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Modernizing a Tubular Reactor from a Petrochemical Plant in Order to Increase the Production Capacity

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Abstract

In this paper we suggest, in an original way, the modernizing and designing of a tubular reactor from a petrochemical plant, isomerization section (methyl-tertiary-butyl-ether) in order to increase the production capacity.

Key words: *tubular reactor, petrochemical plant, production capacity*

Generalities

In order to increase the production capacity of the plant (methyl tertiary butyl ether) it is important to introduce in the flow sheet a modernized RXA reactor, along with the existing RXB reactor. We will obtain the following advantages:

- increasing of the conversion in the isomerization section due to the slower volume flow;
- avoiding the plant's shutdown in order to change the used catalyst.

The reactors are thermochemical equipment that performs simultaneously the technological process and the heat transfer. For this equipment, the heat transfer between the two fluids is realized almost integral at the level of the surfaces of the elements that represent the intermediate filling that it contacts the gases and the liquid droplets. Compared to the void heat exchangers, for the ones with filling it can be obtained an enlargement of the heat exchange surface, in order to reduce the dimensions of the equipment.

Description of the Existing Equipment

The RXA reactor is a vertical reactor used to hydrogenate the hydrocarbons, having the tubular beam fixed with flanges. The equipment was built for low corrosive fluids against carbon steel, both in the shell space and in the tubular space.

The suspension is made on four lateral supports. The equipment is a welded carbon steel construction having technological connections.

The tubular beam (room where C_5 + hydrogen + catalyst fraction will flow) is made of tube plates welded on the shell of the equipment and 374 pipes $\varnothing 57 \times 4$ mm, arranged in triangle

with a step of 67 mm, on a single transit. The filling, respectively the catalyzer from the RXA reactor, is a catalyzer typical for the ions exchange, namely: Amberlyst 35.

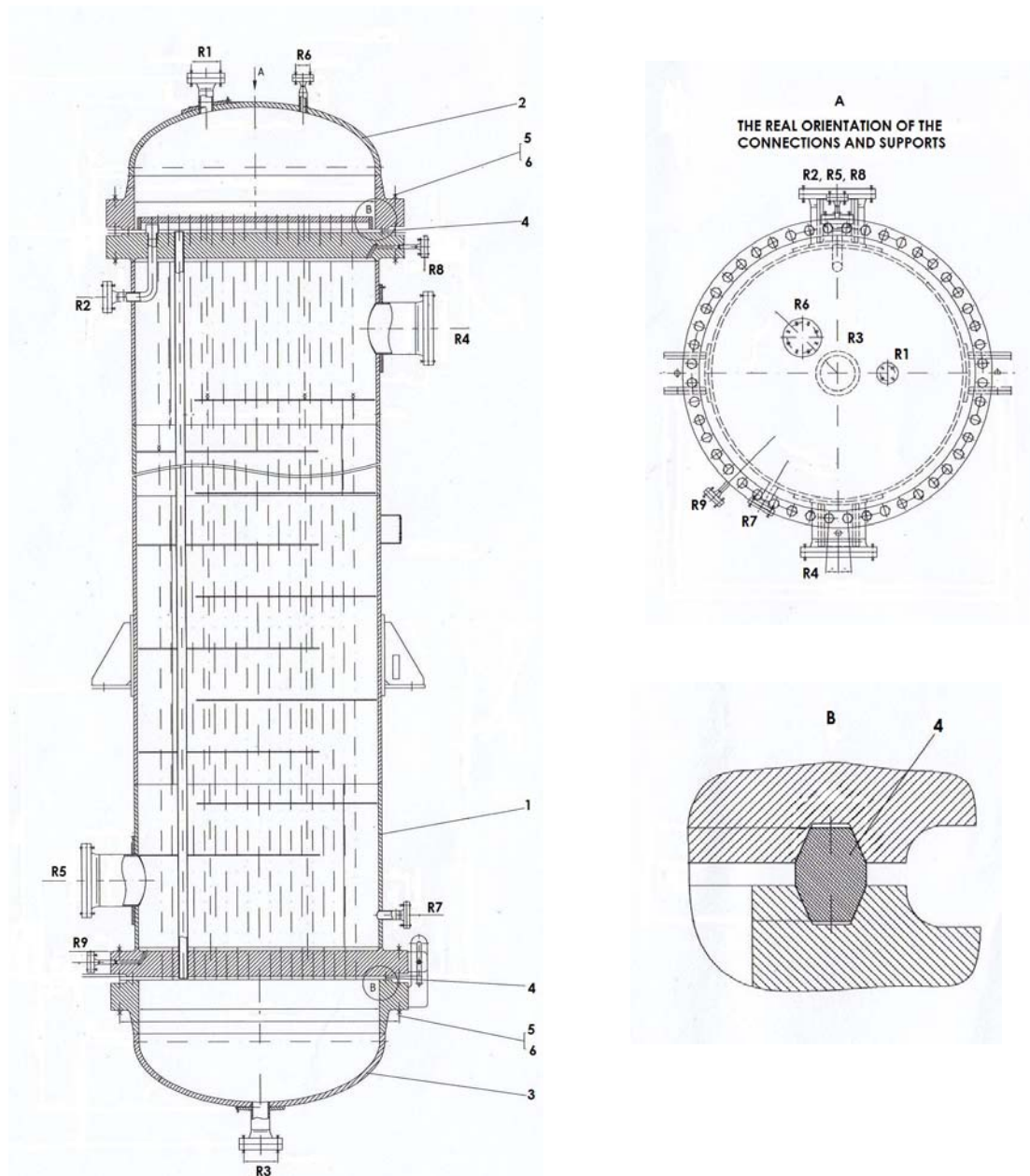


Fig. 1. RXA Reactor: 1 – shell; 2 – cover; 3 – bottom; 4 – biconical ring; 5 – double-ended bolt; 6 – bolt nut; R1 – effluent inlet; R2 – product inlet; R3 – effluent outlet; R4 – water inlet; R5 – water outlet; R6 – manometer connection; R7 – water drain pipe; R8 – vent pipe; R9 – waste water drain pipe.

The main technical characteristics of the reactor are:

- maximum allowable working pressure:
 - o in the shell: 0.8 MPa;
 - o in the pipes: 6.0 MPa.
- walls temperature:
 - o maximum allowable working temperature: 75⁰C in the shells and 100⁰C in the pipes;
 - o calculus temperature: 100⁰C in the shell and 100⁰C in the pipes;

- o minimum allowable working temperature: 20⁰C in the shell and 30⁰C in the pipes;
- volume: 4.75 m³ in the shell and 6.25 m³ in the pipes;
- heat transfer area: 374 m²;
- empty reactor mass: 30450 kg.

The main characteristics in terms of dimensional and materials are:

- the reactor shell:
 - o shell diameter: 1500 mm;
 - o shell thickness: 20 mm;
 - o total length: 6000 mm;
 - o material: R3;
- tubular plates:
 - o outside diameter: 1850 mm;
 - o plate thickness: 182 mm;
 - o hole diameter for pipe: 57^{+0.10} mm;
 - o distribution of holes: triangle;
 - o step between holes: 67 mm;
- pipe, fascicle:
 - o outside diameter: 57 mm;
 - o thickness: 4 mm;
 - o length: 6010 mm;
 - o material: OLT35R, STAS: 10382-88.

RXA Reactor Modernization

In order for the technological process from the Isomerization plant to develop at normal parameters, the reactor must ensure the methyl tertiary butyl ether needed.

For this it is necessary that the reactor should be modernized to meet the technological flow and it should be verified according to the new parameters, namely:

- maximum allowable working pressure:
 - o in the shell: 0.5 MPa;
 - o in the pipes: 1.0 MPa;
- walls temperature:
 - o maximum allowable working temperature: 70⁰C in the shell and 80⁰C in the pipes;
 - o calculus temperature: 100⁰C in the shell and 100⁰C in the pipes;
 - o minimum allowable working temperature: 20⁰C in the shell and 20⁰C in the pipes;
- volume: 4.75 m³ in the shell and 6.25 m³ in the pipes;
- heat transfer area: 374 m².

The following measures are proposed in order to modernize the RXA reactor:

- replacing the fascicle pipes (374 pipes of 57x4 mm diameter, carbon steel pipes, OLT35R type) with stainless steel pipes 10TiNiCr180 according to STAS 10358-88 (X6CrNiTi: 18-10 according to SR-EN-10216-5, equivalent of W1.4541 after DIN), material resistant to the corrosion that exists in pipes area;

- coating the tubular plates (made of R3 steel) with stainless material, of the same quality as the X6CrNiTi 18-10 pipe according to SR-EN-10216-5. The coating will be realized by loading with welding;
- coating the covers, the inferior cover and the superior cover made of steel, R3 bottom type and R4 flange type, with sheet of 1.5mm thickness, X6CrNiTi 18-10 quality. The coating will be made using overlapping layers method;
- manufacturing a support and a grill in order to support the catalyst; this equipment will be located inside the inferior cover;
- manufacturing of the connections for the pipes of input / output fluids from the reactor, including process automation.

The material proposed for the tubular fascicle X6CrNiTi 18-10, usually used for corrosive environments, has the chemical composition presented in table 1

Table 1.

Element	C	Cr	Ni	Ti
%	< 0.10	17.0/19.0	9.5/11.5	>5% C

Chromium and nickel are the main alloying elements of this type of steel.

The mechanical characteristics of X6CrNiTi 18-10 steel are given in table 2.

Table 2.

Characteristic	$R_{P_{0.2}}^{20}$	R_m^{20}	$R_{P_{0.2}}^{100}$	Z	HRC
	N/mm ²				
X6CrNiTi 18-10	210	500	180	40	130 - 190

The meanings of these characteristics are the following:

- $R_{P_{0.2}}$ - conventional flowing limit (technical) at the temperature: $t = 20^{\circ}\text{C}$, in N/mm^2 ;
- R_m^{20} - minimum breaking strenght of the steel at the temperature: $t = 20^{\circ}\text{C}$, in N/mm^2 ;
- Z – lengthening, %;
- HRC – hardness;
- $R_{P_{0.2}}^{100}$ - conventional flow limit of the steel at the temperature: $t = 100^{\circ}\text{C}$, in N/mm^2 .

Computation of the Main Elements of the Reactor

Table 3 summarizes the design of the main elements of the reactor.

Covers Coating

The covers coating – lower and upper – has the role to assure the totally passing of the pipes section, on stainless steel, steel with a huge resistance to the working fluid from this section. This coating will be done using a technology made by an authorized company.

The coating method is the layer elements welding method.

Table 3.

Calculated element	Design conditions	Allowable stress	Strength thickness	Design thickness
Reactor ring	- calculation pressure: $p = 0.5 \text{ MPa}$; - calculation temperature: $t = 100^\circ \text{C}$; - inner diameter: $D_i = 1500 \text{ mm}$; - material: R3, STAS 2883/2-76; - corrosion addition: $c_1 = 3 \text{ mm}$; - seam coefficient of resistance: $Z = 0.95$.	calculation temperature $f_a^t = \min \left(\frac{R_m^{20}}{c_r}; \frac{R_{p0.2}^t}{c_c} \right)$ $f_a^t = 196.67 \frac{N}{\text{mm}^2}$ $c_r = 2.4$ $c_c = 1.5$	$s_1 = \frac{p D_i}{2 f_a^t z \cdot p}$ $s_1 = 2.5 \text{ mm}$	$s_p = s_0 + c_1 + c_2$ $s_p = 6.6 \text{ mm}$ It is adopted: $s_p = 20 \text{ mm}$
<u>Tubular plate</u> Bending calculation	- material: R3; - tubular plate's exterior threshold height: $c_1 = 5 \text{ mm}$; - tubular plate's interior threshold height: $c_2 = 5 \text{ mm}$; - addition of corrosion on one side: $c_3 = 3 \text{ mm}$.	$f_a^t = \min \left(\frac{R_m^{20}}{c_r}; \frac{R_{p0.2}^t}{c_c} \right)$ $f_a^t = 180 \frac{N}{\text{mm}^2}$	$T = \frac{F \cdot G}{3} \sqrt{\frac{p_c}{\eta \cdot f_a^t}}$ $\eta = 0.343$ $T = 66.18 \text{ mm}$	$s_p = T + c_1 + c_2$ $s_p = 66.18 + 5 + 5 + 3 = 79.18 \text{ mm}$ It is constructive adopted: $s_p = 182 \text{ mm}$
<u>Tubular plate</u> Shear calculation	- maximum pressure of the tubular plate: $p_c = 1.0 \text{ MPa}$; - equivalent diameter of the limit circle from the center of the pipes: $D_L = 4 \frac{A}{C}$; - distribution pipes perimeter measured in multiples of steps from the extreme pipes' center to another: $c = 4355 \text{ mm}$; - total surface included in C perimeter: $A = 139640 \text{ mm}^2$; - $d_c = 57 \text{ mm}$; - $l = 67 \text{ mm}$; - $D_L = 128.257$	$f_a^t = 180 \frac{N}{\text{mm}^2}$ (previously calculated)	$T = \frac{0.31 D_L}{\left(1 - \frac{d_c}{l}\right)^2} \cdot \frac{p_c}{f_a^t}$ $T = 9.915 \text{ mm}$	$s_p = T + c_1 + c_2$ $s_p = 9.915 + 5 + 5 + 3 = 22.915 \text{ mm}$ It is constructive adopted: $s_p = 182 \text{ mm}$
Reactor's pipe	- calculation pressure: $p_c = 1.0 \text{ MPa}$; - interior diameter of the pipe: $D_i = 49 \text{ mm}$; - quality coefficient of the welded joint: $z = 1.0$	$f_a^t = \min \left(\frac{R_m^{20}}{c_r}; \frac{R_{p0.2}^t}{c_c} \right)$ $f_a^t = 117.34 \frac{N}{\text{mm}^2}$ $c_r = 2.4$ $c_c = 1.5$	$s_1 = \frac{p_c \cdot D_i}{2 f_a^t z - p_c}$ $s_1 = 2.5 \text{ mm}$	$s_p = 4.0 \text{ mm}$

Fixing the anticorrosive steel coating (with a thickness of 1.5 ... 3.0 mm) is made by manual welding or point welding. The main steel has to be very well cleaned (preferably using quartz sand blasting; it is not allowed metal brush cleaning).

Setting the lower cover had the role to assure the catalyst support, taking into account that the passing section of the fluid through the grid support of the gauze must have a hydraulic resistance as low as possible.

Determining the Return on Investment

Introducing in the technological flow the modernized RXA reactor, 25000 – 35000 tones of methyl tertiary butyl ether can be obtained annually.

Taking into account that initially the plant was designed for a production capacity of 15000 tones per year, we will consider an increasing of methyl tertiary butyl ether production with 15000 tones per year.

$$15000 \text{ t/year} \cdot 370 \text{ u.m.} = 5550000 \text{ u.m./year}$$

The estimated value (by Romanian National Bank) of the update rate “i” for the next 3 years is 24%, $i = 0.24$.

We, also, know the value of the investment: 497725 u.m.

Because we don't speak about a new reactor, the amortization should be for a longer period (15 years of lifetime). So, it will be adopted the accelerated amortization of the investment.

Table 4. Investment and gross returns values

Year	Investment value	Gross returns
2010	495725	
2011	-	400581
2012	-	322401

According to the above, we will have:

$$\sum VB_A = \frac{400581}{1.24} + \frac{322401}{1.24^2} = 323049 + 209678 = 532727 \text{ u.m.}$$

We can notice that the investment is profitable, because:

$$\sum VB_A = 532727 \text{ u.m.} > I = 495725 \text{ u.m.}$$

Conclusions

In this paper we suggested, in an original way, some measures for modernizing the RXA reactor from the Isomerization section in order to increase the production capacity.

These suggestions improve the reactor functions both technical and economic, and they are:

- replacing the pipes made of carbon steel, OLT35R type with pipes made of stainless steel X6CrNiTi18-10 type, Srt-EN-10216-5;
- coating the tubular plates and the covers of the reactor using stainless material of the same quality as the pipes;
- the suggested solutions contribute to the increasing period of functioning of the reactor, using optimal technological parameters, without maintenance interruptions;

- the investment will be amortized over time, due to a long period of functioning, without shutdowns or repairs, assuring a good reliability, and it will not determine disruptions in the technological flow. This will determine the increasing of the methyl tertiary butyl ether production (from C4 fractions resulted in Catalytic Cracking plant), needed to produce the ecological gasoline, according to the new European standards.

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Modernizarea unui reactor tubular existent într-o instalație petrochimică cu scopul măririi capacității sale de producție

Rezumat

În cadrul lucrării se propune cu caracter original modernizarea și proiectarea unui reactor tubular existent într-o instalație petrochimică, secția Izomerizare (metil-terț-butil-eter) pentru mărirea capacității de producție a instalației.