Optimization of Hydrodynamic Regimes of the Process of Obtaining Bitumen

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Abstract. In article given the results of optimization the hydrodynamic regimes of the process of obtaining bitumen from oil sludge. Optimization was carried out by the Box Wilson method "Steep climb".

Keywords: optimization, refining, rotation, oil sludge, bitumen, pressure, temperature, speed, concentration

1 Introduction

One of the most important scientific areas in the field of oil refining in recent decades has been targeted research to identify new opportunities for intensifying the process of liquid-phase oxidation of residual petroleum feedstock (RHO) taking into account the laws of physical and chemical mechanics of petroleum dispersed systems (OPS) and the qualified use of secondary products of petrochemistry and oil refining [1]. At the same time, the solution of urgent scientific and applied problems of optimizing operational characteristics and operational quality control of bitumen products remains relevant [2].

Bitumen, being one of the most well-known engineering and construction materials, is widely used, suffice it to name road construction, roofing materials, paint and varnish and cable industry, construction of buildings and structures, pipeline laying, so the demand for high-quality petroleum bitumen has a constant upward trend [3, 4]. This is primarily due to the increased requirements for the quality of produced oil bitumen and the implementation of a number of increasing requirements imposed by consumers of this type of product [5].

The purpose of the experiment is to determine a new direction of the gradient for the steep ascent procedure. This constitutes the content of the second cycle of the procedure. By analogy with the above, we select the variation intervals for each of the factors and fill in the table of factor values during experimentation. Next, we draw up an experiment plan, implement it, and place the results in the experiment implementation table [6].

Table 1. The influence of various factors.

Factor's name	Units	Minimum allowed value	Maximum allowable value	The mode of process's implementation
Temperature	deg.	30	120	50
Pressure	kgs/sm^2	1,5	3,5	2
Speed rotation of the mixer	rev/min	40	70	45

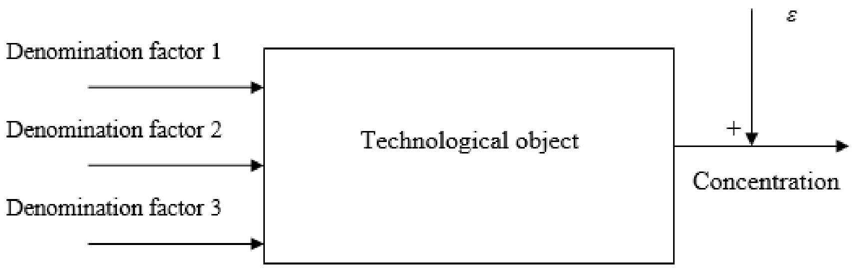

Fig. 1. The influence of various factors.

2. Materials and Methods

The value of the variation interval for each of the factors is limited from below, first of all, by the errors of instruments and devices, with the help of which the values of the factors are measured and set during experimentation. Concerning the upper limit, no specific statements can be made.

However, one can take: $0.05 \cdot x_{0j} \leq \Delta_j \leq 0.07 \cdot x_{0j}$,

where Δ_j - factor variation interval x_j; x_{jB} - maximum allowable value x_{jH} - minimum allowable value x_j.

Thus, we have

$\Delta_1 = 0{,}05 \cdot (120 - 30) = 4{,}5$, what more $0{,}05 \cdot 50 = 2{,}5$

$\Delta_2 = 0{,}05 \cdot (3{,}5 - 1{,}5) = 0{,}1$, what equals $0{,}05 \cdot 2 = 0{,}1$

$\Delta_3 = 0{,}05 \cdot (70 - 40) = 1{,}5$, what less $0{,}05 \cdot 45 = 2{,}25$

Table 2. The influence of various factors.

#	Factor's name	Units	Lower level	Upper level
1	Temperature	deg.	47,5	52,5
2	Pressure	kgs/sm2	1,9	2,1
3	Speed rotation of the mixer	rev/min	43,5	46,5

After constructing a plan for a full factorial experiment 2^3, carrying out randomization and implementation of experiments, we have:

Table 3. Implementation Experiment.

#	Plan of experiment						Result			
	Temperature		Pressure		Speed of rotation		Concentration			
	Cod	mean	Cod	mean	Cod	mean	Por #	mean	Por #	mean
1	-1	47,5	–1	1,9	-1	43,5	7	41,53	1	37,61
2	+1	52,5	–1	1,9	-1	43,5	5	42,43	3	42,14

3	–1	47,5	+1	2,1	- 1	43,5	9	45,00	13	42,40
4	+1	52,5	+1	2,1	-1	43,5	6	46,81	16	46,41
5	–1	47,5	–1	1,9	+1	46,5	4	45,27	11	43,50
6	+1	52,5	-1	1,9	+1	46,5	2	46,00	12	45,30
7	–1	47,5	+1	2,1	+1	46,5	14	48,41	15	48,02
8	+1	52,5	+1	2,1	+1	46,5	8	49,10	10	50,03

The result of calculating the estimates of the regression coefficients and checking their significance are summarized in the table:

Table 4. The influence of various factors.

Assim. of coeff.	The meaning of assim	The meaning of statistics	T_{cr}	Result of testing hypothesis
$\bar{b}_0$	45,0013	138,65	2.31	1
$\bar{b}_1$	1,0263	3,16	2.31	1
$\bar{b}_2$	2,0288	6,25	2.31	1
$\bar{b}_3$	1,9600	6,03	2.31	1
$\bar{b}_{12}$	0,0313	0,096	2.31	0
$\bar{b}_{13}$	-0,3800	1,17	2.31	0
$\bar{b}_{23}$	-0,0850	0,26	2.31	0

Thus, the model in normalized variables has the form:

$$y = 45 + 1{,}02 \cdot x_1 + 2{,}03 \cdot x_2 + 1{,}96 \cdot x_3$$

Fisher's criterion $F = S^2_{a\partial}/S^2_e$

$$F=2{,}76,\ v_1=4,\ v_2=8,$$

According to the Fisher distribution table, we determine $S_{\kappa p} = 3{,}84$

Thus, the resulting model is adequate. In natural variables, the model has the form:

$$y = 45 + 1{,}02 \cdot (x_1 - 50)/4{,}5 + 2{,}03 \cdot (x_2 - 2)/0{,}1 + 1{,}96 \cdot (x_3 - 45)/1{,}5$$

After reducing like terms, we have:

$$y = -65{,}73 + 0{,}23 \cdot x_1 + 20{,}3 \cdot x_2 + 1{,}3 \cdot x_3,,$$

where, x_1 −temperature in ^0C; x_2 −pressure, kgs/sm^2; x_3 −Speed rotation of the mixer in rot/min; y −the concentration of product *A* in %.

The resulting model contains a linear component; therefore, the maximum concentration value should be at the border of the experimentation area. The average value of the output-controlled parameter is maximum at the maximum values of the input factors (*Y*=45,00 %). Therefore, it is possible to increase the concentration of product A by changing the process modes. In this regard, it is advisable to use the steep ascent procedure to optimize the process.

After reducing like terms, we have:

$$y = 22{,}85 + 0{,}15 \cdot x_1 + 1{,}94 \cdot x_2$$

To obtain the coordinates of the second point in the steep ascent procedure, it is necessary to obtain the product again:

$$\delta_j = b_j \cdot \Delta_j,$$

$$\delta_1 = 1{,}66 \cdot 4{,}5 = 2{,}97$$

$$\delta_2 = 1{,}94 \cdot 0{,}1 = 0{,}19$$

Further on the procedure is selected from all δ_j maximum and is taken as the base value δ_0. In this case $\delta_0 = \delta_1 = 2{,}97$.

$$\lambda_j = \lambda_б \cdot \delta_j / |\delta_0|$$

For our case, choosing a base step equal to half the variation interval for the first factor $\lambda_б = 0{,}5 \cdot \Delta_1 = 0{,}5 \cdot 4{,}5 = 2{,}25$ we have:

$$\lambda_1 = \lambda_б \cdot \delta_1 / |\delta_0| = 2{,}25 \cdot 2{,}97/2{,}97 = 2{,}25$$

$$\lambda_2 = \lambda_б \cdot \delta_2 / |\delta_0| = 2{,}25 \cdot 0{,}19/4{,}54 = 0{,}15$$

3. Results and Discussion

At the 27th step, we find a new extremum. This marks the completion of the third cycle of the steep ascent procedure. Now it is necessary to re-plan and implement a full factorial experiment in the area, the center of which has the coordinates:

Temperature = 97,25 ^0C ;

Pressure = 2,94 kgs/sm^2*;*

Speed rotation of mixer = 63,30 rot./min.

By analogy with the above, we select the variation intervals for each of the factors and fill in the table of factor values during experimentation.

Next, we draw up an experiment plan, implement it, and place the results in the experiment implementation table.

Choose the interval of variation:

$\Delta_1 = 0{,}05 \cdot (120 - 30) = 4{,}5$, what more $0{,}05 \cdot 97{,}25 = 4{,}86$

$\Delta_2 = 0{,}05 \cdot (3{,}5 - 1{,}5) = 0{,}1$, what less $0{,}05 \cdot 2{,}94 = 0{,}15$

Table 5. The Comparison of Main Results.

Model: $y = 22{,}85 + 0{,}15 \cdot x_1 + 1{,}94 \cdot x_2$								
Version #1		Factors			Results			
Denomination		*Tem-pera-ture*	*Pres sure*	*Speed rot. of mixer*	*The concentration of product A*			
Starting point		83,75	2,04	63,30				
Working step		2,25	0,15	0				
Number of steps	*The type of experi-ment*				*By model*	*Experiments*		*Midd.*
					$\bar{y}$	y_2	y_1	*Y*
22	M	86,00	2,19	63,30	78,24			
23	M	88,25	2,34	63,30	81,48	75.55	75.37	75,46
24	P	90,50	2,49	63,30		75.13	78,20	76,66
25	P	92,75	2,64	63,30		77,74	77,15	77,74
26	P	95,00	2,79	63,30		77,81	78,32	78,06
27	P	97,25	2,94	63,30		79,78	80,63	80,20

28	P	99,50	3,09	63,30		77,11	80,34	78,72
29	P	101,75	3,24	63,30		75,84	77,47	76,65
30	P	104,00	3,49	63,30		69,18	67,38	68,28

Table 6. Factor Values During Experimentation.

#	Factor's name	Units	Lower level	Upper level
1	Temperature	deg.	92,75	101,75
2	Pressure	kgs/sm^2	2,84	3,04
3	Speed rotation of the mixer	rev/min	63,30	63,30

After constructing a plan for a full factorial experiment 2^3, carrying out randomization and implementation of experiments, we have:

Table 7. Implementation Experiment.

#	Plan of experiment						Result			
	Temperature		*Pressure*		*Speed of rotation*		*Concentration*			
	Cod	*mean*	*Cod*	*mean*	*Cod*	*mean*	*Por #*	*mean*	*Por #*	*mean*
1	-1	92,75	–1	2,84	-	63,30	8	77.15	3	78,85
2	+1	101,75	–1	2,84	-	63,30	13	77,98	6	79,48
3	–1	92,75	+1	3,04	-	63,30	1	78,54	15	80,2
4	+1	101,75	+1	3,04	-	63,30	10	80,55	12	79,08
5	–1	92,75	–1	2,84	-	63,30	7	78,68	9	76,90
6	+1	101,75	-1	2,84	-	63,30	16	79,08	2	77,84

#	Plan of experiment						Result			
	Temperature		*Pressure*		*Speed of rotation*		*Concentration*			
	Cod	*mean*	*Cod*	*mean*	*Cod*	*mean*	*Por #*	*mean*	*Por #*	*mean*
7	–1	92,75	+1	3,04	-	63,30	11	80,64	14	77,95
8	+1	101,75	+1	3,04	-	63,30	5	79,16	4	80,6

The result of calculating the estimates of the regression coefficients and checking their significance are summarized in the table:

Table 8. Estimates of the Coefficients of the Mode.

Assim. of coeff.	The meaning of assim	The meaning of statistics	T_{cr}	Result of testing hypothesis
$\bar{b}_0$	78,9175	257,356	2.31	1
$\bar{b}_1$	0,3037	0,0991	2.31	0
$\bar{b}_2$	0,6725	2,193	2.31	0
$\bar{b}_3$	-0,0612	0,200	2.31	0
$\bar{b}_{12}$	-0,0463	0,151	2.31	0
$\bar{b}_{13}$	0,0100	0,033	2.31	0
$\bar{b}_{23}$	0,0588	0,192	2.31	0

4. Conclusion

Thus, the model in normalized variables has the form: y=78,92. Fisher's criterion F=1,19 v_1=7, v_2=8, $F_{кр}$=3,50. Therefore, the resulting model is adequate. The results of experimentation in the region with the center corresponding to the coordinates of the partial extremum showed that only the coefficient is significant b_0.

The value of his score is 78.92. Therefore, the optimal mode for the implementation of the process has been achieved.

Based on the results of the study, the following conclusions can be drawn: the recommended optimal mode of operation that provides the maximum value of the concentration of the product corresponds to the following values of the input factors.

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