate was adjusted at the same, TMT of MERT was 24℃ lower than that of bare tube. In this condition, coking rate of MERT was around 50% lower and ethylene and propylene yield was also increased in MERT.(See Table 2-test 2).
The test data shown in Table 2 is under the P/E ratio of 0.45 which is severe condition. The tests were carried out in the range of P/E ratio from 0.45 to 0.70, and the same tendency, especially the increasing of the yields was observed in all tests.

In ethane test (see Table 3), when the conversion was adjusted at the same of 65%, the TMT of MERT was 56 ℃ lower than that of bare. And ethylene yield could be increased by 3%. When the selectivity was adjusted at the same level, ethane conversion of MERT should be raised up. Even in this condition, the TMT of MERT was 25℃ lower than that of bare tube.

In this case, the ethylene yield was 8% higher than that of bare. The test result also suggested that coking rate of MERT was much less than that of bare.

Based on these pilot plant tests, it can be said that the concept described in Fig. 4 was somewhat occured in actual furnace.

Because no catastrophic coking problem was reported in commercial plants where MERT tubes were preliminary installed, MERT performance tests in commercial plants were started. Firstly MERT test was performed in U coil furnace in1997. In the test operation, the TMT of MERT was found to be approximately 50F lower than that of the other bare tubes in the same furnace. This may suggest that if the firing could be increased as much as the temperature drop of MERT, the capacity could be increased by 33% without sacrificing tube life. Due to efficient heating by MERT, the feed rate of MERT section was 2 to 3% higher than the average value of Bare section under the same firing condition. The most remarkable point was that the pressure drop increasing rate of MERT was 2/3 of that of bare tubes. This may suggest the MERT has less coking rate than the bare tubes and can extend run length by 50%.

CONCLUSION

Through the above mentioned tests, it is found MERT has mixing effect and has following advantages.

Higher capacity, Extend tube life(Low TMT), Extend run length(low coking rate)

The yield improvement is now studying in commercial furnace tests and computer simulation. Because ethylene cracking tubes are used in several types of coils[(2)(3)], several factors such as the coil arrangement, the length of MERT, the position installed should be taken into accountin the adequate application of MERT to commercial plants. The MERT has a internal protrusion which may cause for higher friction factor which is related to higher pressure drop. The higher the pressure drop, the longer the residence time which may cause for decreasing yield. The mixing effect in MERT should overcome the pressure drop effect.

It was reported that thousands of chemical reactions might be occured in the hydrocarbon thermal cracking process[(5)], and these decompositions might be endothermic reactions. In order to estimate the mixing effect, theoretically and experimental approach should be required.

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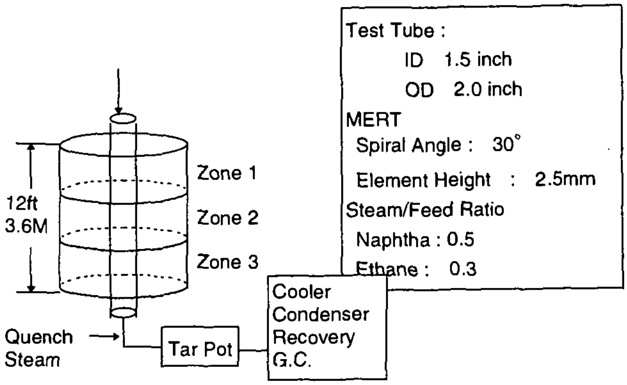

Fig. 8 Pyrolysis Pilot Plant Test

Table 1 Naphtha Composition (wt%)

Paraffins	28.06
Isoparaffins	34.70
Aromatics	11.35
Naphthens	23.96
Olefins	0.68

C4's	P	0.06
	I	0.07
C5's	P	12.24
	I	13.21
	N	0.40
C6's	P	9.09
	I	6.85
	A	0.75
	N	11.51
	O	0.00

C7's	P	5.36
	I	8.69
	A	5.56
	N	11.38
	O	0.40
C8's	P	1.07
	I	5.43
	A	5.04
	N	0.63
	O	0.28

C9's	P	0.23
	I	0.29
	A	0.00
	N	0.03
C10's	P	0.00
	I	0.16
	N	0.02
C12's	N	0.00
	A	0.00
C15's	P	0.00
	I	0.00

Table 2 Prototype Test of MERT (Naphtha) P/E : 0.45

Test 1	MERT	Bare
Ethylene Yield (wt%)	27.6	25.3
Propylene Yield (wt%)	12.4	11.4
Feed Rate (kg/h)	12.0	8.4
TMT (℃)	892	892
Coking Rate (g/h)	0.68	1.34

Test 2	MERT	Bare
Ethylene Yield (wt%)	27.6	25.5
Propylene Yield (wt%)	12.4	11.6
Feed Rate (kg/h)	12.0	12.0
TMT (℃)	892	916
Coking Rate (g/h)	0.68	1.47

Table 3 Prototype Test of MERT (Ethane)

Test 1	MERT	Bare
Ethylene Yield (wt%)	52	49
Ethane Conversion(%)	65	65
Ethylene Selectivity(%)	80	75
TMT (℃)	1003	1059

Test 2	MERT	Bare
Ethylene Yield (wt%)	57	49
Ethane Conversion(%)	75	65
Ethylene Selectivity(%)	76	75
TMT (℃)	1034	1059

Test 3	MERT	Bare
Coking Rate (g/h)	1.3	3.3
TMT (℃)	1034	1059

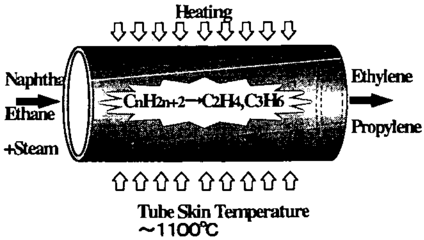

Fig. 1 Cracking Tube

Fig. 2 Cross Sectional Overview of MERT

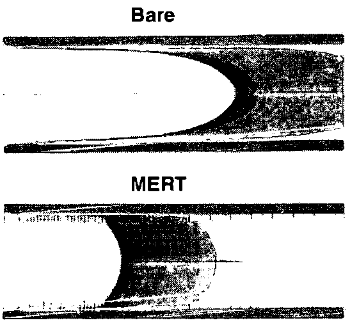

Fig. 3 Analysis of Fluid Temperature

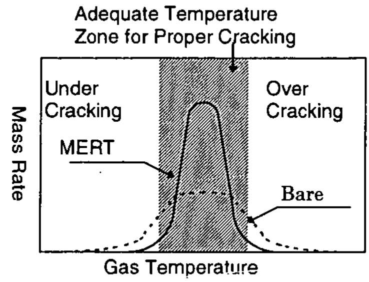

Fig. 4 Homogeneous Chemical Reaction in Tube

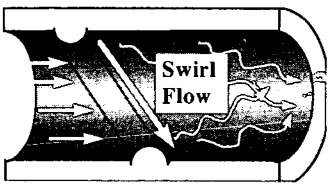

Fig. 5 Swirl Flow

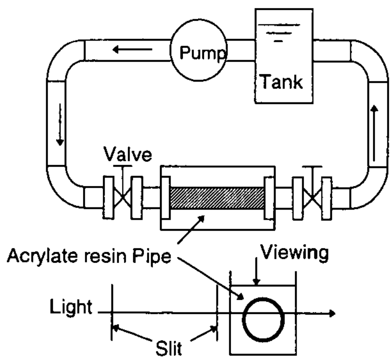

Fig. 6 Visualization Test by Water Flow

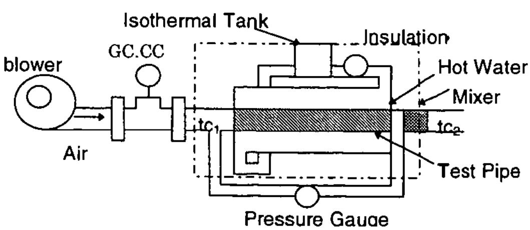

Fig. 7 Heat Transfer Coefficient and Pressure Drop Measurement Apparatus