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Research Note

Shadow Effect Minimization in Thermal Cracking Reactor Coils Through Variable Cross-Section

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Olefins, major blocks of the petrochemical industry, are produced through thermal cracking of hydrocarbons in long tubular reactors, suspended in large gas fired furnaces. Furnace performance is affected by heat-flux imbalances in individual heater passes. Circular tubes suspended in the cracking furnaces suffer from significant non-uniformity of heat flux, tube skin temperature and coking rate profiles around the tube perimeter, due to the presence of "front" and "shadow" sides on the tubes. This non-uniformity impacts the rate of coke formation and furnace run length. Since the thermal cracking heat is mainly transmitted through radiation at the high temperatures required by the operation, special care must be considered to minimize the shadow effects. The simulation results of the naphtha cracking furnace coils of Arak petrochemical ethylene plant (CRACSIM [1]) prove that smoother circumferential heat flux, tube skin temperature and coking rate profiles are obtained for the elliptical cross-section tubes. This uniformity in the elliptical cross-section favors the run length of the furnace and the tube metal life.

INTRODUCTION

The most important large-capacity initial monomers for the petrochemical industry are ethylene and propylene. At present, the worldwide production of ethylene is about 90 million tons and propylene 46 million tons. These are produced by thermal cracking of naphtha in the tubular reactors that is suspended in the gas-fired furnaces. Cracking furnaces are controlled on the basis of the process gas exit temperature and/or composition. Thermocouples inserted in intermediate locations of the coil do not last very long since the cracking temperature is too high. Therefore, the external tube skin temperature is measured periodically by radiation pyrometers, through peepholes in the furnace walls. Tube skin temperature distribution is one of the most important parameters that effects the run lengths and tube metal life of the reactor. The variables that influence this distribution are the configuration of tubes, the type of burner and the structure of furnace. The simulation of the firebox was developed by Hottel [2,3], Vercammen [4], Froment [5] and Paramenswaran [6]. The multi-zone mathematical model has been used by Sadrameli [7] for the simulation of the cracking furnaces assuming one-dimensional conduction heat transfer in the tubes. The furnace walls, reactor coils and flue gas volume are discretised into a number of isothermal surface and volume zones with uniform properties. For the calculation of the direct and total-exchange areas, a fundamental approach considering individual band absorption by carbon dioxide and water is considered. In addition, the position of the burners in the furnace walls and the flue gas flow pattern in the firebox are explicitly accounted for. Simulation results are provided for naphtha cracking furnaces in Arak petrochemical complex. This model has been further extended by Sadrameli [8] to permit a rigorous calculation of the circumferential non-uniformity under reaction conditions. In the present paper, application of the reactor tubes with elliptical cross-section, as an alternative to the conventional circular thermal cracking coils, is investigated. Suspending the elliptical tubes in the furnace with the major axis parallel to the tube row increases the front side and decreases the shadow side on the reactor coils. This investigation presents simulation results for a single row of naphtha cracker with elliptical cross-section coils of different sizes, obtained through

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Table 3. Temperature profiles for the circular and elliptical tube ($Z = 22.5$ m).

Angle (deg)	**Circular (°C)**			**Elliptical (°C)**	
	$a/b = 1$	$a/b = 1.1$	$a/b = 1.2$	$a/b = 1.3$	$a/b = 1.4$
0	862.57	869.68	868.31	867.11	864.01
10	865.72	871.84	870.23	868.87	864.78
20	869.83	874.44	871.98	871.41	866.04
30	874.31	877.69	873.69	873.24	866.87
40	878.91	881.04	875.39	874.96	867.52
50	883.22	883.99	877.17	876.42	868.43
60	887.54	886.77	879.31	877.51	869.49
70	891.42	889.45	882.28	878.85	870.77
80	894.41	892.22	885.45	880.21	872.38
90	896.03	893.66	887.44	881.18	873.38
100	894.41	892.22	885.45	880.21	872.38
110	891.42	889.45	882.28	878.85	870.77
120	887.54	886.77	879.31	877.51	869.49
130	883.22	883.99	877.17	876.42	868.43
140	878.91	881.04	875.39	874.96	867.52
150	874.31	877.69	873.69	873.24	866.87
160	869.83	874.44	871.98	871.41	866.04
170	865.72	871.84	870.23	868.87	864.78
180	862.57	869.68	868.31	867.11	864.01

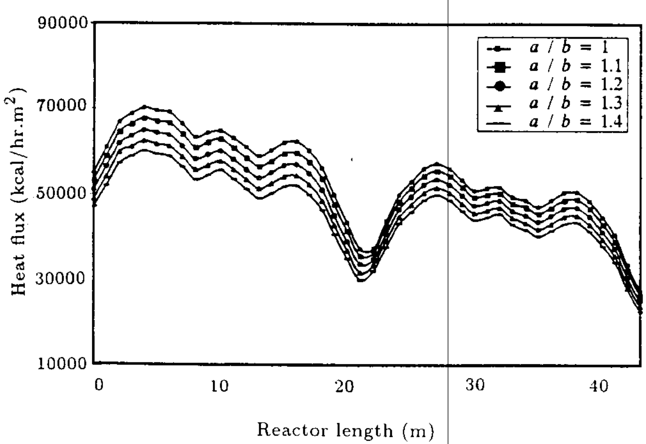

Figure 2. Heat flux profiles for circular and elliptical cross-section.

experimental results, the results of the present simulation have been compared with the simulated results presented in the literature [9]. Figure 2 demonstrates the heat flux profiles along the reactor tubes at different elliptical diameter ratios. The results clearly prove that while the general form of the profiles remains unchanged, the elliptical shape tubes face lower heat flux. Figure 3 illustrates the calculated circumferential heat flux profiles of the reactor tubes at different elliptical diameter ratios. The discrepancies between the temperature values at zero (front view of the

Table 4. Heat flux profiles for the circular and elliptical tubes ($Z = 1$ m).

Angle (deg)	**Circular (W/m^2)**		**Elliptical (W/m^2)**		
	$a/b = 1$	$a/b = 1.1$	$a/b = 1.2$	$a/b = 1.3$	$a/b = 1.4$
0	48436.09	48467.01	45722.65	42523.91	40010.28
10	49068.32	49068.01	46587.27	43208.32	40704.53
20	50455.85	50218.76	47693.45	44389.52	41897.27
30	52113.47	51568.32	49002.19	45998.39	43455.04
40	53804.29	53008.98	50410.87	47627.52	45128.71
50	55475.75	54296.08	51838.41	49119.22	46770.22
60	57045.89	55779.11	53229.34	50488.84	48283.53
70	58417.73	57193.34	54519.59	51706.94	49584.43
80	59471.13	58776.34	55909.83	53027.82	50528.94
90	60086.91	59888.21	57033.29	53819.79	51072.27
100	59471.13	58776.34	55909.83	53027.82	50528.94
110	58417.73	57193.34	54519.59	51706.94	49584.43
120	57045.89	55779.11	53229.34	50488.84	48283.53
130	55475.75	54296.08	51838.41	49119.22	46770.22
140	53804.29	53008.98	50410.87	47627.52	45128.71
150	52113.47	51568.32	49002.19	45998.39	43455.04
160	50455.85	50218.76	47693.45	44389.52	41897.27
170	49068.32	49068.01	46587.27	43208.32	40704.53
180	48436.09	48467.01	45722.65	42523.91	3978549

burner) and 90 degrees reflect the shadow effects on the temperatures. Circumferential non-uniformity is of particular importance for severe operating conditions, whereby the tube skin temperature is high and close to the limits imposed by the tube material properties. Therefore, a representative tube skin temperature is a necessity and the measurements should be correctly interpreted. The circumferential temperature variations at different radial positions of the tube are depicted in Figure 4. They clearly show that the maximum temperatures are always at the zones which are facing the front walls (0 and 180 degrees), which receive the maximum radiation from the furnace wall and the burners and the minimum temperatures occur in the zones at both sides of the tubes (90 and 270 degrees), due to the shadow effect of the neighboring tubes. Cracking furnaces are controlled on the basis of the process gas exit temperature and/or composition. Thermocouples inserted in intermediate locations of the coil do not last very long since the cracking temperature is too high. Therefore, the external tube skin temperature is measured periodically by the radiation pyrometers, through peepholes in the furnace walls. The simulated results demonstrate that the observed temperatures depend upon the location of the peephole with respect to the tubes. The values of the tube skin temperatures and the heat flux on the tubes are also listed in Tables 3 and 4. Unfortunately, except

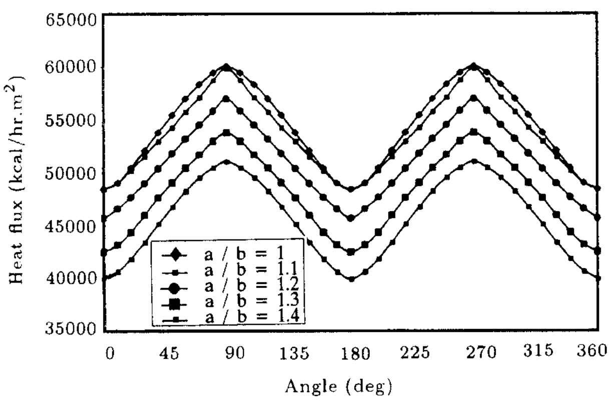

Figure 3. Circumferential heat flux profiles on the tube of the reactor.

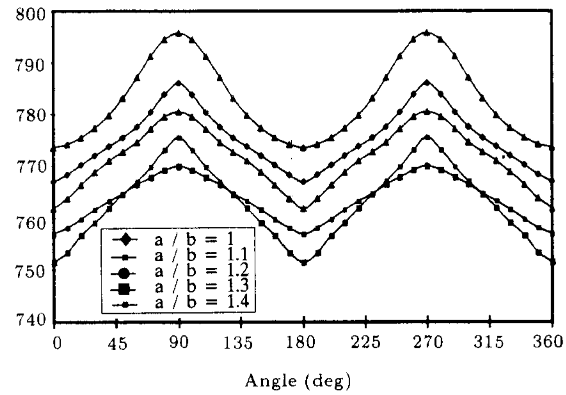

Figure 4. Circumferential temperature profiles at different elliptical diameter ratios.

Table 5. Comparison of the tube skin temperature profiles between model and literature [9].

Circular				Elliptical					
$a/b = 1$				$a/b = 1.1$			$a/b = 1.4$		
T(°C)				T(°C)			T(°C)		
Length(m)	A	B	% Error	A	B	%Error	A	B	% Error
5	858	854	-0.47	857	853	-0.47	850	845	-0.59
7	878	877	-0.11	877	876	-0.11	868	867	-0.11
10	888	888	0.00	887	887	0.00	876	878	0.23
12	900	891	-1.01	889	890	0.11	894	881	-1.45
13	912	901	-1.21	911	900	-1.21	900	891	-1.01
22	895	891	-0.45	894	890	-0.45	888	881	-0.79
25	880	887	0.79	879	886	0.79	869	877	0.92
26	880	876	-0.45	879	875	-0.46	869	866	-0.35
32	910	899	-1.21	909	898	-1.21	900	890	-1.11
35	913	900	-1.42	912	899	-1.43	906	891	-1.66
38	922	911	-1.19	921	910	-1.19	919	905	-1.52
39	933	920	-1.39	932	919	-1.39	925	910	-1.62
40	935	921	-1.49	934	920	-1.49	927	911	-1.73
45	922	906	-1.74	921	905	-1.74	919	896	-1.59

A: this work, B: [9]

for the tube skin temperatures which are measured by the pyrometer, other thermal characteristics of the furnace such as gas and refractory temperatures and heat flux measurement are impossible or inaccurate. Non-uniformity of temperature along the perimeter of the vertical coils shown in the results of Tables 3 and 4 is considered to be significant. Even with a coil, the difference between maxima and minima can be of the order of 30°C. Nevertheless, these differences cannot be always detected, since temperature measurement relies upon infrared pyrometer, through peepholes in the walls of the furnace, so that only certain view angles are possible. The comparison between the results of the present three-dimensional model and the published results for the elliptical tubes (Table 3) in the literature [9] is presented in Table 5. Agreement between the present simulated results and the published data are observed from the percentage error, which is less than 2%. The model and simulation software presented here are used as a guide for plant operators in olefin plants to control the furnace parameters.

NOMENCLATURE

Cp	heat capacity of gas species (J/mol.K)
E	black body emissive power (W/m^2)
h_p	process gas convection coefficient (W/m^2.K)
k	thermal conductivity of tube (W/m.K)
q	heat flux (W/m^2)
Q	heat flux (W/m^2)
r	tube radius (m)

Re	external tube radius (m)
Ri	internal tube radius (m)
S	wetted area (m^2)
T	temperature (C)
W	wetted perimeter (m)
Z	axial reactor coordinate (m)
Z_iZ_j	total exchange area between zones i and j (m^2)
α	thermal diffusivity (m^2/s)
θ	tube perimeter angle

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