Experimental Identification of Natural Gas Cooling Process

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Abstract— **This paper describes an experimental identification of nonlinear process of natural gas cooling. Identification is carried out by using *Matlab* and *simplex* optimization method. Cooler's linear model is determined experimentally by recording system transients for several operating points. Recording is executed for change of the reference value of cooler's output gas temperature, with different temperatures of disturbance value (regeneration gas). To reduce the influence of input gas temperature's low frequency oscillations on accuracy of optimal model's parameters determination, transients of controller output and output gas temperature are recorded for increased controller's gain coefficient and integral time constant. Optimal values of the first and second order transfer functions with dead time (FODT and SODT) are determined, which result in the smallest transient error in relation to the real natural gas cooler. Since determined parameters of cooler's model change significantly, elaboration and implementation of natural gas temperature adaptive controller is proposed.**

I. INTRODUCTION

Accurate mathematical model is essential for design and tuning of quality system controllers. The procedures of mathematical model determination can be analytical or experimental [1], [2], [3].

Analytical procedures of system identification can be quite complicated because of the complexity of system to be identified. Furthermore, expressive nonlinearities as well as change of conditions and operation regimes complicate analytical procedure of system identification even more. Therefore, experimental methods of system identification are used for that purpose.

There is a quite extensive literature on system identification. Most of them are based on certain steps [4]: the data record, the set of models or the model structure and determining the "best" model in the set, guided by the data. The obtained model must pass the model validation tests. The system identification procedure is repeated until the model passes the validation tests. These models are usually determined in discrete time, because of the nature of data collection from the system, which is discrete.

For the systems with expressive dead time, like the natural gas cooling process, it would take a very long time for experimenting with orders of discrete polynomials, especially with the number of delay steps. There is also need for converting discrete transfer functions into continuous ones. Thereby, additional zeros may occur in the continuous transfer functions, which don't exist in real system.

Therefore, this paper proposes another method of system identification, that is optimization of continuous transfer functions's parameters directly, along with the dead time. By using this procedure, above problems are avoided and system identification is simplified.

In this paper the response on reference step change is used for determination of cooler's dynamic model and parameters. Using *Matlab* and *simplex* optimization method [5], [6], optimal parameters of cooler's transfer functions are determined in different conditions, i.e. different disturbance values (temperatures of regeneration gas).

Second section describes the construction of natural gas cooling system in CPS Molve III. Results of determination of cooler's dynamic model and parameters in different operation conditions are described in third section. Conclusions are given in fourth section, and references are given in final section.

II. DESCRIPTION OF NATURAL GAS COOLING SYSTEM

CPS Molve III plant, with gas flow capacity of $5 \cdot 10^6$ $\mathrm{m}^3/\mathrm{day}$, is built for preparation of crude gas for transport in INA Naftaplin's backbone gas pipeline system, elimination of noxious substances and separation of valuable hydrocarbons. To perform this task, gas is treated with aMDEA (**M**ethyl **Di**Ethanol **A**mine) mixture. For separation of sulphur from CO_2 current, Lo-Cat procedure is applied. Besides that, water and mercury are separated from natural gas.

After technological process of CO_2 and H_2S separation in aMDEA system, natural gas enters the cooling section. Input gas temperature in that section reduces from 60 to 32 °C. Besides input gas, a regeneration gas returns to the cooling system input (Fig. 1), with temperature varying from 30 to 270 °C. Cooler's output gas temperature control system consists of controller TIC-3404, asynchronous drive, gearbox, fan, cooler E-3401 and temperature sensor, see Fig. 1.

Controller is implemented in the main programmable logic controller (PLC) *Advant Controller 450* (AC 450), from ABB's PLC family. It's a computer based unit in distributed, integrated industrial automation system assembly *ABB Master*. In software part of AC 450, a temperature controller is implemented. Controller operates the speed of fan via asynchronous drive and frequency converter.

Temperature controller of the cooler's output gas TIC-3404 is implemented as PID controller via function block PIDCON in ABB Advant Controller 400 Series assembly. A PIDCON controller normally performs a complete control function independently. The characteristics of the PIDCON process controller can be found in [7].

The fans are driven by asynchronous drives and frequency converters of modern construction. Exceptional dynamic performance and accuracy of speed control is achieved by direct torque control (DTC) algorithm.

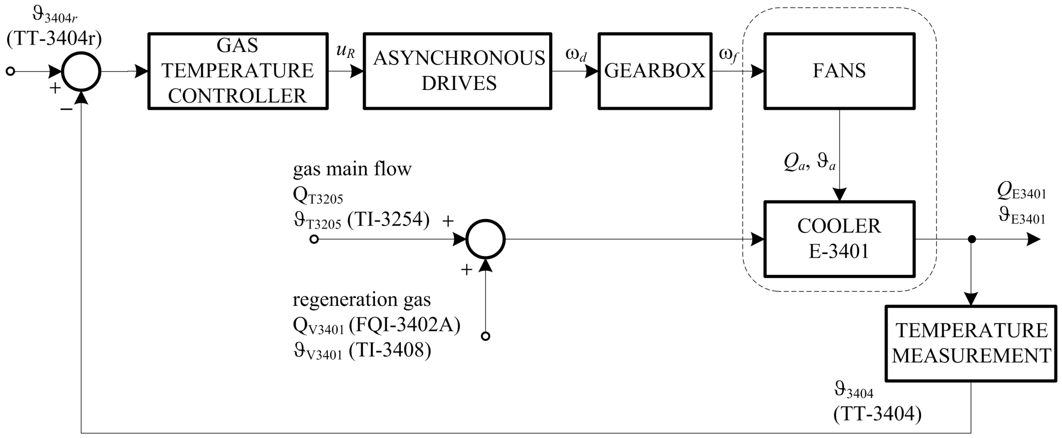


Fig. 1. Block schematic of natural gas cooler E-3401 temperature control system.

III. IDENTIFICATION OF NATURAL GAS COOLER'S MODEL PARAMETERS

Block schematic of the natural gas cooler E-3401 temperature control system is shown on Fig. 1.

Pounce time of the asynchronous drive to the nominal speed equals $2-3$ s, so drive equivalent time constant equals approximately 1 s and can be neglected in relation to the time constants of cooler and temperature sensor, which have one to two order of magnitudes higher value. Asynchronous drive gain coefficient K_{as} is determined by nominal values of speed ($\omega_{dn} = 151.84\ \mathrm{s}^{-1}$) and controller output voltage ($u_{Cn} = 10$ V), and equals:

$$K_{as} = \frac{\omega_{dn}}{u_{Cn}}. \tag{1}$$

Transmission ratio of gearbox i is determined by fan speed ω_f and drive speed ω_d ratio, this is belt drive radius r_d and belt fan radius r_f ratio:

$$i = \frac{\omega_f}{\omega_d} = \frac{r_d}{r_f}. \tag{2}$$

Cooler airflow Q_a (Fig. 1) is the nonlinear function of the fan speed ω_f and resistance of the air and cooler R_{ac}:

$$Q_a = f_1(\omega_f, R_{ac}). \tag{3}$$

Resistance of the air and cooler R_{ac} is approximately parabolic function, i.e. it is approximately dependent of square of fan speed ω_f:

$$R_{ac} = f_2(\omega_f^2). \tag{4}$$

Cooler gain coefficient K_c depends of the fan speed ω_f, cooling air temperature ϑ_a and regeneration gas temperature ϑ_{V3401}.

The main gas flow at the cooler input Q_{T3205} is approximately constant and equals $Q_{T3205} = 130.000\ \mathrm{m}^3/\mathrm{h}$. The temperature of the main gas flow ϑ_{T3205} oscillates around mean value 60 °C with amplitude 1 °C. Period of oscillations of the main gas flow temperature equals $t_\vartheta = 450$ s ($f_\vartheta = 2.2$ mHz).

Regeneration gas flow through cooler Q_{V3401} is approximately constant and equals $Q_{V3401} = 18.000\ \mathrm{m}^3/\mathrm{h}$, while regeneration gas temperature ϑ_{V3401} significantly changes in range of $\vartheta_{V3401} = 30 - 270$ °C.

The gas flow at the cooler output Q_{E3401} is equal to sum of the main gas flow Q_{T3205} and regeneration gas flow Q_{V3401}:

$$Q_{E3401} = Q_{T3205} + Q_{V3401}. \tag{5}$$

Therefore, the gas temperature at the cooler output ϑ_{V3401} depends of air temperature ϑ_a, regeneration gas temperature ϑ_{V3401} and cooler airflow Q_a:

$$\vartheta_{E3401} = f_3(\vartheta_{V3401}, \vartheta_a, Q_a). \tag{6}$$

Temperature sensor has time constant of order of magnitude $T_{TT3404} \approx 30$ s.

Based on relations (1) to (6), dynamic behavior of the natural gas cooler with asynchronous drives, fans and temperature sensor, can be satisfactorily described with transfer function with dead time T_{dt} and one time constant T_1, or two time constants T_1, T_2:

$$G_{p1}(s) = \frac{\Delta\vartheta_{3404}(s)}{\Delta u_R(s)} = \frac{K_p e^{-T_{dt}s}}{1 + T_1 s}, \tag{7}$$

$$G_{p2}(s) = \frac{\Delta\vartheta_{3404}(s)}{\Delta u_R(s)} = \frac{K_p e^{-T_{dt}s}}{(1 + T_1 s)(1 + T_2 s)}. \tag{8}$$

Dead time T_{dt} represents the time needed for establishment of the airflow through the cooler and it depends on fan speed ω_f:

$$T_{dt} = f_4(\omega_f). \tag{9}$$

Time constant T_1 represents the cooler thermal time constant, which depends on fan speed ω_f, cooling air temperature ϑ_a and regeneration gas temperature ϑ_{V3401}:

$$T_1 = f_5(\omega_f, \vartheta_a, \vartheta_{V3401}). \tag{10}$$

Time constant T_2 represents temperature sensor's time constant:

$$T_2 = T_{TT3404}. \tag{11}$$

Gain coefficient K_c of the cooler with fan and temperature sensor depends on the fan speed ω_f, cooling air temperature ϑ_a and regeneration gas temperature ϑ_{V3401}:

$$K_c = f_6(\omega_f, \vartheta_a, \vartheta_{V3401}). \tag{12}$$

Total gain coefficient of the process unit K_p is equal to the product of asynchronous drive gain coefficient K_{as}, gearbox i, and cooler with fan and temperature sensor K_c:

$$K_p = K_{as} \cdot i \cdot K_c. \tag{13}$$

Because of the gain coefficient K_p, dead time T_{dt} and time constant T_1 dependence on regeneration gas temperature ϑ_{V3401} and air temperature ϑ_a, values of those parameters are determined experimentally from responses to step change of the system reference (input) value ϑ_{3404r}, for different values of regeneration gas temperature ϑ_{V3401}.

The waveforms of the cooler and heater temperatures, their controller outputs, temperatures of the main and regeneration gas, regeneration gas flow, recorded with mean value of the main gas flow $131,286\ \mathrm{m^3/h}$, mean value of the outside air temperature $0.9\ ^\circ\mathrm{C}$, controller integral time constant $T_I = 180$ s and controller gain coefficient $K_R = 3-5$, are shown on Fig. 2.

Gauge signals, shown with different colors on Fig. 2, have the following meanings:

FER01	TI-3254	- main gas temperature;
FER02	TI-3408	- regeneration gas temperature;
FER03	TT-3404	- cooler's output gas temperature;
FER05	TT-3422	- heater's output gas temperature;
FER06	TIC-3404 OUT	- cooler's controller output;
FER07	TIC-3422 OUT	- heater's controller output;
FER08	FQI-3402A	- regeneration gas flow.

Recorded data about initial (0) and final (∞) values of the temperature controller output u_R, gas temperature at the cooler output ϑ_{3404} and regeneration gas temperature ϑ_{3408} are given in TABLE I. The data is recorded at the mean value of the main gas flow $131,286\ \mathrm{m^3/h}$, mean value of the outside air temperature $0.9\ ^\circ\mathrm{C}$ and controller integral time constant $T_I = 180$ s. The recorded data is used for cooler's model parameters identification.

Optimization of the model's transfer function parameters (7) and (8) is carried out using program package *Matlab*, *simplex* optimization method [5], [6] and recorded transients of the system. Block schematic for organizing optimization of model parameters in *Matlab* is given on Fig. 3. From recorded input data, i.e. controller output voltage (TIC-3404 OUT), and output data, i.e. cooler's output gas temperature (TT-3404), changes of those values around initial stationary values (Δu_R and Δy) are generated. That is accomplished by subtracting initial values (u_{C0} and y_0) from total values (u_R and y). In that way, change of controller output value Δu_R is generated, which represents input value to cooler's model. Model at it's output gives change of output value Δy_M. Error of cooler's model e is obtained by subtracting change of cooler output value Δy from change of cooler's model output value Δy_M. Integral square error criterion was used for optimization:

$$I = \int e^2(t)dt. \tag{14}$$

Obtained results for first order transfer function width dead time (FODT) $G_{p1}(s)$ (7), for transients shown on Fig. 2, are given in TABLE II.

Obtained results for second order transfer function with dead time (SODT) $G_{p2}(s)$ (8), for transients shown on Fig. 2, are given in TABLE III.

From TABLE II and III comparison it is seen that maximum transient error values e_m are approximately the same. Therefore, FODT transfer function $G_{p1}(s)$ (7), as well as SODT transfer function $G_{p2}(s)$ (8), approximate the cooler's dynamic behavior equally well. Gain coefficients K_p are also the same for both transfer functions (TABLES II and III).

However, in case 1 from TABLES II and III maximum transient error equals $e_m = 25\%$ and occurs before change of reference signal. This indicates that in cooler's model stationary state isn't established. In other operating points, maximum transient error has values in range $e_m = 10-20\%$, which is not completely satisfying for accuracy of cooler's model identification. These errors are caused by constant change of main gas temperature at the cooler input.

To reduce the influence of constant change of the main gas temperature at the cooler input on accuracy of cooler's model identification, process values recording is carried out with increased controller gain coefficient to values: $K_R = 4-6$ and increased controller integral time constant to value: $T_I = 300$ s. In that way the amplitude of the main gas flow oscillations at the cooler's input is reduced.

The same waveforms as on Fig. 2, recorded with mean value of the main gas flow $127,149\ \mathrm{m^3/h}$, mean value of the outside air temperature $3.9\ ^\circ\mathrm{C}$, controller integral time constant $T_I = 300$ s and controller gain coefficient $K_R = 4-6$, are shown on Fig. 4.

Recording conditions and belonging controller gain coefficients K_R are given in TABLE IV.

TABLE I

DISPLAY OF CONDITIONS FOR DIFFERENT OPERATING POINTS ON FIG. 2 RECORDED WITH $K_R = 3-5$ AND $T_I = 180$ s.

N^o	K_R	$u_R(0)$ [%]	$u_R(\infty)$ [%]	$\vartheta_{3404}(0)$ [°C]	ϑ_{3404} (∞)[°C]	$\vartheta_{3408}(0)$ [°C]
1	3	42.4	26.5	27.3	31.3	69
2	4	46.9	56.5	31.9	28.4	229
3	5	60.7	54.2	28.5	31.7	268
4	4	51.5	62.1	31.4	27.8	271
5	4	42.1	32.7	27.4	31.4	62

TABLE II

PARAMETERS OF TRANSFER FUNCTION $G_{p1}(s)$ (7) DETERMINED USING *MATLAB* FOR OPERATION POINTS GIVEN IN TABLE I ($K_R = 3-5$ AND $T_I = 180$ s).

N^o	K_p	T_1 [s]	T_{dt} [s]	e_m [%]
1	−0.28237	135.18	126.83	25.1
2	−0.33294	173.29	91.327	17.7
3	−0.34138	147.89	94.285	11.2
4	−0.28076	123.24	111.97	15.9
5	−0.42687	142.91	78.184	18.9

TABLE III

PARAMETERS OF TRANSFER FUNCTION $G_{p2}(s)$ (8) DETERMINED USING *MATLAB* FOR OPERATION POINTS GIVEN IN TABLE I ($K_R = 3-5$ AND $T_I = 180$ s).

N^o	K_p	T_1	T_2	T_{dt}	e_m
1	−0.28392	137.12	11.598	113.99	24.9
2	−0.32775	100.93	100.51	43.309	17.7
3	−0.33834	89.473	80.613	53.199	10.4
4	−0.28001	77.415	77.415	72.336	15.5
5	−0.42459	86.034	86.022	34.628	10.2

Trace	Name	Description	Type	Status	Ruler Time	Ruler Value	Filter	Time Offset	Limits
☑ 🟥	FER01	TI 3254	Line	GOOD	15:57:15 13-0	61.469059	1.000000		☐ 🟥
☑ ⬜	FER02	TI 3408	Line	GOOD	15:57:13 13-0	30.531075	1.000000		☐ ⬜
☑ 🟧	FER03	TT 3404	Line	GOOD	15:57:13 13-0	31.421696	1.000000		☐ 🟧
☐ 🟦	FER04	TI 3426	Line	GOOD	08:58:16 13-0	31.493759	1.000000		☐ 🟦
☑ 🟪	FER05	TT 3422	Line	GOOD	15:57:35 13-0	294.681488	1.000000		☐ 🟪
☑ 🟫	FER06	TIC 3404 OUT	Line	GOOD	15:57:35 13-0	28.770096	1.000000		☐ 🟫
☑ 🟥	FER07	TIC 3422 OUT	Line	GOOD	15:57:35 13-0	84.028137	1.000000		☐ 🟥
☑ 🟩	FER08	FQI 3402A	Line	GOOD	15:57:33 13-0	16055.06445	1.000000		☐ 🟩

Fig. 2. Process values transient waveforms recorded with mean values of main gas flow $131,286\ \mathrm{m}^3/\mathrm{h}$, outside air temperature $0.9\ ^\circ\mathrm{C}$, controller integral time constant $T_I = 180$ s and controller gain coefficient $K_R = 3 - 5$.

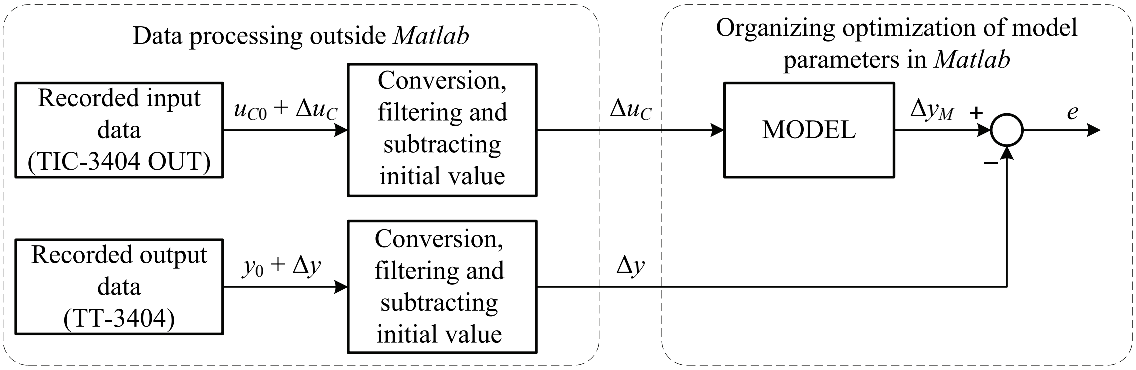
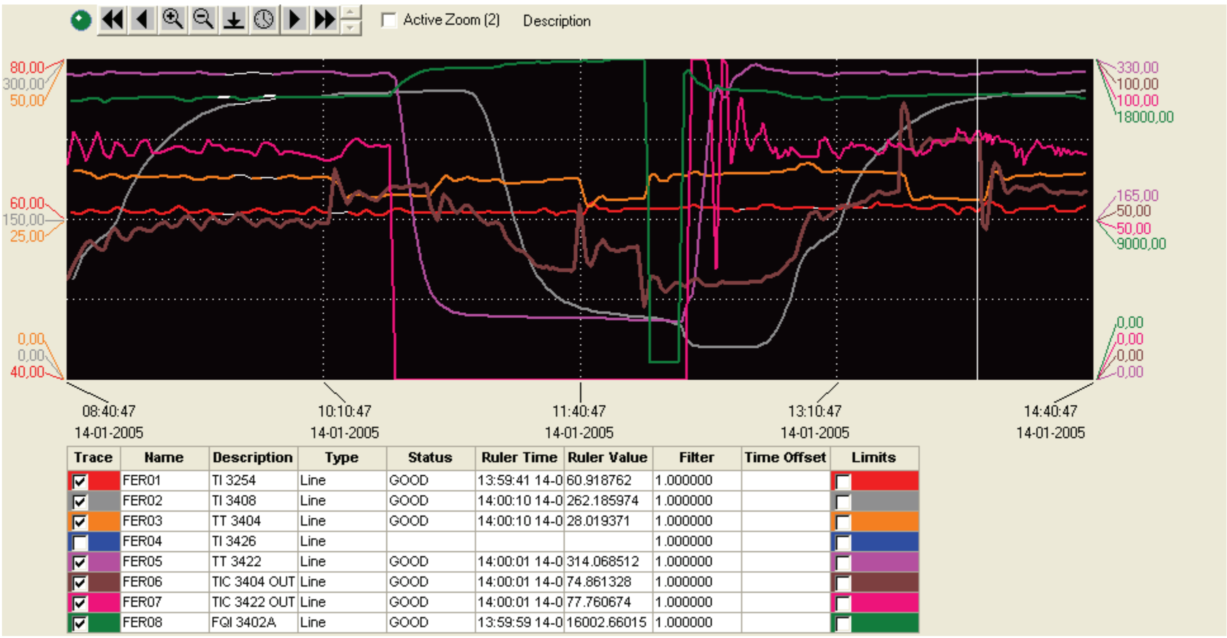


Fig. 3. Block schematic for organizing optimization of model parameters in *Matlab*.



Trace	Name	Description	Type	Status	Ruler Time	Ruler Value	Filter	Time Offset	Limits
☑ 🟥	FER01	TI 3254	Line	GOOD	13:59:41 14-0	60.918762	1.000000		☐ 🟥
☑ ⬜	FER02	TI 3408	Line	GOOD	14:00:10 14-0	262.185974	1.000000		☐ ⬜
☑ 🟧	FER03	TT 3404	Line	GOOD	14:00:10 14-0	28.019371	1.000000		☐ 🟧
☐ 🟦	FER04	TI 3426	Line				1.000000		☐ 🟦
☑ 🟪	FER05	TT 3422	Line	GOOD	14:00:01 14-0	314.068512	1.000000		☐ 🟪
☑ 🟫	FER06	TIC 3404 OUT	Line	GOOD	14:00:01 14-0	74.861328	1.000000		☐ 🟫
☑ 🟥	FER07	TIC 3422 OUT	Line	GOOD	14:00:01 14-0	77.760674	1.000000		☐ 🟥
☑ 🟩	FER08	FQI 3402A	Line	GOOD	13:59:59 14-0	16002.66015	1.000000		☐ 🟩

Fig. 4. Process values transient waveforms recorded with mean values of main gas flow $127,149\ \mathrm{m}^3/\mathrm{h}$, outside air temperature $3.9\ ^\circ\mathrm{C}$, controller integral time constant $T_I = 300$ s and controller gain coefficient $K_R = 4 - 6$.

TABLE IV

DISPLAY OF CONDITIONS FOR DIFFERENT OPERATING POINTS ON FIG. 4 RECORDED WITH $K_R = 4 - 6$ AND $T_I = 300$ s.

N^o	K_R	$u_R(0)$ [%]	$u_R(\infty)$ [%]	$\vartheta_{3404}(0)$ [°C]	ϑ_{3404} (∞)[°C]	$\vartheta_{3408}(0)$ [°C]
1	5	48.9	55.7	31.6	28.4	265
2	5	60.5	52.1	28.9	31.0	270
3	5	34.7	41.7	30.7	28.1	70
4	4	40.9	30.3	28.0	32.0	59
5	6	58.4	74.0	32.4	28.0	231

TABLE V

PARAMETERS OF TRANSFER FUNCTION $G_{p1}(s)$ (7) DETERMINED USING *MATLAB* FOR OPERATION POINTS GIVEN IN TABLE IV ($K_R = 4 - 6$ AND $T_I = 300$ s).

N^o	K_p	T_1 $[s]$	T_{dt} $[s]$	e_m [%]
1	-0.36776	202.86	71.876	15.4
2	-0.38489	160.43	81.807	20.3
3	-0.49210	223.39	85.534	12.4
4	-0.36137	146.64	80.047	16.2
5	-0.25301	169.88	83.227	12.6

Obtained results for FODT transfer function $G_{p1}(s)$ (7), for transients shown on Fig. 4, are given in TABLE V.

Obtained results for second order transfer function with dead time (SODT) $G_{p2}(s)$ (8), for transients shown on Fig. 4, are given in TABLE VI.

From comparison of TABLES V and VI with TABLES II and III, it is seen that increase of controller gain coefficient from $K_R = 3 - 5$ to $K_R = 4 - 6$ and integral time constant from $T_I = 180$ s to $T_I = 300$ s resulted in reduced maximum transient errors. The error is reduced about 20% for FODT transfer function $G_{p1}(s)$ (7) and about 50% for SODT transfer function $G_{p2}(s)$ (8). By that, the accuracy of the cooler's model identification is also increased. To sum it all up, increase of controller gain coeficient and integral time constant resulted in reduced influence of the constant oscillations of main gas temperature at the cooler's input on accuracy of model identification.

From comparison of TABLES V and VI, it is seen that maximum transient error e_m for FODT transfer function $G_{p1}(s)$ (7) has about 50% higher value than for SODT transfer function $G_{p2}(s)$ (8). Maximum transient error for SODT transfer function equals $e_m = 4.3 - 14.6\%$, so it can be considered that the cooler's model experimental identification is done with satisfied accuracy.

Cooler's model gain coefficients K_p have approximately the same values for both transfer functions $G_{p1}(s)$ (7) and $G_{p2}(s)$ (8) (TABLES V and VI). Cooler's model dead time T_{dt} is determined more accurately with FODT transfer function $G_{p1}(s)$ (7) (TABLE V), than with SODT transfer function $G_{p2}(s)$ (8) (TABLE VI). In cases 1 and 4, for SODT transfer function $G_{p2}(s)$ (8) (TABLE VI), time constant T_2 is significantly smaller than time constant T_1, so dead time T_{dt} in FODT transfer function $G_{p1}(s)$ (7) (TABLE V) is approximately equal to sum of dead time T_{dt} and time constant T_2 in SODT transfer function $G_{p2}(s)$ (8) (TABLE VI). In those cases time constants T_1 are approximately the same for both transfer functions.

TABLE VI

PARAMETERS OF TRANSFER FUNCTION $G_{p2}(s)$ (8) DETERMINED USING *MATLAB* FOR OPERATION POINTS GIVEN IN TABLE IV ($K_R = 4 - 6$ AND $T_I = 300$ s).

N^o	K_p	T_1	T_2	T_{dt}	e_m
1	-0.36008	164.08	55.803	33.928	11.6
2	-0.37780	89.896	89.896	39.595	13.6
3	-0.48134	143.53	92.498	36.184	7.65
4	-0.36003	130.14	33.769	53.882	14.6
5	-0.25095	99.806	99.806	36.811	4.33

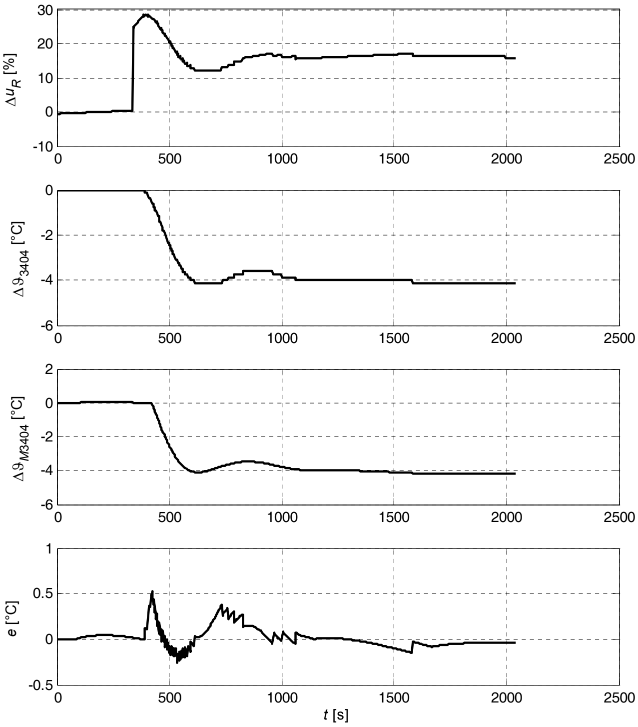


Fig. 5. Responses of change of cooler's gas output temperature $\Delta\vartheta_{3404}$ (TT-3404), cooler's model output $G_{p1}(s)$ $\Delta\vartheta_{M3404}$ and error e with parameters N^o 5 from TABLES IV and V on change of controller output voltage Δu_R (TIC-3404 OUT) ($K_R = 4 - 6$, $T_I = 300$ s).

Responses of change of cooler's output temperature $\Delta\vartheta_{3404}$ (TT-3404), cooler's model output $G_{p2}(s)$ $\Delta\vartheta_{M3404}$ and error e on change of controller output voltage Δu_R (TIC-3404 OUT), with conditions N^o 5 from TABLES IV, V and VI ($K_R = 4 - 6$, $T_I = 300$ s), for FODT transfer function $G_{p1}(s)$ (7) are given on Fig. 5 and for SODT transfer function $G_{p2}(s)$ (8) on Fig. 6. These figures show that maximum transient error for FODT transfer function $G_{p1}(s)$ (7) is greater and occurs at the beginning of the transient (Fig. 5), while maximum transient error for SODT transfer function $G_{p2}(s)$ (8) is approximately 3 times smaller (Fig. 6).

The jaggy responses of controller output Δu_R, output temperature $\Delta\vartheta_{3404}$ and error e on Fig. 5 and 6 are caused by signal quantization in the procedure of A/D conversion.

It is necessary to emphasize that maximum transient error e_m before the change of reference value is smaller or equal to maximum transient error after the change of reference value (Fig. 5, 6). Therefore, increased controller gain coefficient from $K_R = 3 - 5$ to $K_R = 4 - 6$ and integral time constant from $T_I = 180$ s to $T_I = 300$ s resulted in reduced maximum transient errors and in increased accuracy of natural gas cooler's model identification. However, constant oscillations of gas temperature at the cooler's input are not

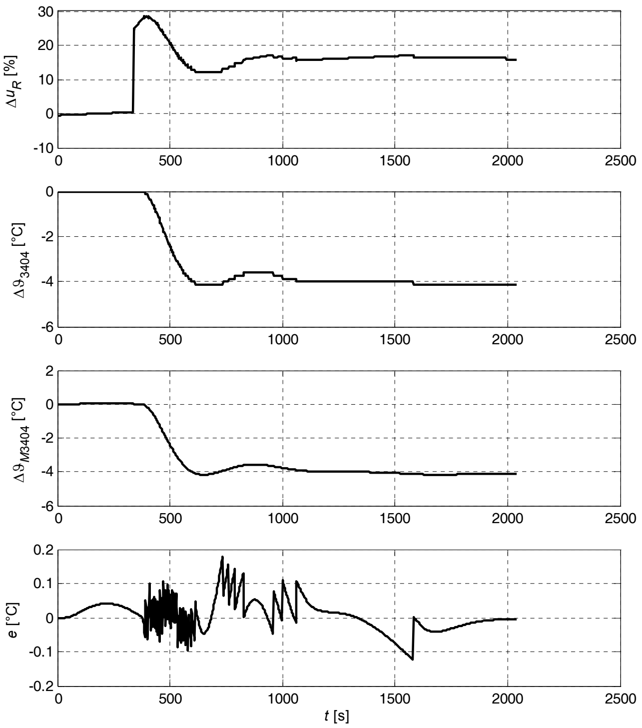


Fig. 6. Responses of change of cooler's gas output temperature $\Delta\vartheta_{3404}$ (TT-3404), cooler's model output $G_{p2}(s)$ $\Delta\vartheta_{M3404}$ and error e with parameters N^o 5 from TABLES IV and VI on change of controller output voltage Δu_R (TIC-3404 OUT) ($K_R = 4 - 6$, $T_I = 300$ s).

completely eliminated, so it is necessary to consider the possibilities and ways of eliminating those oscillations.

It is seen from TABLES II, III, V and VI that change of regeneration gas temperature ϑ_{3408} (TT-3408) (TABLES I and IV), significantly changes gain coefficient K_p, dead time T_{dt} and time constant T_1 of cooler's model. This indicates that constant values of PI controller parameters does not result in satisfactorily good dynamic behavior of cooler's output gas temperature control system. Therefore, it is necessary to embed some of adaptive control algorithms, which would result in approximately the same cooler's output gas temperature control system dynamic behavior, with different regeneration gas temperatures and environment air temperature used in cooler.

IV. CONCLUSION

This paper describes the procedure of determination of optimal values of natural gas cooler's dynamic model parameters, using *Matlab* and *simplex* optimization method. Natural gas cooler's dynamic model is determined by recording transients of the controller output voltage and cooler's output gas temperature, with different values of disturbance (regeneration gas) temperature.

To reduce the influence of constant change of the main gas temperature at the cooler input on accuracy of cooler's model identification, process values recording is carried out with increased controller gain coefficient and integral time constant. In that way amplitude of main gas flow oscillations at the cooler's input is reduced, but not quite eliminated. This resulted in reduced maximum transient errors and increased accuracy of cooler's model parameters identification.

Accompanied figures show that maximum transient error for FODT transfer function $G_{p1}(s)$ is higher than for SODT transfer function $G_{p2}(s)$ and occurs at the beginning of the transient. Besides that, the values of the gain coefficient K_p are approximately the same for both transfer functions. However, values of dead times T_{dt} are significantly different. In two cases optimization of SODT transfer function parameters $G_{p2}(s)$ resulted in much smaller value of T_2 than T_1. In that case, dead time T_{dt} of FODT transfer function $G_{p1}(s)$ is approximately equal to sum of dead time T_{dt} and time constant T_2 of SODT transfer function $G_{p2}(s)$. In other cases time constants T_1 and T_2 of SODT transfer function $G_{p2}(s)$ obtained have values of same order of magnitude, so it is not possible to determine equivalent dead time.

Constant oscillations of cooler's input gas temperature significantly effect the accuracy of determination of cooler's model optimal parameters. Therefore, it is necessary to consider possibilities and ways of eliminating those oscillations.

Optimization results show that change of regeneration gas temperature (disturbance value), significantly changes gain coefficient K_p, dead time T_{dt} and time constant T_1 of cooler's model. This indicates that constant values of PI controller parameters does not result in satisfactorily good dynamic behavior of the cooler's output gas temperature control system. Therefore, a robust control strategy is necessary, but only robust PI controller design is not sufficient for quality cooler's output gas temperature control system dynamic behavior. The proposed algorithm is model reference adaptive control with modified signal adaptation algorithm, which acts as an outer control loop, with the inner PI feedback control loop. That algorithm has proved to be robust in [8]. In that way both robust and high performance control would be achieved.

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