

NOVEL CERAMIC COATINGS FOR THE PETROLEUM INDUSTRY

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Coking.com seminar
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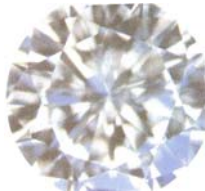
Requirements of Coatings for High Temperature Applications

- Thermal Stability at the Operating Metal Temperature
- Adhesion to metal surface, preferably infusion into the metal grain
- Resistance to attack by chemical reactions (sulfidation, oxidation)

Diamond and Cubic Zirconia



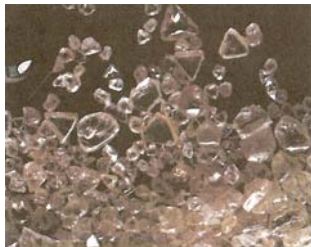
Cut / polished cubic zirconia



Cut / polished diamond



loose cubic zirconia



Loose diamonds

Table 1: Thermogravimetric Analysis of Diamond and Cubic Zirconia

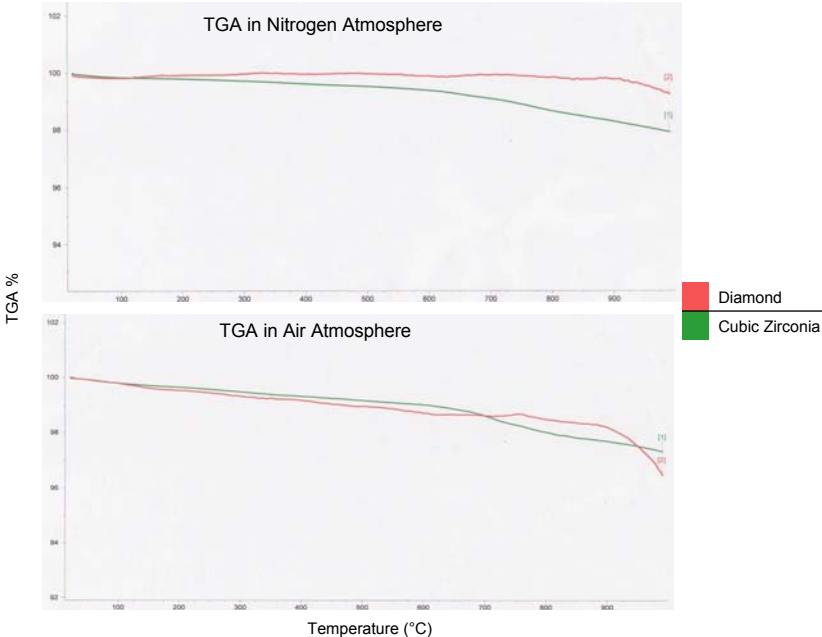




Table 2
Thermal Fouling Test Unit
&
New and Fouled Heat Exchanger Tube

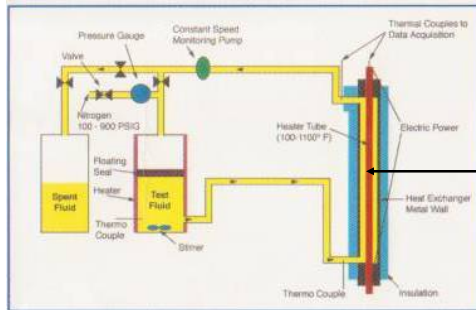


Table 3
Thermal Fouling Graphs of Low and High Petroleum Stream

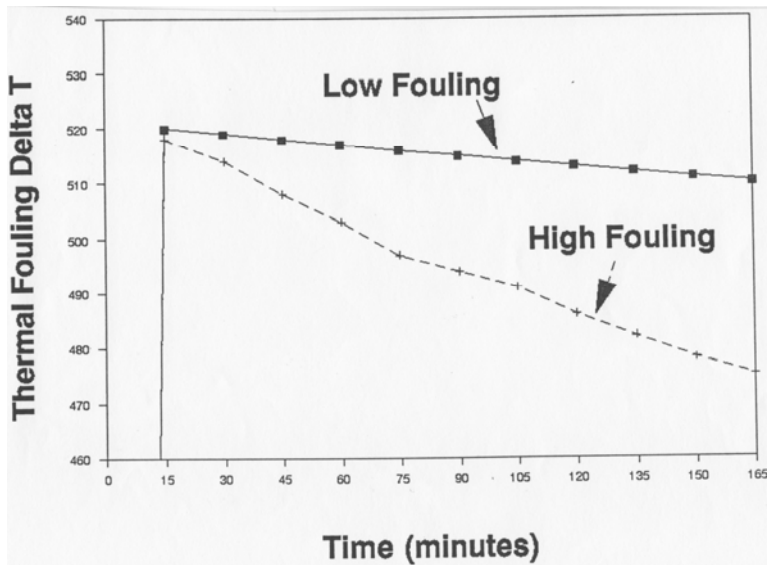
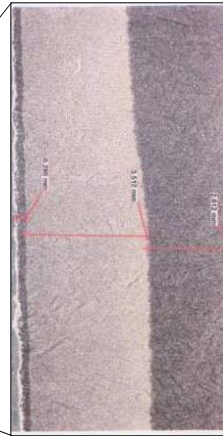


Table 4: Cokified Steam Cracker Furnace Tube and Caburization



Cokified Furnace Tube



Carburized Furnace Tube

Table 5
Fouling of Naptha Using Varying Exchanger Metallurgies

Heater Metal Type	C/S 1018	S/S 304	S/S 316
Heater metal temp (°F)	1000	1000	1000
Unit pressure (psig)	750	750	750
Fluid flow rate (cc/min)	3.0	3.0	3.0
Test time (minutes)	180	180	180
Thermal Fouling (ΔT , °F)	46	11	10

Table 6
Fouling of Crude Oil Using Varying EFTA Coated Exchanger Tubes

Metal Coating Type	C/S 1018	Aluminum	Silicon
Heater metal temp (°F)	1000	1000	1000
Unit pressure (psig)	750	750	750
Fluid flow rate (cc/min)	3.0	3.0	3.0
Test time (minutes)	180	180	180
Thermal Fouling (ΔT , °F)	46	21	19

Table 7
Thermal Fouling Testing of Carbon/Steel 1018 Exchanger Tubes

Test Operating Conditions			
	C/S 1018	C/S 1018	C/S 1018
Exchanger Heater	C/S 1018	C/S 1018	C/S 1018
Exchanger temp (°F)	800	900	1010
Unit pressure (psig)	950	950	950
Unit Atmosphere	Nitrogen	Nitrogen	Nitrogen
Oil flow rate (cc/min)	3.0	3.0	3.0
Test time (minutes)	180	180	180
Thermal Fouling Measurements			
15 minutes	0	0	4
30 minutes	0	4	8
45 minutes	6	11	21
60 minutes	10	16	67
75 minutes	14	21	74
90 minutes	18	28	90

Table 8
Thermal Fouling Testing of Zirconium Coated Heat Exchanger Tubes

Test Operating Conditions			
Exchanger Heater	1	2	3
Exchanger temp (°F)	1010	1010	1010
Unit pressure (psig)	950	950	950
Unit Atmosphere	Nitrogen	Nitrogen	Nitrogen
Oil flow rate (cc/min)	3.0	3.0	3.0
Test time (minutes)	180	180	180
Thermal Fouling Measurements			
15 minutes	5	3	12
30 minutes	22	21	30
45 minutes	33	32	36
60 minutes	41	45	36
75 minutes	45	45	36
90 minutes	47	45	36
Effectiveness (%)	52.0	53.0	62.0

Table 9: Fouled Carbon Steel and Zirconium Exchanger Metal Heater Tubes



Carbon Steel Exchanger



Mist Coated Exchanger

Table 10
 Fouling Graphs of Carbon Steel and Zirconium Exchanger Heater Metal

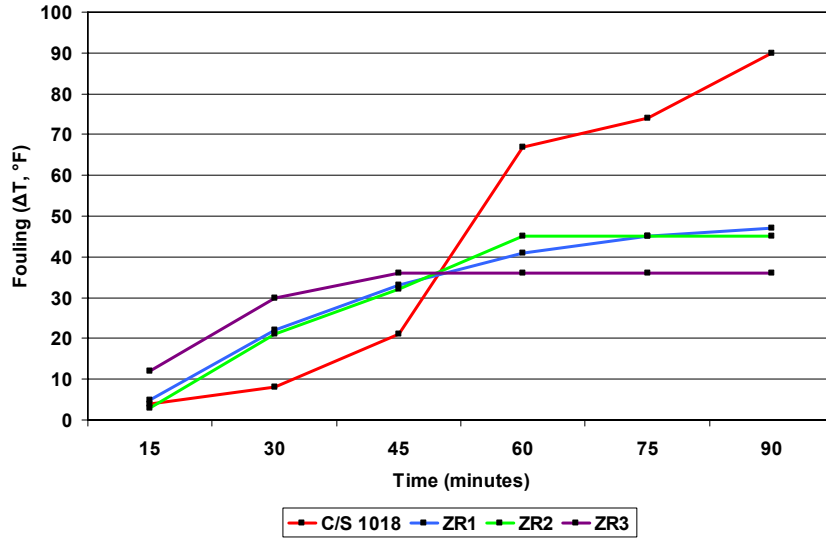
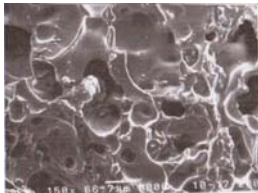


Table 11: Scanning Electron Micrograph of Fouling Deposits



Carbon Steel Fouling Deposits



Zirconium Fouling Deposits



Delayed Coker Furnace Tube Deposits

Table 12: Aromaticity (C/H) Atomic ratio of Fouling Deposits

	Carbon Steel Deposit	ZR1 Deposit	ZR2 Deposit	ZR3 Deposit	Delayed Coker Deposit
Carbon (wt. %)	88.94	89.14	89.10	89.04	
Hydrogen (wt. %)	5.77	6.12	5.59	5.84	
Oxygen (wt. %)	1.49	1.04	1.16	1.20	
Carbon/hydrogen atomic ratio	1.28	1.21	1.30	1.27	2.24, 2.53, 2.37, 2.66, 2.61, 2.64, 2.40, 2.48, 2.41

Table 13: Summary of Thermal Analysis of Deposits (TGA, 20 - 1000°C/air)

	Carbon Steel Deposit	Zirconium Coating Deposit		Delayed Coker Furnace Deposit	
		A	B	A	B
Coke (wt. %)	99.2	99.2	99.7	93.4	94.1
Coke decomposition temp (°C)	521	545 - 630	546 - 675	628	597

Table 14: Thermal Gravimetric Analysis of Exchanger Deposit and Delayed Coker Furnace Deposit

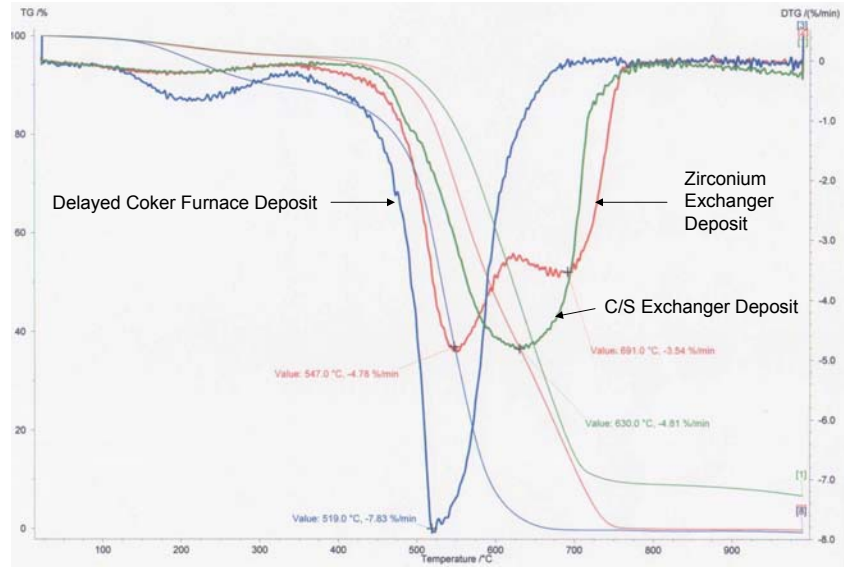
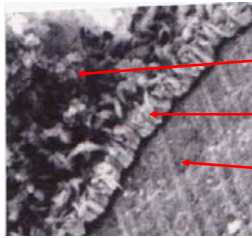


Table 15
EDS Analysis of Zirconium Exchanger Tube
Before and After Fouling Test

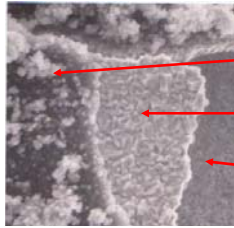
	Before Fouling Test		After Fouling Test	
Carbon (wt. %)	0.00	0.00	90.09	89.46
Aluminum (wt. %)	8.82	0.34		
Zirconium (wt. %)	62.18	37.7		
Silicon (wt. %)	0.00	3.49		
Iron (wt. %)	27.54	53.35		
Sulfur (wt. %)	-	-	4.66	6.36
Oxygen (wt. %)	0.00	0.00	4.65	4.18



Coke Deposit

Iron Sulfide Layer

Tube Metal



Coke Deposit

Iron Sulfide Layer

Tube Metal



Coke Deposit

Iron Sulfide Layer

Tube Metal

Table 16
Delayed Coker
Furnace Tube
Deposit