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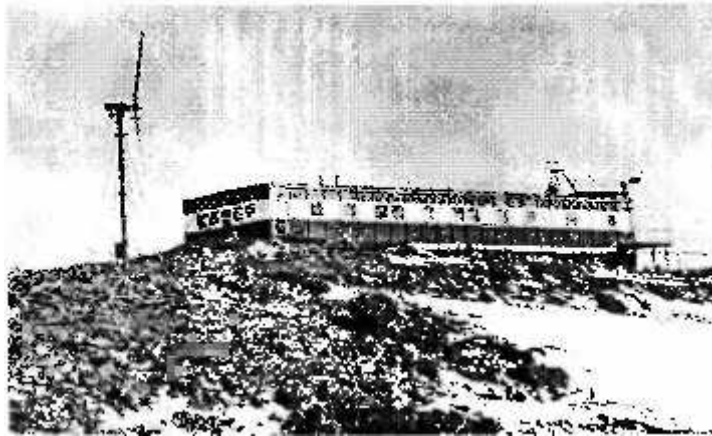
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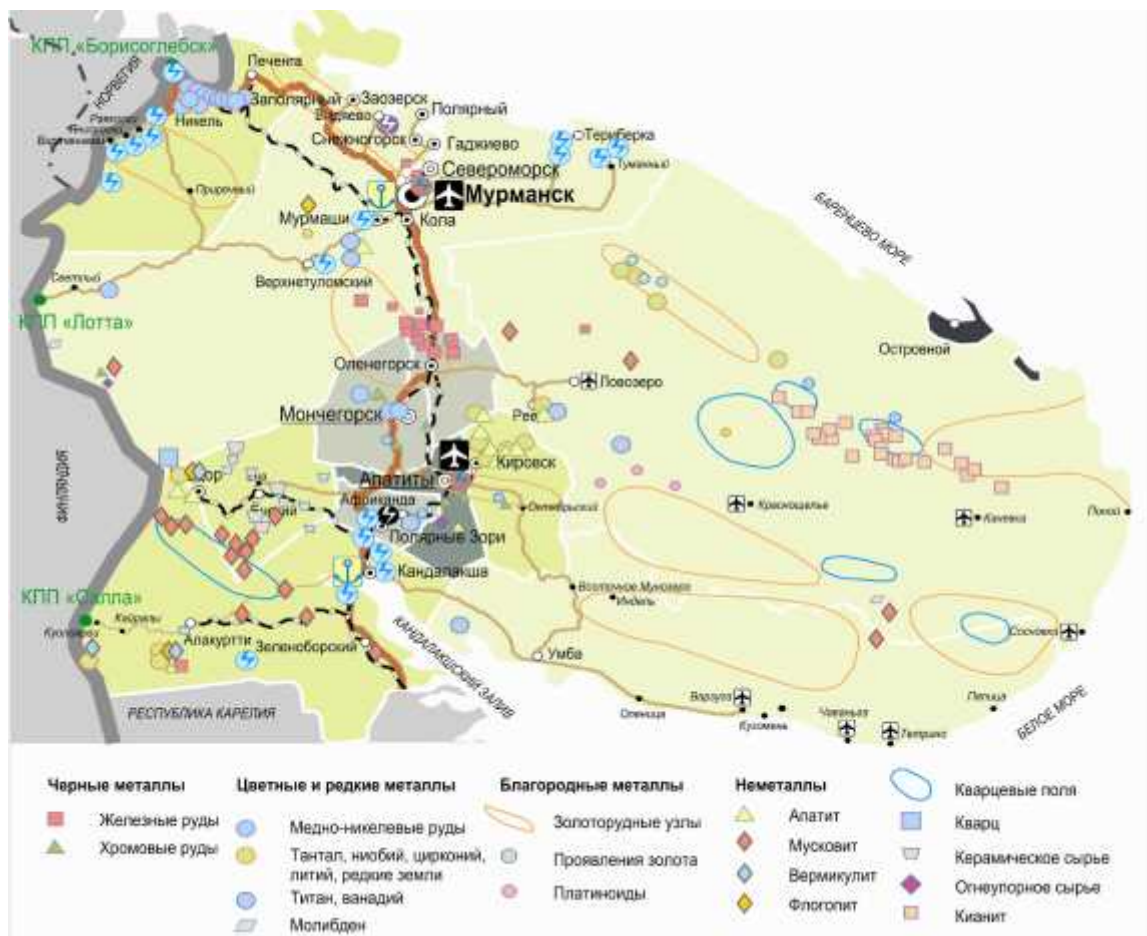
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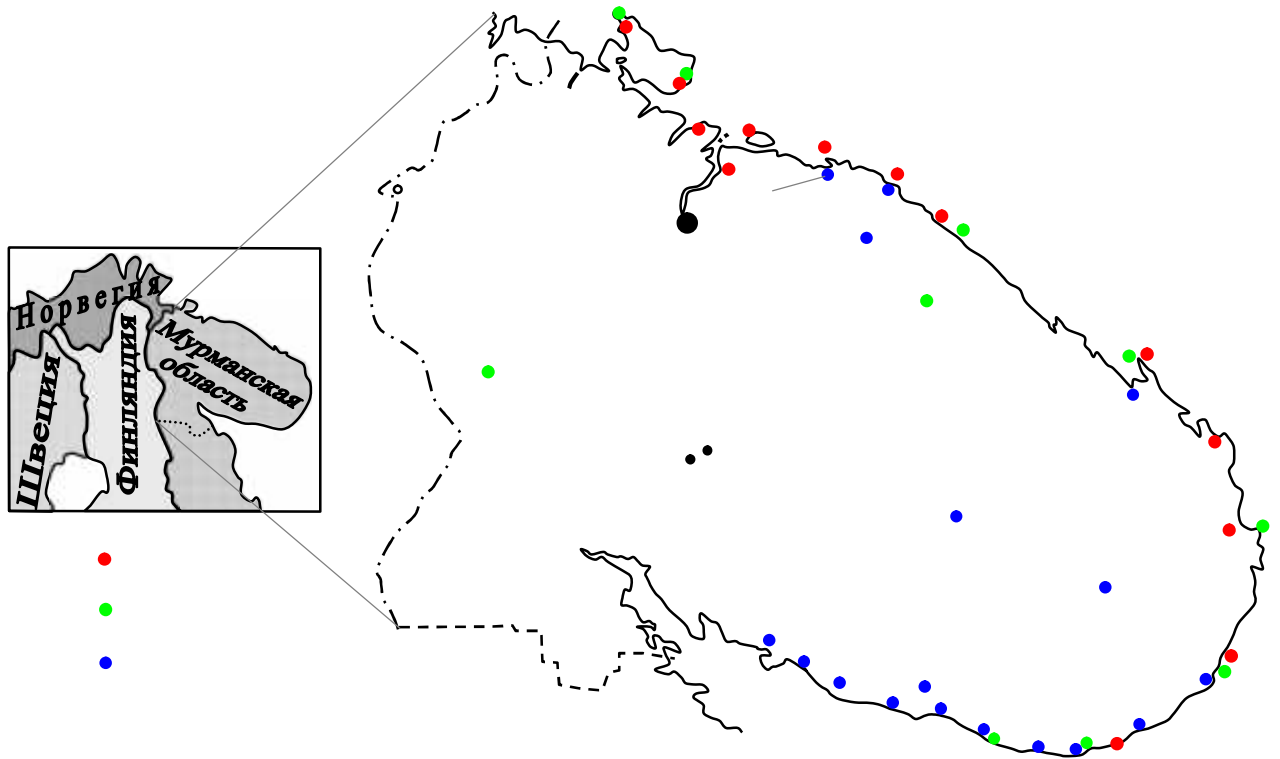
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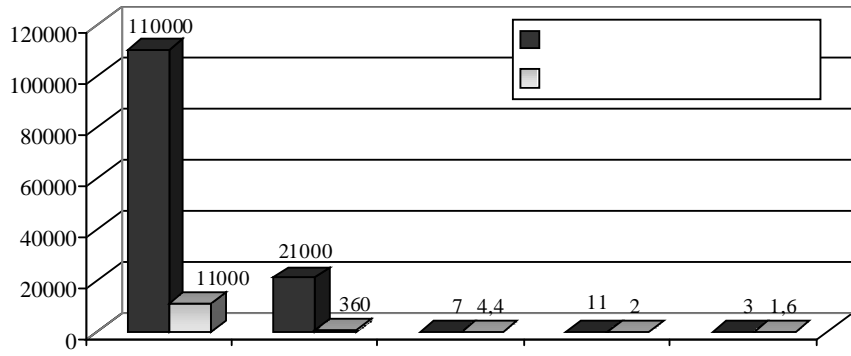
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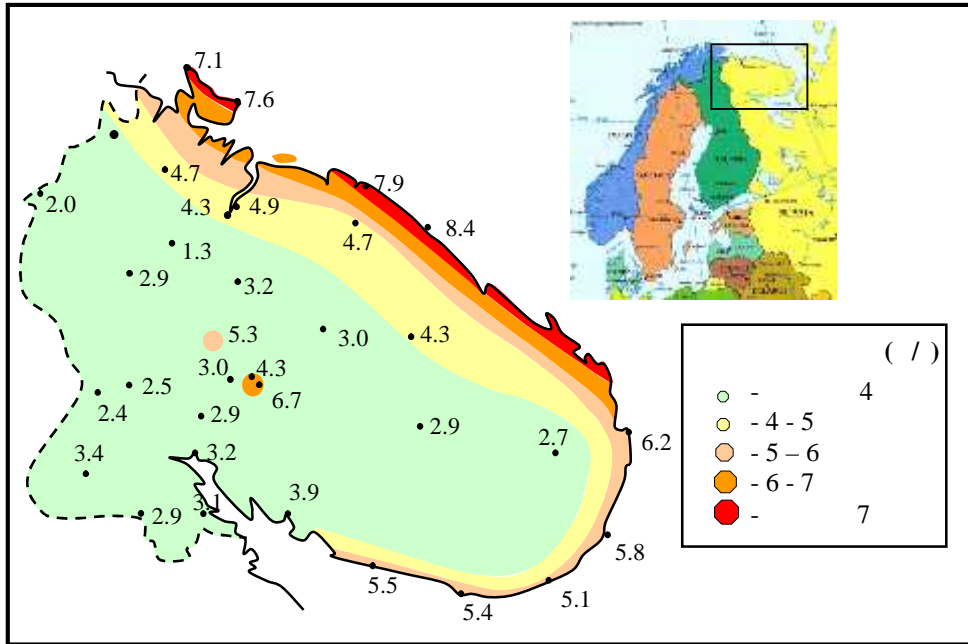
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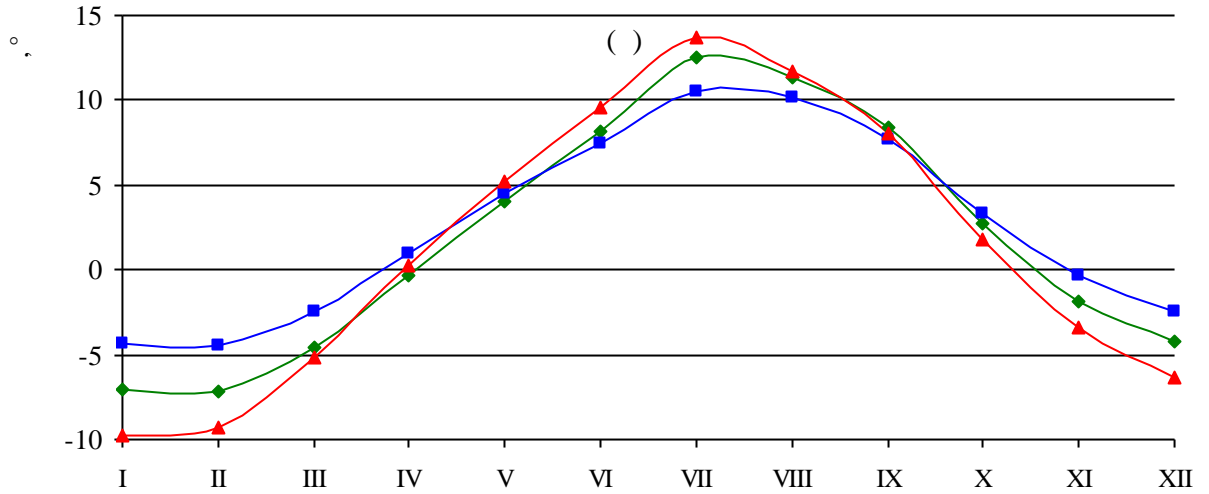
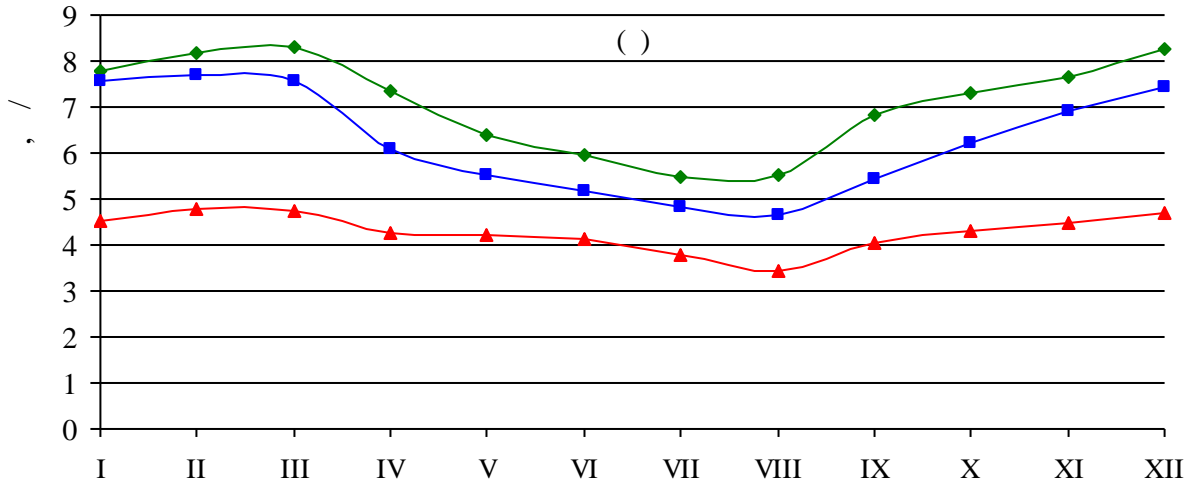
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.	Antaris	2014-2016	140	- -
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c.	Antaris	2015	4,5	« - »

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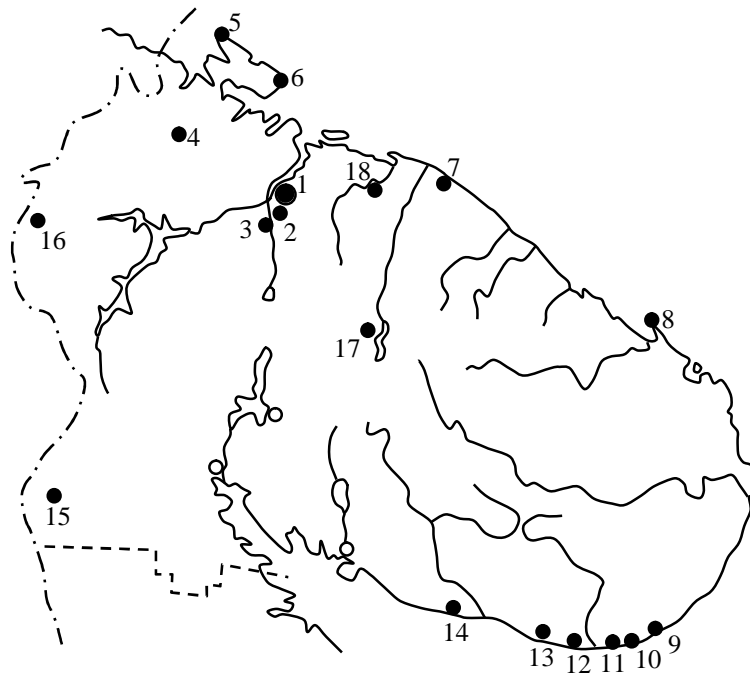
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2.1

T_1 ϵ_1 , C_p - $Q_1 = \epsilon_1 C_p T_1$, $\frac{dQ_1}{dt} = C_p \left(\frac{d\epsilon_1}{dt} T_1 + \epsilon_1 \frac{dT_1}{dt} \right)$, $Q_3 = \epsilon_3 C_p T_3$, $Q_2 = \epsilon_3 C_p T_2$, $Q^{(0)} = \epsilon_1 C_p T_2$, $Q^{(0)} = \epsilon^{(0)} C_p T_2$.

$$Q_1 = \epsilon_1 C_p T_1, \tag{2.1}$$

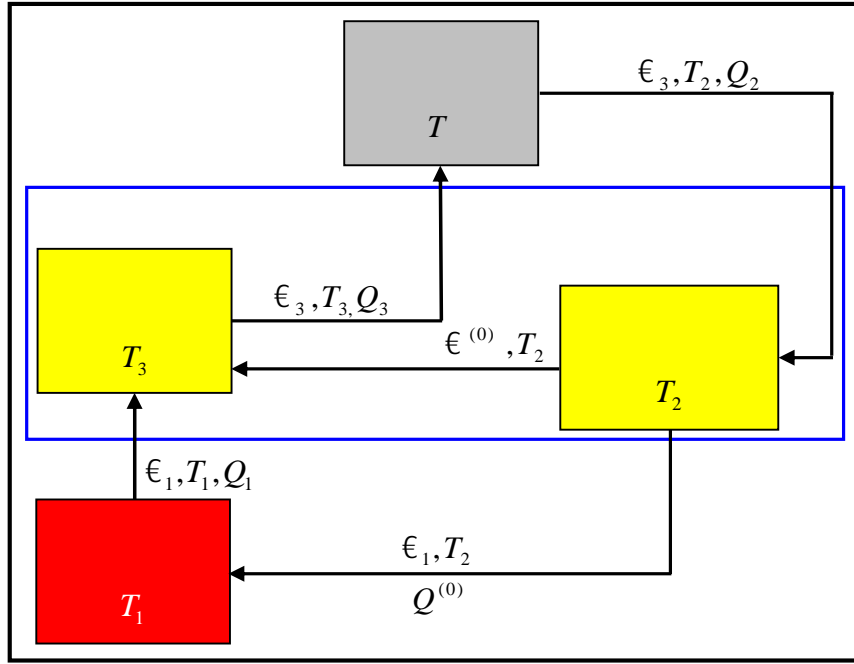
$$\frac{dQ_1}{dt} = C_p \left(\frac{d\epsilon_1}{dt} T_1 + \epsilon_1 \frac{dT_1}{dt} \right), \tag{2.2}$$

$$Q_3 = \epsilon_3 C_p T_3, \tag{2.3}$$

$$Q_2 = \epsilon_3 C_p T_2, \tag{2.4}$$

$$Q^{(0)} = \epsilon_1 C_p T_2, \tag{2.5}$$

$$Q^{(0)} = \epsilon^{(0)} C_p T_2. \tag{2.6}$$



2.1 -

: ϵ T -

; Q -

$$Q_3, Q_2, Q^{(0)} \quad Q^{(0)}, \quad (2.2) -$$

$$\begin{cases} \frac{dQ_1}{dt} = C_p \left(\frac{d\epsilon_1}{dt} T_1 + \epsilon_1 \frac{dT_1}{dt} \right) \\ \frac{dQ_2}{dt} = C_p \left(\frac{d\epsilon_3}{dt} T_2 + \epsilon_3 \frac{dT_2}{dt} \right) \\ \frac{dQ_3}{dt} = C_p \left(\frac{d\epsilon_3}{dt} T_3 + \epsilon_3 \frac{dT_3}{dt} \right) \\ \frac{dQ^{(0)}}{dt} = C_p \left(\frac{d\epsilon_1}{dt} T_2 + \epsilon_1 \frac{dT_2}{dt} \right) \\ \frac{dQ^{(0)}}{dt} = C_p \left(\frac{d\epsilon^{(0)}}{dt} T_2 + \epsilon^{(0)} \frac{dT_2}{dt} \right) \end{cases} \quad (2.7)$$

2.2

($T_1, T_2 \quad T_3$)

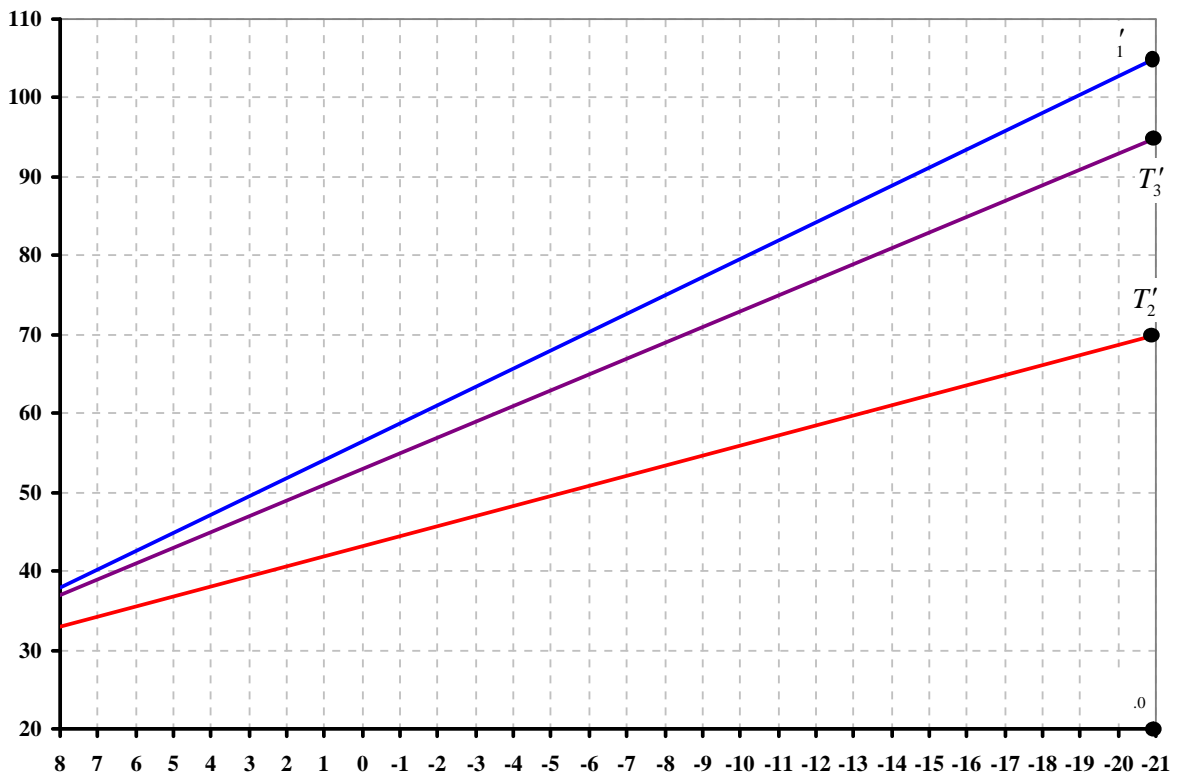
: 150/70, 130/70, 115/70, 105/70

95/70.

$T_{,0}$ (0,92) 21° .
105/70

2.2.

2.1



2.2 -

($i=105^\circ$, $T'_2=70^\circ$, $T'_3=95^\circ$) : 1, 3 2 -

2.2

$$y = kx + b, \quad y -$$

$$T_1, T_3 \quad T_2 \quad :$$

$$T_1 = -\frac{67}{29}T + \frac{1638}{29}, \tag{2.8}$$

$$T_3 = -2T + 53, \tag{2.9}$$

$$T_2 = -\frac{37}{29}T + \frac{1253}{29}. \tag{2.10}$$

:

$$\begin{cases} \frac{dT_1}{dt} = -\frac{67}{29} \frac{dT}{dt} \\ \frac{dT_3}{dt} = -2 \frac{dT}{dt} \\ \frac{dT_2}{dt} = -\frac{37}{29} \frac{dT}{dt} \end{cases} \tag{2.11}$$

2.3

() [90].

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Q_2 ,

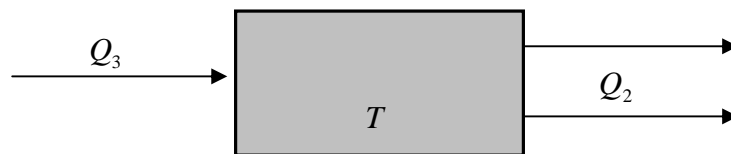
Q_3

(2.3).

2.1 -

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	0,98	0,92
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	-35	-30
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	-40	-35
	-28	-25
()	-23	-21
-	-24	-22
	-34	-29
	-27	-24



2.3 -

:

$$\frac{d(V C_p T)}{dt} = Q_3 - Q_2 - qV k_v(T - T) \tag{2.12}$$

$$V C_p \frac{dT}{dt} = \epsilon_3 C_p (T_3 - T_2) - qV k_v(T - T), \tag{2.13}$$

$$V C_p \frac{dT}{dt} -$$

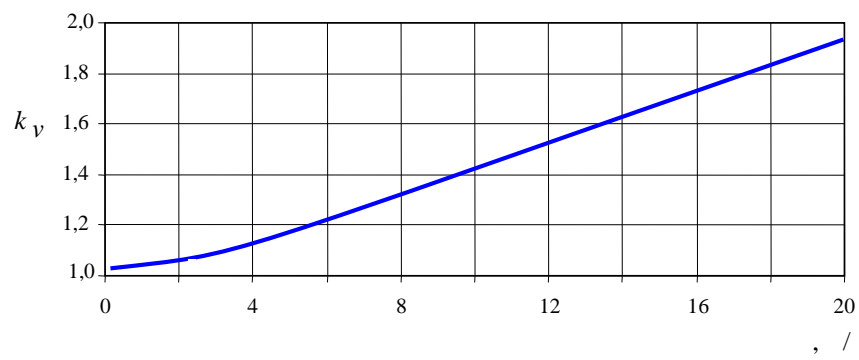
(, ,); $qV k_v(T - T)$ -

[30]; q - , / $^3 \dots$;
 V - , 3 ; C - ((18-20°
), / 3 ; -
 [90, 91]); - , ° ; k_v - ,
 (2.4) [30].
 (2.13)

(2.13) t :

$$T = \frac{\epsilon_3 C_p T_3 - \epsilon_3 C_p T_2}{qV k_v} + e^{-\frac{q}{C_p} t} \cdot \left(T_0 - T_0 - \frac{\epsilon_{3_0} C_p T_{3_0} - \epsilon_{3_0} C_p T_{2_0}}{qV k_{v_0}} \right) + T. \quad (2.14)$$

T , T_2 T_3



2.4 -

($T = \text{const}$)

$$\frac{dT}{dt} = 0. \quad (2.15)$$

(2.13) :

$$\epsilon_3 C_p (T_3 - T_2) = qV k_v (T - T). \quad (2.16)$$

[92]:

$$Q_1 = Q^{(0)} + Q_0, \tag{2.17}$$

$$Q_0 = qV k_v (T - T_0) -$$

(2.1) (2.5)

(2.17)

:

$$\epsilon_1 C_p T_1 = \epsilon_1 C_p T_2 + qV k_v (T - T_0). \tag{2.18}$$

2.4

[54].

$$\epsilon_1',$$

(2.18)

:

$$\epsilon_1' C_p T_1' = \epsilon_1' C_p T_2' + qV k_v (T - T_{,0}), \tag{2.19}$$

$$\epsilon_1' C_p T_2' -$$

$$T_{,0}; qV k_v (T - T_{,0}) -$$

,
 $T_{,0}$.

$$\epsilon'_1 = \frac{qV \cdot k_v (T - T_{,0})}{C_p \cdot (T'_1 - T'_2)} = \text{onst.} \quad (2.20)$$

$$\epsilon'_3 \quad (\quad) \quad ,$$

:

$$\epsilon'_3 C_p T'_3 = \epsilon'_3 C_p T'_2 + qV \cdot k_v (T - T_{,0}), \quad (2.21)$$

$$\epsilon'_3 C_p T'_3 - \epsilon'_3 C_p T'_2 - \quad , \quad , \quad ,$$

$T_{,0}$.

$$\epsilon'_3 = \frac{qV \cdot k_v (T - T_{,0})}{C_p \cdot (T'_3 - T'_2)} = \text{onst.} \quad (2.22)$$

:

$$\epsilon'^{(0)} + \epsilon'_1 = \epsilon'_3. \quad (2.23)$$

$$\epsilon'^{(0)}, \quad :$$

$$\epsilon'^{(0)} = \epsilon'_3 - \epsilon'_1 = \text{onst.} \quad (2.24)$$

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$$(2.19) \quad (2.21).$$

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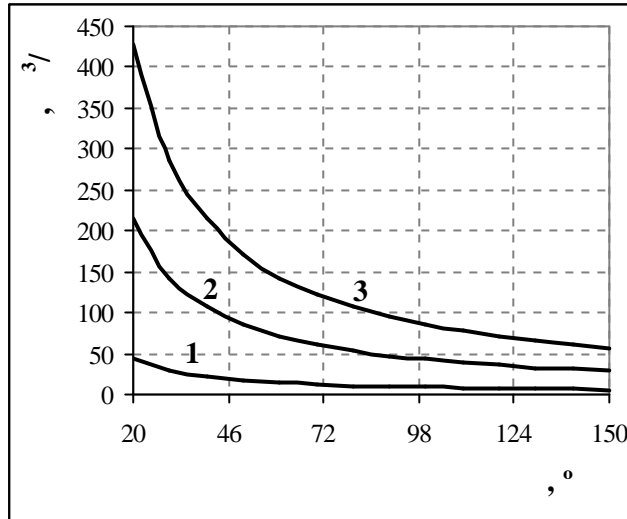
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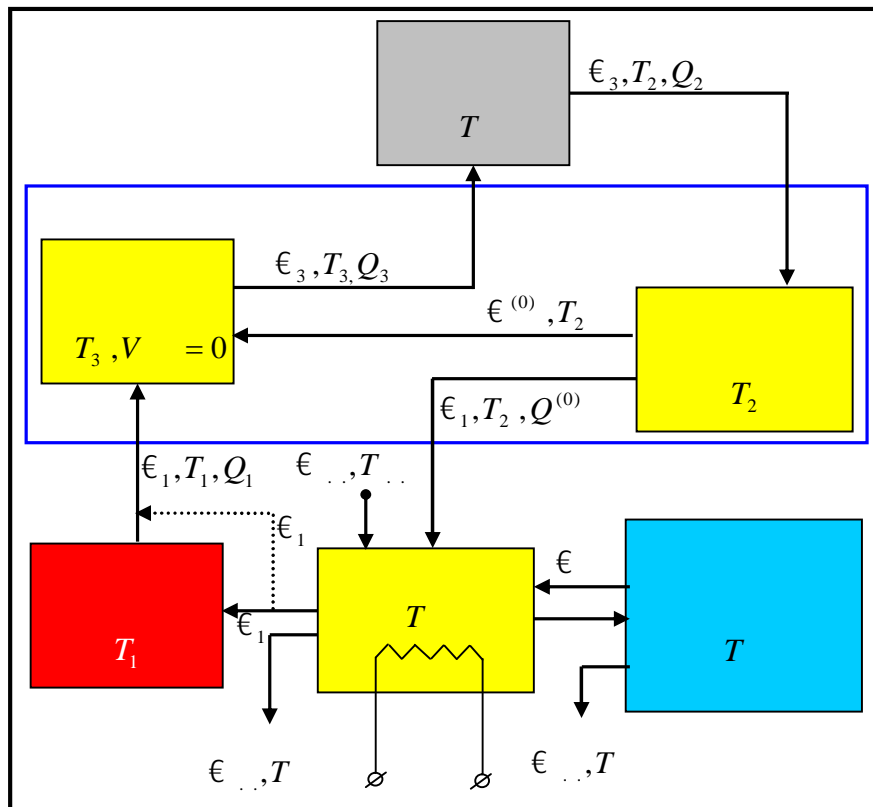
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[95].

2.8). (2.7 1,5 -

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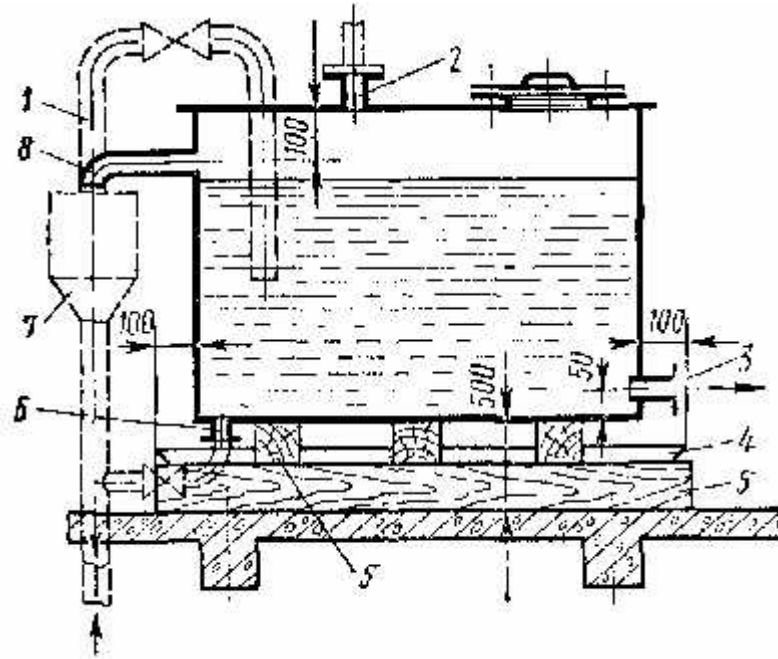
	- ()	/	- / 3'	,	-	3'	-
	0,837	-	2242	59737	16,4	26,6	11,69
	4,187	-	1000	11941	3,27	11,94	5,25
	2,09	232,6	1602	3644	1	2,274	1

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2.7 -

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T_1 95° ,

T_1

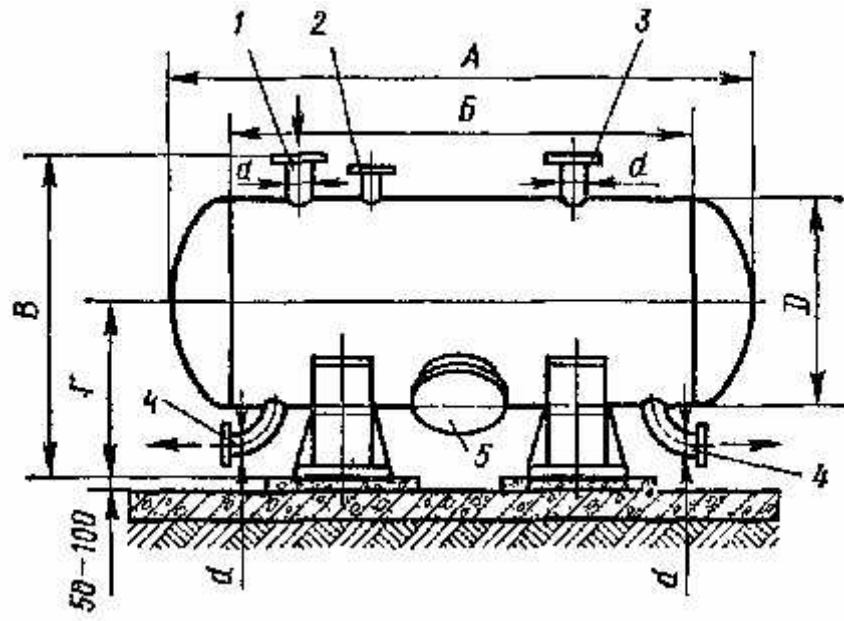
T_3

T_2

(.2.9).

T_3

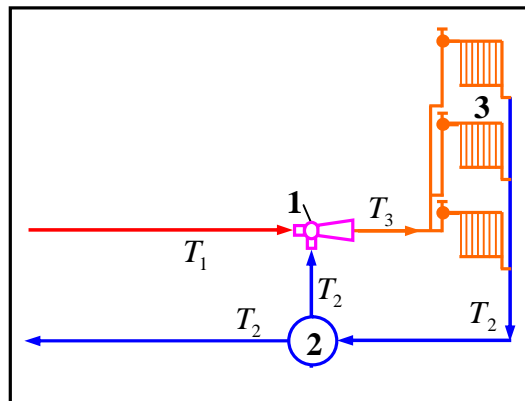
T_2 .



2.8 - : 1 - , 2 -
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2.9 - : 1 - , 2 - , 3 -

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2.6

[54].

[96].

[54]:

T_2
 ϵ_1 .

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 $T T_1$

$T > T_1$ $T > T$

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(). , $T < T_1$

$T < T$,

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$T = T_1$,

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95-99 ° .

$Q^{(0)}$ Q ,
 Q .

$$\frac{d(V C_p T)}{dt} = Q^{(0)} - Q - K F (T -) \tag{2.25}$$

$$\frac{d(V C_p T)}{dt} = v C_p T - v C_p T - K F (T -) , \tag{2.26}$$

$Q = K F (T -)$, $V T -$

, ° ; € - , ° ; $T -$

, ° ; $K -$

, / ° ; $F -$, ° .

V C_p ,

(2.26) [54]:

$$\frac{dT}{dt} = \frac{\epsilon (T - T_0)}{V} - \frac{K F (T -)}{V C_p} \tag{2.27}$$

20 95°

(2.27)

(t=0) $T_0, \epsilon_0, T_0, T_0$ [54]:

$$\begin{aligned}
& \frac{\epsilon T + \frac{K F}{C_p}}{\epsilon + \frac{K F}{C_p}} + \left(\exp \left[- \left(\frac{\epsilon}{V} + \frac{K F}{V C_p} \right) \cdot t \right] \right) \\
& \left(T_0 - \frac{\epsilon_0 T_0 + \frac{K F}{C_p}}{\epsilon_0 + \frac{K F}{C_p}} \right)
\end{aligned} \tag{2.28}$$

2.7

[90] [91]
18-20° .

25° .

(25°),
(18°).

(2.13),

$$V C_p \frac{dT}{dt} = Q_3 - Q_2 - qV k_v (T - T_0), \tag{2.29}$$

$$V C_p \frac{dT}{dt} -$$

(,)

20%,

80% -

$$V (0,8 \cdot C_1 + 0,2 \cdot C_2) \frac{dT}{dt} = Q_3 - Q_2 - qV k_v (T - T_0), \tag{2.30}$$

$$C_1 = 0,36 \text{ kcal/m}^3 \cdot \text{K}$$

$$; C_2 =$$

$$T = \frac{Q_3 - Q_2}{qV k_v} + \left[\exp\left(-\frac{q}{(0,8 \cdot C_1 + 0,2 \cdot C_2)} t\right) \right] \cdot (T_0 - T_0 - \frac{Q_3 - Q_2}{qV k_v}) + T_0 \tag{2.31}$$

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Q

$$qV k_v (T - T_0).$$

18-25° (2.10, 2).

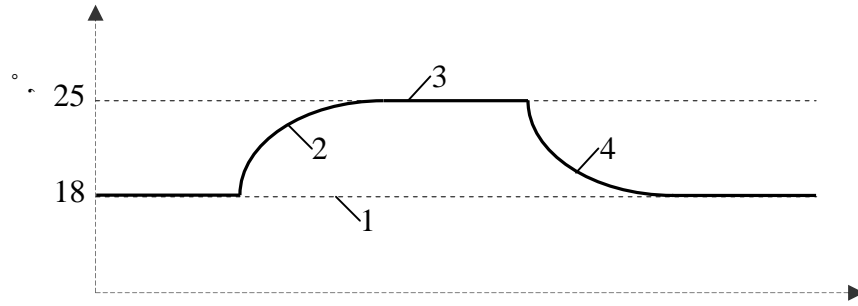
(2.30)

$$V(0,8 \cdot C + 0,2 \cdot C) \frac{dT}{dt} = Q - qV k_v(T - T_0) \tag{2.32}$$

(2.32),

(2.31),

$$T = \frac{Q}{qV k_v} + \left[\exp\left(-\frac{q}{(0,8 \cdot C + 0,2 \cdot C)} t\right) \right] \cdot \left(T_0 - T_0 - \frac{Q}{qV k_v} \right) + T_0 \tag{2.33}$$



2.10 -

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18°, 2 4 -

25°

(2.16).

25° (= 25°) (2.10, 3).

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(25 18° (2.10, 4))

(2.33).

18° (2.10, 1) (2.16).

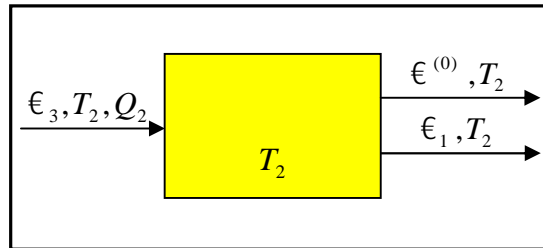
25° (2.10, 2),
(2.33),

2.8

« + » (2.6).

T_2 ϵ_3 .
 $\epsilon^{(0)}$, ϵ_1 .
 T_2 -

2.11).



2.11 -

:

$$\epsilon_3 - \epsilon^{(0)} - \epsilon_1 = 0, \tag{2.34}$$

$\epsilon^{(0)}$ -

$$\frac{d\epsilon^{(0)}}{dt} = \frac{d\epsilon_3}{dt} - \frac{d\epsilon_1}{dt}, \tag{2.35}$$

$\epsilon^{(0)}$,

$$Q_2 = Q^{(0)} + Q^{(0)}. \tag{2.36}$$

(2.6).

T_2

ϵ_1

T

ϵ

T

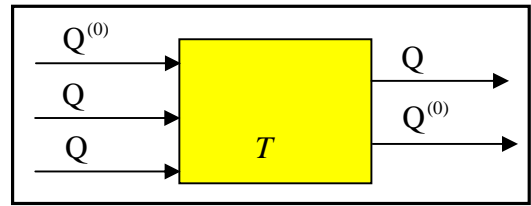
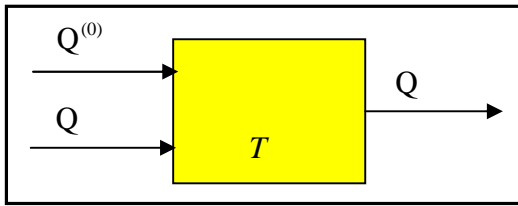
T

ϵ

T_1 .

1.

(2.12,).



2.12 -

$$Q = Q^{(0)} + Q, \tag{2.37}$$

Q

$$\frac{dQ}{dt} = \frac{dQ^{(0)}}{dt} + \frac{dQ}{dt}. \tag{2.38}$$

$$(2.37) \quad Q = \epsilon_1 C_p T$$

$$T = \frac{Q}{\epsilon_1 C_p}. \tag{2.39}$$

:

$$\frac{dT}{dt} = \frac{1}{C_p \epsilon_1} \cdot \frac{dQ}{dt} - \frac{Q}{C_p \epsilon_1^2} \cdot \frac{d\epsilon_1}{dt}, \quad (2.40)$$

2.

(2.12,).

:

$$Q = Q^{(0)} + Q + Q - Q^{(0)}. \quad (2.41)$$

(2.38)

:

$$\frac{dQ}{dt} = \frac{dQ^{(0)}}{dt} + \frac{dQ}{dt} + \frac{dQ}{dt} - \frac{dQ^{(0)}}{dt}. \quad (2.42)$$

,

:

$$\begin{cases} \frac{dQ}{dt} = \frac{dQ^{(0)}}{dt} + \frac{dQ}{dt} + \frac{dQ}{dt} - \frac{dQ^{(0)}}{dt} \\ \frac{dT}{dt} = \frac{1}{C_p \epsilon_1} \cdot \frac{dQ}{dt} - \frac{Q}{C_p \epsilon_1^2} \cdot \frac{d\epsilon_1}{dt} \end{cases}. \quad (2.43)$$

(2.1).

-

(2.6),

:

$$Q_1 = Q + Q, \quad (2.44)$$

 $Q -$

(2.17) (2.44),

« + »:

$$Q = Q_0 - Q = Q - Q^{(0)}. \quad (2.45)$$

:

$$\frac{dQ}{dt} = \frac{dQ}{dt} - \frac{dQ^{(0)}}{dt}. \quad (2.46)$$

(2.45) (2.46)

2.9

« + + »

+ + »

(2.7), (2.11), (2.43) (2.27), (2.30), (2.46)

 $T_{1_0}, T_{2_0}, T_{3_0}, T_{1_0}, T_{2_0}, T_{3_0}, Q_{1_0}, Q_{2_0}, Q_{3_0}, Q^{(0)}_{1_0}, Q^{(0)}_{2_0}, Q_{1_0}, Q_{2_0}$:

$$\left\{ \begin{array}{l}
 \frac{dT_1}{dt} = -\frac{67}{29} \frac{dT}{dt} \\
 \frac{dT_3}{dt} = -2 \frac{dT}{dt} \\
 \frac{dT_2}{dt} = -\frac{37}{29} \frac{dT}{dt} \\
 \frac{dT}{dt} = \frac{Q_3 - Q_2 - qV k_v (T - T_0)}{V (0,8 \cdot C_p + 0,2 \cdot C_v)} \\
 \frac{dT}{dt} = \frac{(T - T_0) K F (T - T_0)}{V C_p} \\
 \frac{dT}{dt} = \frac{1}{C_{p1}} \cdot \frac{dQ}{dt} - \frac{Q}{C_{p1}^2} \cdot \frac{d_1}{dt} \\
 \frac{dQ_1}{dt} = C_p \left(\frac{d_1}{dt} T_1 + \frac{dT_1}{dt} \right) \\
 \frac{dQ_2}{dt} = C_p \left(\frac{d_3}{dt} T_2 + \frac{dT_2}{dt} \right) \\
 \frac{dQ_3}{dt} = C_p \left(\frac{d_3}{dt} T_3 + \frac{dT_3}{dt} \right) \\
 \frac{dQ^{(0)}}{dt} = C_p \left(\frac{d_1}{dt} T_2 + \frac{dT_2}{dt} \right) \\
 \frac{dQ^{(0)}}{dt} = C_p \left(\frac{d^{(0)}}{dt} T_2 + \frac{d^{(0)} T_2}{dt} \right) \\
 \frac{dQ}{dt} = \frac{dQ^{(0)}}{dt} + \frac{dQ}{dt} + \frac{dQ}{dt} - \frac{dQ^{(0)}}{dt} \\
 \frac{dQ}{dt} = \frac{dQ}{dt} - \frac{dQ^{(0)}}{dt}
 \end{array} \right. \quad (2.47)$$

[54].

$\epsilon^{(0)}$ -

,

:

$$\begin{cases} \epsilon_1 = \frac{qV \cdot k_v (T - T_{,0})}{C_p \cdot (T'_1 - T'_2)} \\ \epsilon_3 = \frac{qV \cdot k_v (T - T_{,0})}{C_p \cdot (T'_3 - T'_2)} \\ \epsilon^{(0)} = \epsilon_3 - \epsilon_1 \end{cases} \quad (2.48)$$

2.4.

T

V

120

8,6 / (10

),

1,8 / (2,1)).

[97].

[1]

0,7-2,0

),

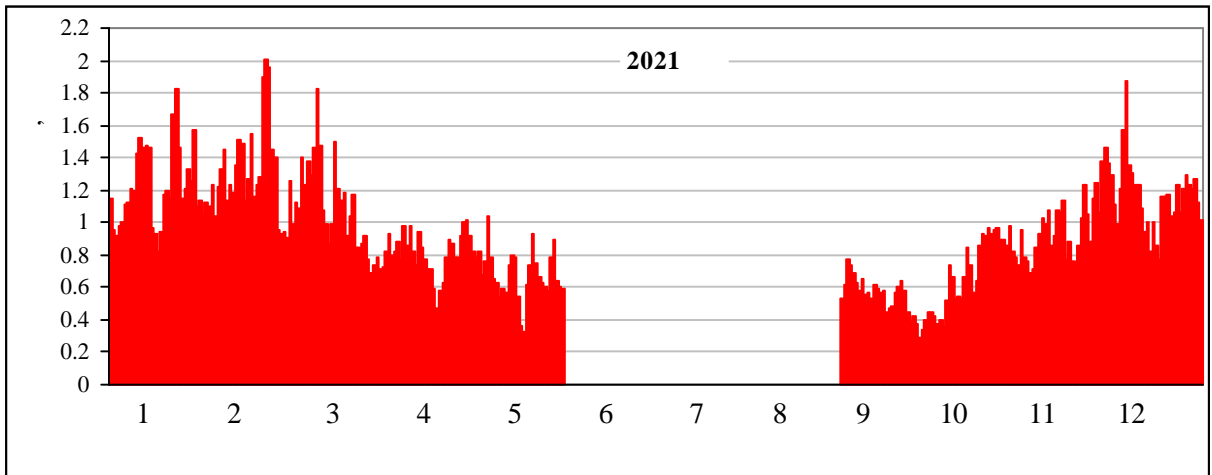
52

65 .

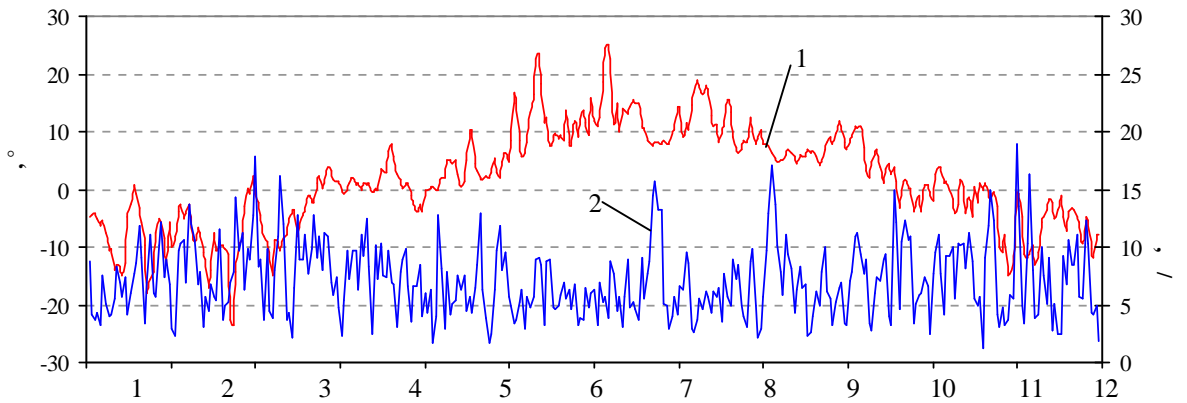
. 2.13.

1 31 2021 (. 2.14,

1 2). . 2.13



. 2.13 -



. 2.14 -

(1) (2) . 1 31 2021 .

31 2021 . . 2.15.

. . 2.13.
. 2.16.

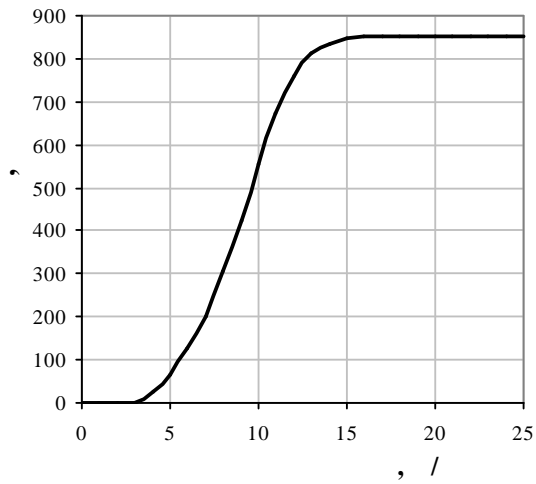
(. 2.16,
),) - (. 2.16,

(. 2.16,).

70-90%,

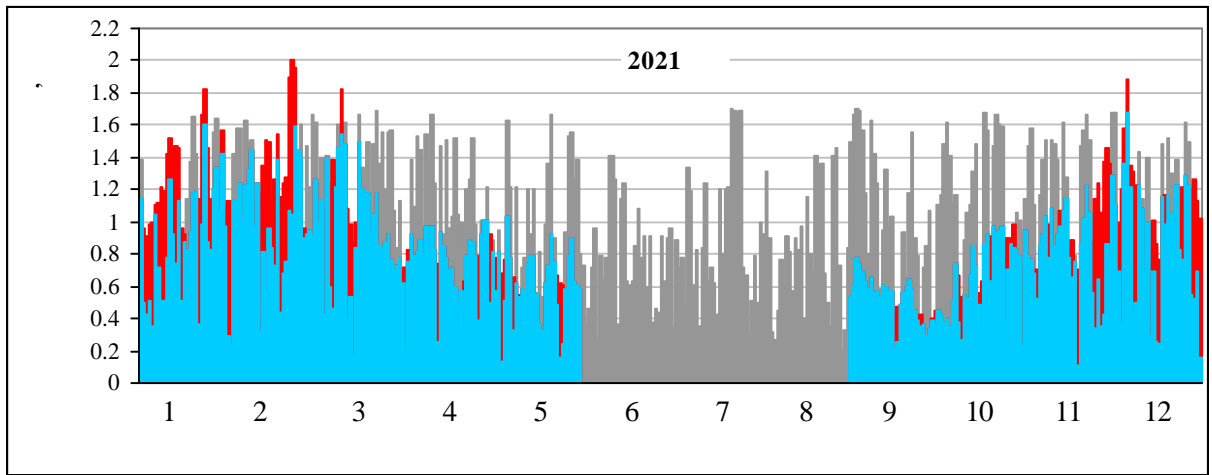
75%,

(. 2.17).



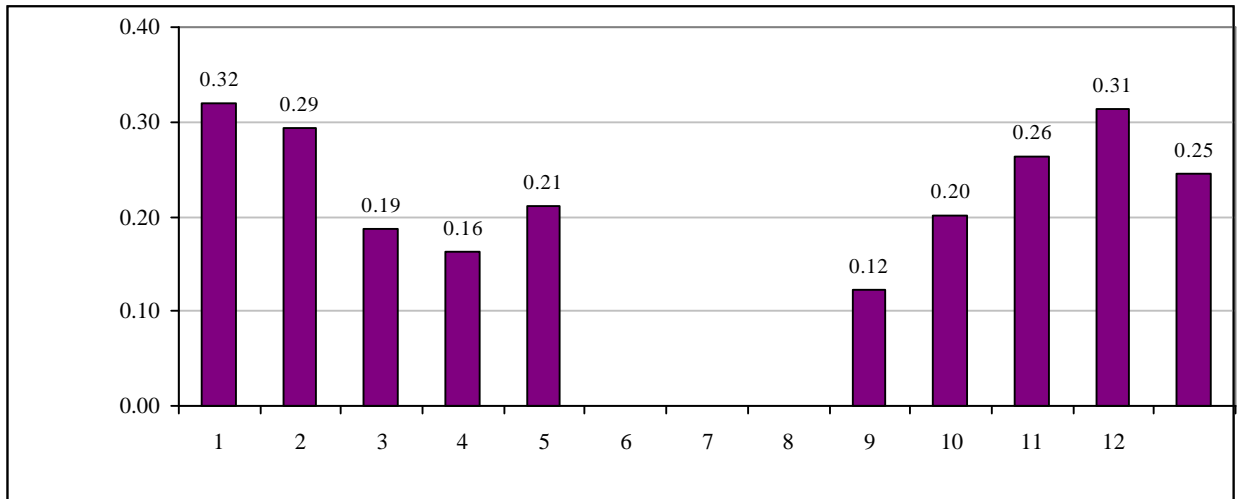
. 2.15 -

Vestas V52/850.



2.16 -

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2.17 -

2.10

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75%.

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3.1

[98].

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[98].

3.1 [98, 99].

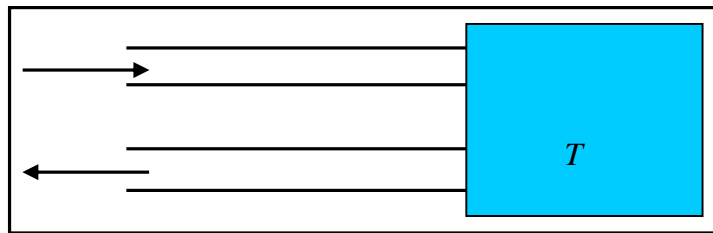
$T^{(0)}$

v .

T ,

T

v



3.1 -

3.2.

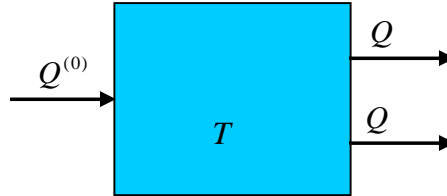
$Q^{(0)}$,

Q ,

Q .

[98, 99]:

$$\frac{d(V C_p T)}{dt} = Q^{(0)} - Q - Q \quad (3.1)$$



3.2 -

$$Q = K F (T - T_0) \quad (3.2)$$

(3.1)

$$\frac{d(V C_p T)}{dt} = v C_p T^{(0)} - v C_p T - K F (T - T_0), \quad (3.3)$$

 $T^{(0)}$ -

(3.3),

(t=0) $T_0, \epsilon_0, T_0^{(0)}, T_0$ [98, 99]:

$$= \frac{\epsilon_0 T_0^{(0)} + \frac{K F}{C_p}}{\epsilon_0 + \frac{K F}{C_p}} + \left(\exp \left[- \left(\frac{\epsilon_0}{V} + \frac{K F}{V C_p} \right) \cdot t \right] \right) \cdot \left(T_0 - \frac{\epsilon_0 T_0^{(0)} + \frac{K F}{C_p}}{\epsilon_0 + \frac{K F}{C_p}} \right) \quad (3.4)$$

$$Q^{(0)} > Q \quad (T^{(0)} > T).$$

(3.4),

$V = v$.

3.3

20°

95°

3

$V = 50$

(3.3,

1).

$V = 150$

5

(3.3,

4).

3.3

150

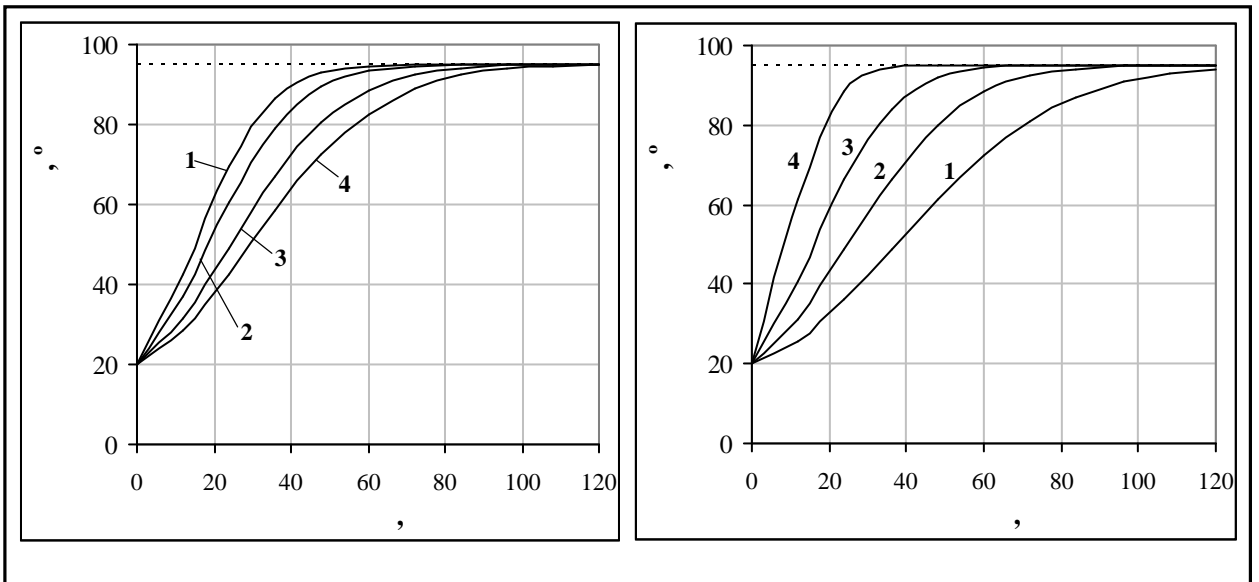
$T^{(0)} = 95^\circ$,

1, 2, 4 10

$T_0 = 20^\circ$.

v ,

(4).



3.3 -

:

$v = 1,5$ $T^{(0)} = 95^\circ$,

1-4

50, 70, 110 150 ;

$v = 1, 2, 4$ 10 ,

1-4.

2.

$$: Q^{(0)} < Q \quad (T^{(0)} < T).$$

3.4 .

$T_0 = 95^\circ$

$T^{(0)} = 35^\circ$

$T^{(0)}$

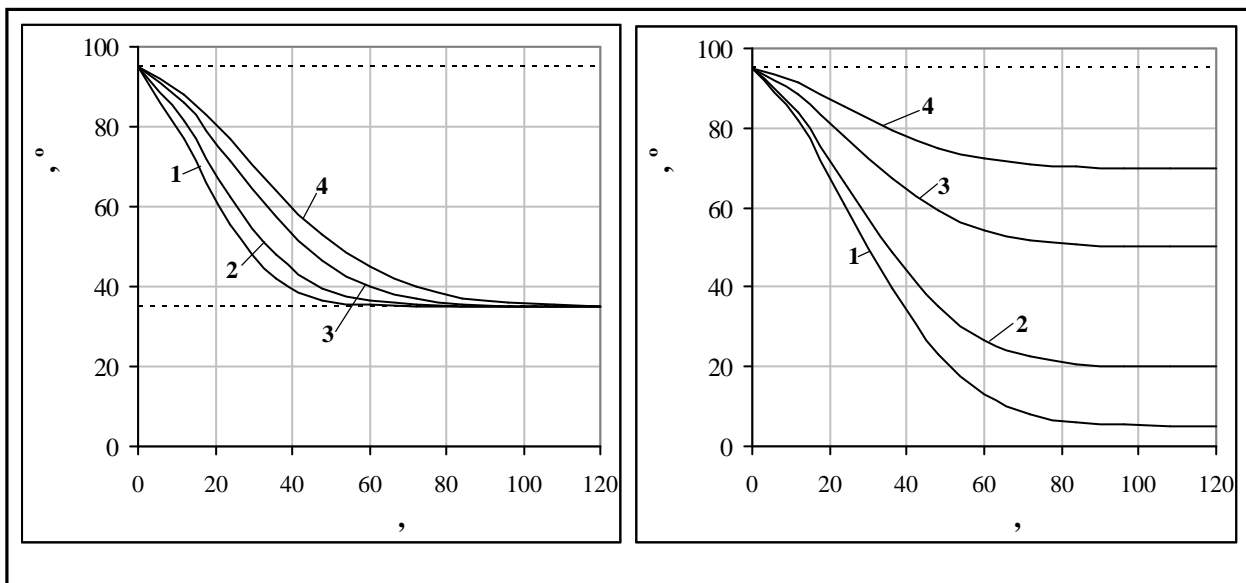
2,5 (50³), 3 (70³), 4 (110³) 5 (150³).

$T^{(0)}$, 150³,
 1,5³ / 3.4 ,
 $T^{(0)}$ 5, 20, 50 70° . $T^{(0)}=5^\circ$

(3.4 ,

1). 4

$T^{(0)}=5^\circ$.



3.4 -

: -

$v = 1,5^3 / T^{(0)}=35^\circ$, 1-4

50, 70, 110 150³; -

, 1-4

$T^{(0)}$ 5, 20, 50 70° .

3.

($v = 0^3$),

$Q^{(0)} = Q = 0$.

(, T) .

:

$$\frac{d(V C_p T)}{dt} = -K F (T - T_0) \tag{3.5}$$

((3.4))

:

$$= + \left(\exp \left[- \frac{K F}{V C_p} \cdot t \right] \right) \cdot (T_0 - T_0) \tag{3.6}$$

,

K .

0), , (K = 3.5 , 1.

(3.5).

,

(

= 20 °).

3.5 ,

.

20 ° ,

1 3.5 .

,

= 0 °

0 °

13

(3.5 , 2),

= -20 °

0 °

7,5 (3.5 , 3).

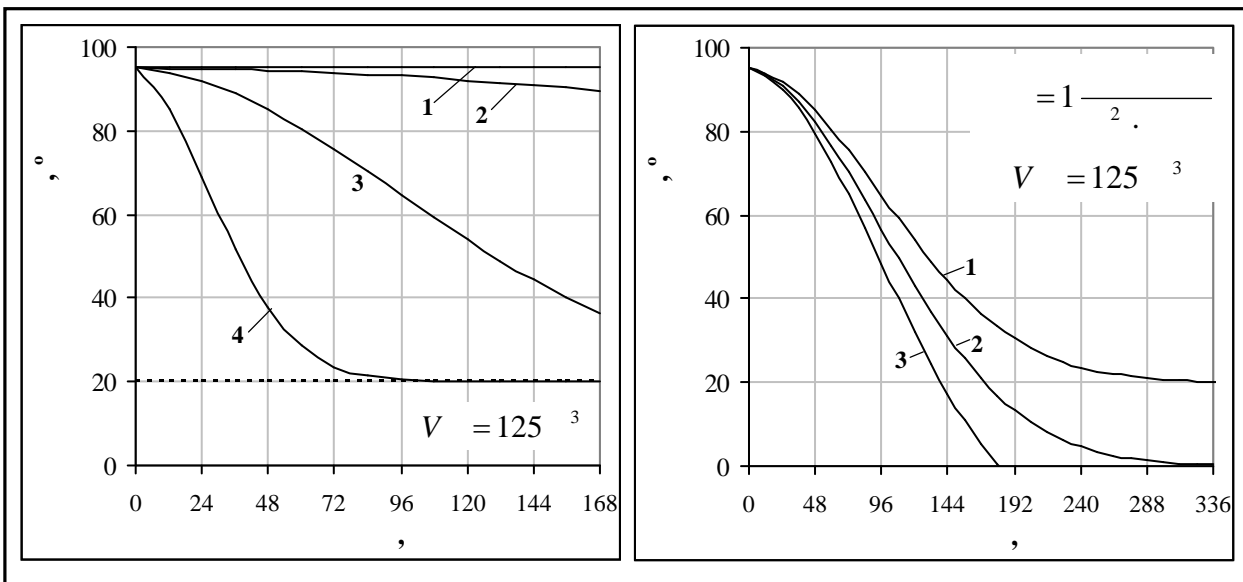
3.2

,

()

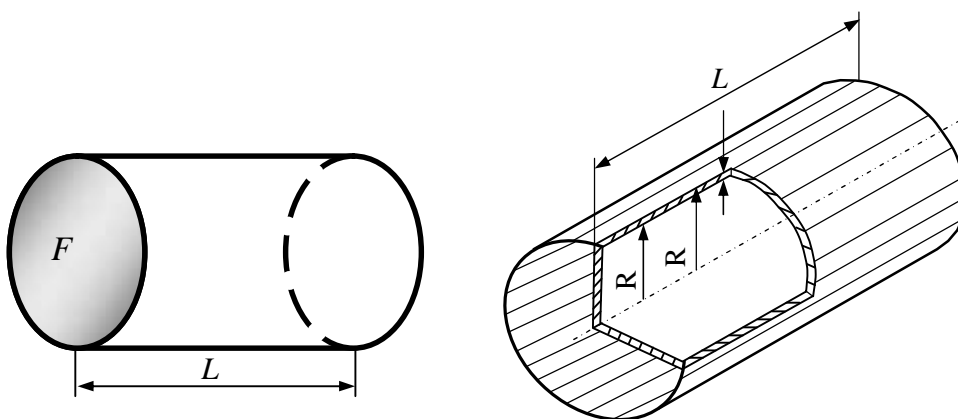
(

3.6) [100].



3.5 -

1-4 $K = 0$;
 $0,05; 1 \cdot 10^{-2} / (\text{с}^2)$; -
 $20,0 \cdot -20^\circ$.

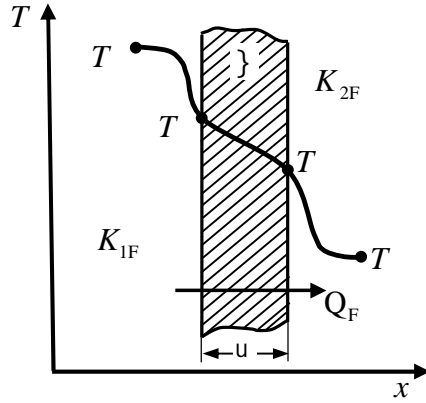


3.6 -

() [100].
 (3.7).
 ()
 1F,
 2F.

$$q_F = K_{1F}(T_1 - T_2) = \frac{\sum_{i=1}^n \lambda_i}{u} (T_1 - T_n) = K_{2F}(T_1 - T_n), \quad (3.7)$$

q_F - , / ²; T - , ° .



3.7 -

n
1, 2, ..., n,
1, 2, ..., ,
:

$$q_F = K_{1F}(T_1 - T_n) = \frac{(T_1 - T_n)}{\sum_{i=1}^n \frac{u_i}{\lambda_i}} = K_{2F}(T_1 - T_n). \quad (3.8)$$

F

, :

$$Q_F = q_F \cdot F, \quad (3.9)$$

$F = f \cdot R^2$ - , ,
2.

() [100].

D D_{ap},

L

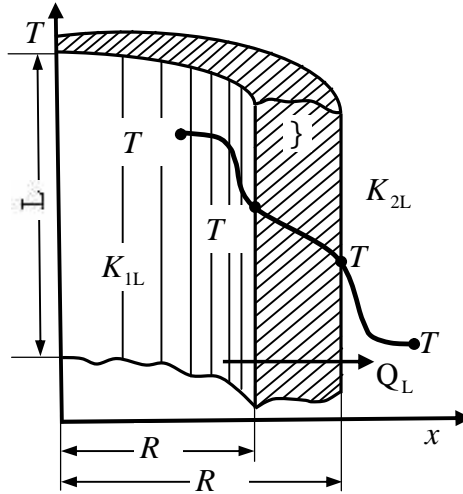
, . 1L,

2L.

(3.8).

$$q_L = K_{1L} D f(T -) = \frac{2f(T -)}{\ln \frac{D}{D}} = K_{2L} D f(T -), \quad (3.10)$$

q_L -



3.8 -

$$q_L = K_{1L} D f(T -) = \frac{2f(T -)}{\sum_{i=1}^n \frac{1}{\ln \frac{D}{D_i}}} = K_{2L} D f(T -). \quad (3.11)$$

$$Q_L = q_L \cdot L. \quad (3.12)$$

$$Q = 2Q_F + Q_L. \quad (3.13)$$

$$T = T.$$

(3.1)

(3.13)

:

$$\frac{d(V C_p T)}{dt} = Q^{(0)} - Q - (2Q_F + Q_L), \quad (3.14)$$

(3.3), (3.7), (3.9), (3.10) (3.12):

$$\frac{d(V C_p T)}{dt} = v C_p T^{(0)} - v C_p T - [2K_{2F} F (T -) + K_{2L} D fL(T -)]. \quad (3.15)$$

(3.15)

[100]:

$$\frac{d(V C_p T)}{dt} = v C_p T^{(0)} - v C_p T - [(2K_{2F} F + K_{2L} D fL) \cdot (T -)]. \quad (3.16)$$

(3.16)

(3.4),

(t=0) $T_0, \epsilon_0, T_0^{(0)}, \epsilon_0$:

$$\begin{aligned} & \epsilon_0 T_0^{(0)} + \frac{(2K_{2F} F + K_{2L} D fL)}{C_p} \\ & = \frac{\epsilon_0 T_0^{(0)} + \frac{(2K_{2F} F + K_{2L} D fL)}{C_p}}{\epsilon_0 + \frac{(2K_{2F} F + K_{2L} D fL)}{C_p}} + \left(\exp \left[- \left(\frac{\epsilon_0}{V} + \frac{(2K_{2F} F + K_{2L} D fL)}{V C_p} \right) \cdot t \right] \right) \end{aligned} \quad (3.17)$$

$$\left(T_0 - \frac{\epsilon_0 T_0^{(0)} + \frac{(2K_{2F} F + K_{2L} D fL)}{C_p}}{\epsilon_0 + \frac{(2K_{2F} F + K_{2L} D fL)}{C_p}} \right)$$

1.

(>),

 $T_0 = 86.5^\circ$.0.001³,

3.1.

3.1 -

$V, \text{ m}^3$	$(\text{m})L,$	$D, \text{ m}$	$\rho, \text{ kg/m}^3$
0.001	0.145	0.1	0.0014

$$T_0 = 24^\circ \text{C} \quad (3.16)$$

$$(3.17),$$

[100]:

$$\frac{d(V C_p T)}{dt} = -[(2K_{2F} F + K_{2L} D f L) \cdot (T - T_0)] \quad (3.18)$$

$$= + \left(\exp \left[- \frac{(2K_{2F} F + K_{2L} D f L)}{V C_p} \cdot t \right] \right) \cdot (T_0 - T_0) \quad (3.19)$$

$$K_{2F} \quad K_{2L},$$

(3.9).

$$T_0 = 86.5^\circ$$

$$K_{2F} = 5 \text{ W/(}^\circ\text{C}\cdot\text{m}^2\text{)} \quad K_{2L} = 10 \text{ W/(}^\circ\text{C}\cdot\text{m}^2\text{)} \quad (3.9, 1)$$

(t=3) 40° :

$$= + \left(\exp \left[- \frac{(2K_{2F} F + K_{2L} D f L)}{V C_p} \cdot t \right] \right) \cdot (T_0 - T_0) =$$

$$= 24 + \left(\exp \left[- \frac{(2 \cdot 5 \cdot 0.008 + 10 \cdot 0.1 \cdot 3.14 \cdot 0.145)}{0.001 \cdot 1163} \cdot 3 \right] \right) \cdot (86.5 - 24) \approx 40^\circ \text{C} \quad (3.20)$$

$$C_p = 1163 \text{ J/(}^\circ\text{C}\cdot\text{kg)} -$$

$$F = f \cdot R^2 = 3.14 \cdot 0.05^2 = 0.008 \text{ m}^2.$$

$$= 24^\circ \text{C} \quad K_{2F} = 5 \text{ W/(}^\circ\text{C}\cdot\text{m}^2\text{)}$$

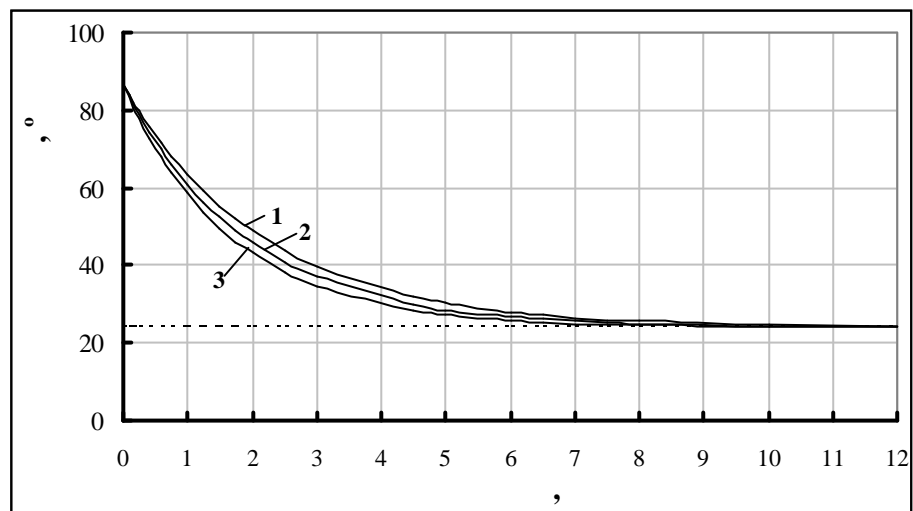
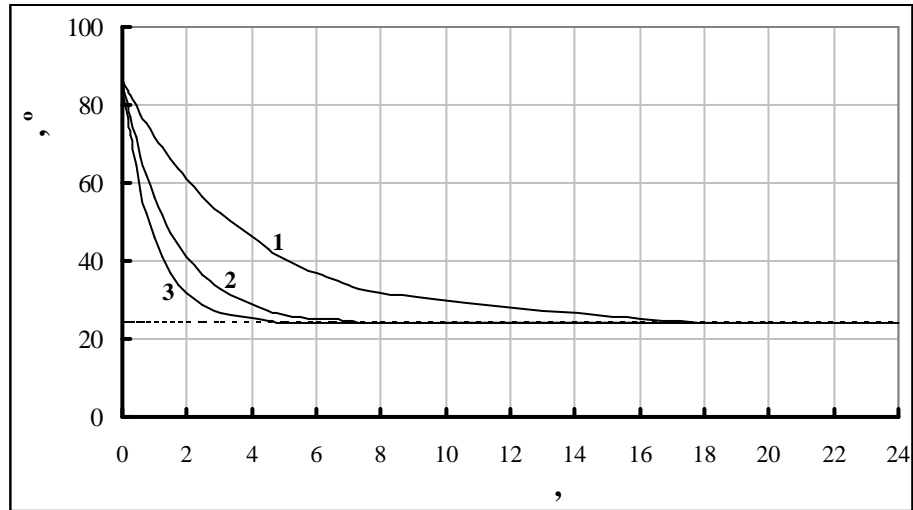
$$17.5 \text{ m} \quad K_{2L},$$

$$5 \text{ m} \quad 25 \text{ W/(}^\circ\text{C}\cdot\text{m}^2\text{)} \quad (3.9), \quad K_{2F} = 5 \text{ W/(}^\circ\text{C}\cdot\text{m}^2\text{)} \quad 15$$

$$\text{W/(}^\circ\text{C}\cdot\text{m}^2\text{)} \quad K_{2L} = 10 \text{ W/(}^\circ\text{C}\cdot\text{m}^2\text{)} \quad 10.5 \quad 7$$

(3.9).

(1) [101].



3.9 -

: -

$K_{2F} = 5$ / (2), 1-3 $K_{2L} = 5, 15, 25$ / (2); -

$K_{2L} = 10$ / (2), 1-3

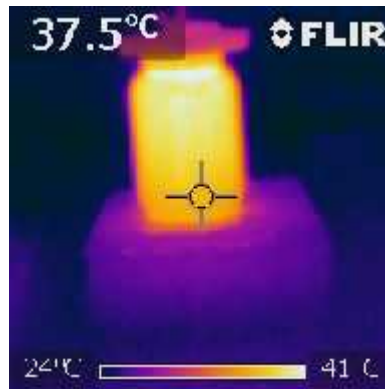
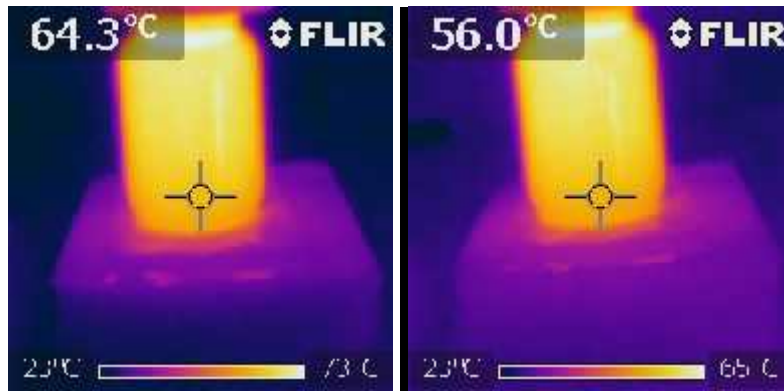
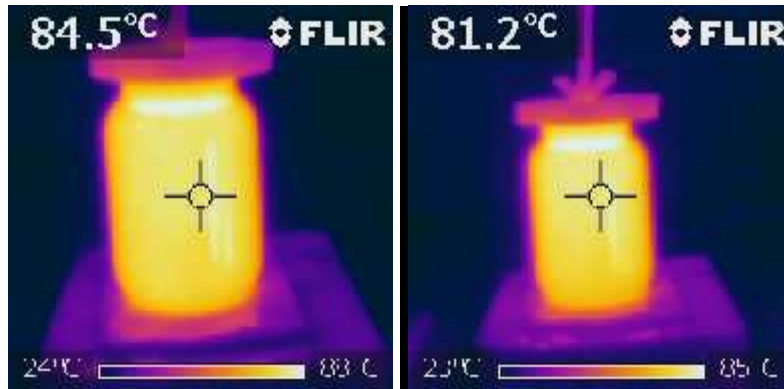
$K_{2F} = 5, 10, 15$ / (2).

2.

24° .

(3.10)

3.11.



3.10 -

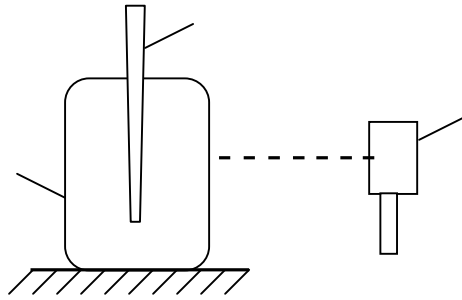
$\rho = \frac{m}{V}$
 $\rho = \frac{5,35}{0,001} = 5350 \text{ kg/m}^3$

$$0,001 \text{ m}^3 = 0,76 \text{ g}$$

$f(\cdot^\circ)$.

0.0014 .

$D = 0.1$ $D = 0.0972$.



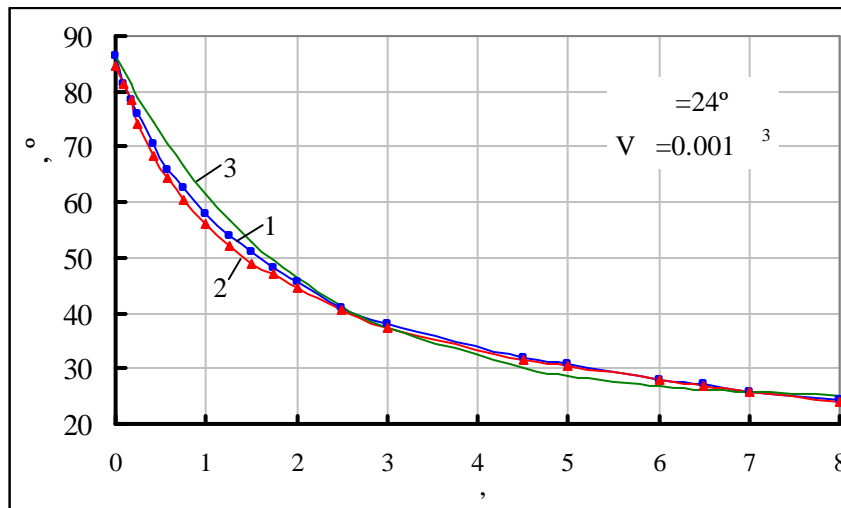
3.11 -

(3.12).

(1)

(2).

3.9,



3.12 -

(1 3)

(2)

: 1 2 -

, 3 -

(3.12, 1 2),
 K_{2L} K_{2F} ,
 3.9,
 3.12,

$$q_L \tag{3.10}$$

$$T = \frac{T + }{2} . \tag{3.21}$$

360 , : 0, 25, 180
 : 86.5, 70.5, 38 28.1° .

$$T = 86.5^\circ = 84.5^\circ :
 q_L = \frac{2f\{T - \}}{\ln \frac{D}{D}} = \frac{2 \cdot 3.14 \cdot 0.76 \cdot (85.5 - 84.5)}{\ln \frac{0.1}{0.0972}} = 168.1 / . \tag{3.22}$$

$$T = 70.5^\circ = 68.3^\circ - q_L = 184.9 / .$$

$$T = 38^\circ = 37.5^\circ - q_L = 42 / .$$

$$T = 28.1^\circ = 28^\circ - q_L = 8.4 / .$$

$$(3.10). = 84.5^\circ$$

$$K_{2L} = \frac{q_L}{D f(T -)} = \frac{168.1}{0.1 \cdot 3.14 \cdot (84.5 - 24)} = 8.8 / (^2.). \tag{3.23}$$

$$= 68.3^\circ - K_{2L} = 13.3 / (^2.).$$

$$= 37.5^\circ - K_{2L} = 9.9 / (^2.).$$

$$= 28^\circ - K_{2L} = 6.7 / (^2.).$$

$$K_{2L} = \frac{8.8 + 13.3 + 9.9 + 6.7}{4} = 9.7 / (^2.). \tag{3.24}$$

(3.7),

76

$$K_{2F} = \frac{9+13.5+10.1+6.8}{4} = 9.8 \quad /(\text{ }^2 \text{ }). \quad (3.25)$$

(3.19),

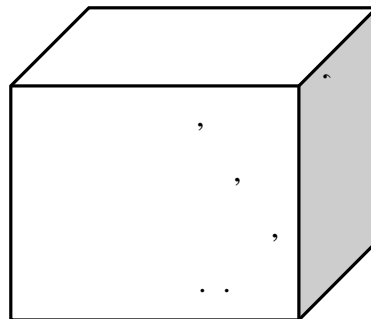
3.12,

3.

3.3

3.13) [102].

[103].



3.13 -

) [102].

18 25° ,

25 18° .

$$Q - Q_0 = 0, \tag{3.26}$$

$Q - Q_0 = \dots, \dots / ;$
 $Q_0 - \dots, \dots / .$

[30]:

$$Q_0 = Q = q V k_v(\dots). \tag{3.27}$$

(3.27)

(3.26)

$$Q, \dots, (\dots)$$

(...):

$$Q + Q_0 - Q = 0. \tag{3.28}$$

$Q,$

(...), (...), (...).

:

$$Q = m C \frac{d}{dt} + m C \frac{dT}{dt}, \tag{3.29}$$

$m, m - \dots, ; C, C -$

, / . ; t - , .

V (...)

$$v \cdot V, \dots v \cdot V - \dots [102]. \dots v, v -$$

, %.

(3.29)

$$Q = v V C' \frac{d}{dt} + v V C' \frac{d}{dt}, \tag{3.30}$$

$C' = C \dots, C' = C \dots - \dots, / ^3 ; \dots -$

, / ^3.

3.2

(3.28)

[102]:

$$V (v C' + v C') \frac{d}{dt} + q V k_v(\dots) = Q. \tag{3.31}$$

:

$$T = \frac{Q}{qV k_v} + \left[\exp\left(-\frac{q}{(v C' + v C'')t}\right) \right] \cdot \left(T_0 - T_0 - \frac{Q_0}{qV k_{v_0}}\right) + T \quad (3.32)$$

104]

3.2 -

[102,

	, / 3		
		/ .	/ 3.
	1,293	0,24	0,31
	1400	0,2	280
-	650	0,2	130
	2300	0,2	460
	500	0,55	275
()	1800	0,21	378

).

(3.27) (3.31),

$$Q_0 = Q x + Q = q V k_v (-) \quad (3.33)$$

$$V (v C' + v C'') \frac{d}{dt} + qV k_v (-) = Q x + Q , \quad (3.34)$$

x -

; Q - ,

(3.34)

«

+ »

$$T = \frac{Q x + Q}{qV k_v} + \left[\exp\left(-\frac{q}{(v C' + v C'')t}\right) \right] \cdot \left(T_0 - T_0 - \frac{Q_0 x + Q_0}{qV k_{v_0}}\right) + , \quad (3.35)$$

[94].

2.16

() .

(3.32),

1

3.14.

ΔT

T (3.14) [102].

() :

$$\Delta T = T - \Delta T, \tag{3.36}$$

ΔT -

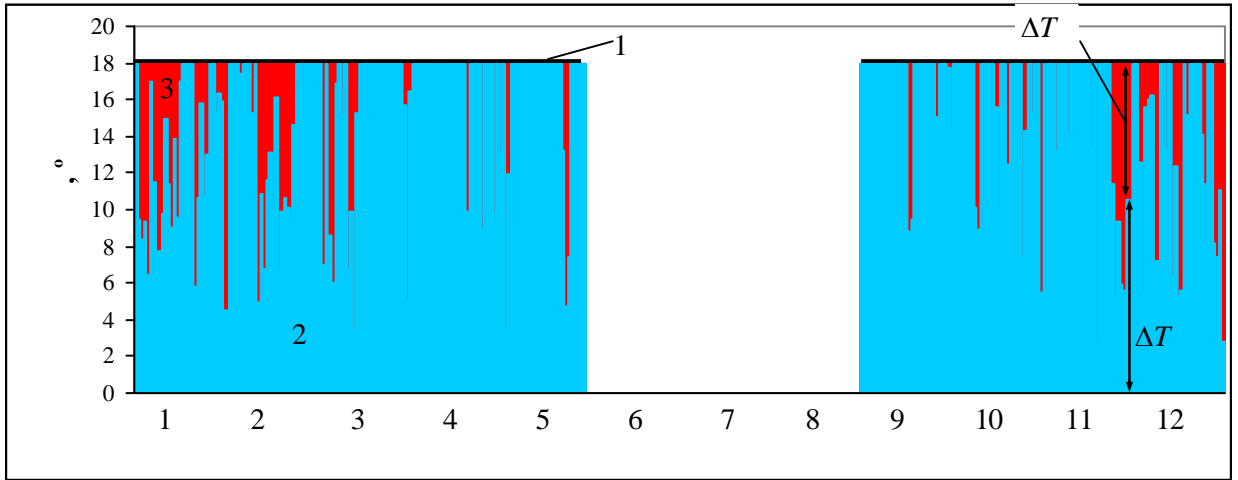
$$\Delta T = \begin{cases} 0, & Q \geq Q \\ \left(\frac{Q}{qV k_v} + T \right) \cdot x, & Q < Q \end{cases} \tag{3.37}$$

$$\Delta T = \begin{cases} T, & Q \geq Q \\ \frac{Q}{qV k_v} + T (1-x), & Q < Q \end{cases} \tag{3.38}$$

$$\Delta T = \begin{cases} 0, & Q \geq Q \\ \left\langle \frac{Q}{qV k_v} + \left[\exp \left(- \frac{q}{(v C' + v C'') t} \right) \right] \right\rangle \cdot x, & Q < Q \\ \left\langle \left(T_0 - T_0 - \frac{Q_0}{qV k_{v_0}} \right) + T \right\rangle \cdot x, & Q < Q \end{cases} \tag{3.39}$$

:

$$\Delta T = \begin{cases} T, & Q \geq Q \\ \frac{Q}{qV k_v} + \left[\exp\left(-\frac{q}{(v C' + v C'')t}\right) \cdot (T_0 - T_0) + T \right] \cdot (1-x) - , & (3.40) \\ - \left[\exp\left(-\frac{q}{(v C' + v C'')t}\right) \right] \cdot \frac{Q}{qV k_v}, & Q < Q \end{cases}$$



3.14 -

: 1 - , 18° ; 2 - (); 3 - ().

« + » 800³ (300²),

27° . (2.4), (32,4° .

q=0,5 /³ . [23].

(C =0,2

/ . ; ... =1400 /³).

22,6 . / .

[102].

1.

(Q = 0).

$$1 \quad (3.34)$$

$$V (v \cdot C' + v \cdot C) \frac{d}{dt} + qV k_v (\dots) = Q \quad (3.41)$$

$$V = 800 \quad 200 \quad (25$$

%), 600 (75 %) -

$$V (0,75 \cdot C' + 0,25 \cdot C) \frac{d}{dt} + qV k_v (\dots) = Q \quad (3.42)$$

v = 0,75 (75 %) v = 0,25 (25 %) -

V .

$$(3.42), \quad (3.35)$$

$$T = \Delta T = \frac{Q}{qV k_v} + \left[\exp\left(-\frac{q}{(0,75 \cdot C' + 0,25 \cdot C)} t\right) \right] \cdot \left(\dots - \frac{Q}{qV k_{v_0}} \right) + \dots \quad (3.43)$$

[102].

$$(t=0) \quad T_0 = 20^\circ$$

$$T = -15^\circ \quad (Q = 0),$$

$$(N = N = 22,6 \quad /). \quad 9 / ,$$

$$k_v = 1,38 \quad (2.4),$$

$$10,4 \quad / .$$

$$(3.43)$$

3.15, 1.

18° -

, 2 - 15°, 7 - 9° .

() .

:

$$T = \left[\exp\left(-\frac{q}{(0,75 \cdot C' + 0,25 \cdot C'')}t\right) \right] \cdot (T_0 - T_0) + T_0 \quad (3.44)$$

: $Q = Q = 0, T_0 = 20^\circ, T = -15^\circ$.

(3.15, 2).

, 9 18° ,

5 0° .



3.15 -

(1)

(2).

2.

() .

(3.35),

$$T = \frac{Q x + Q}{qV k_v} + \left[\exp\left(-\frac{q}{(0,75 \cdot C' + 0,25 \cdot C'')}t\right) \right] \cdot \left(T_0 - T_0 - \frac{Q_0 x + Q_0}{qV k_{v_0}} \right) + \dots \quad (3.45)$$

,

$T = -15^\circ$

($Q = 0$),

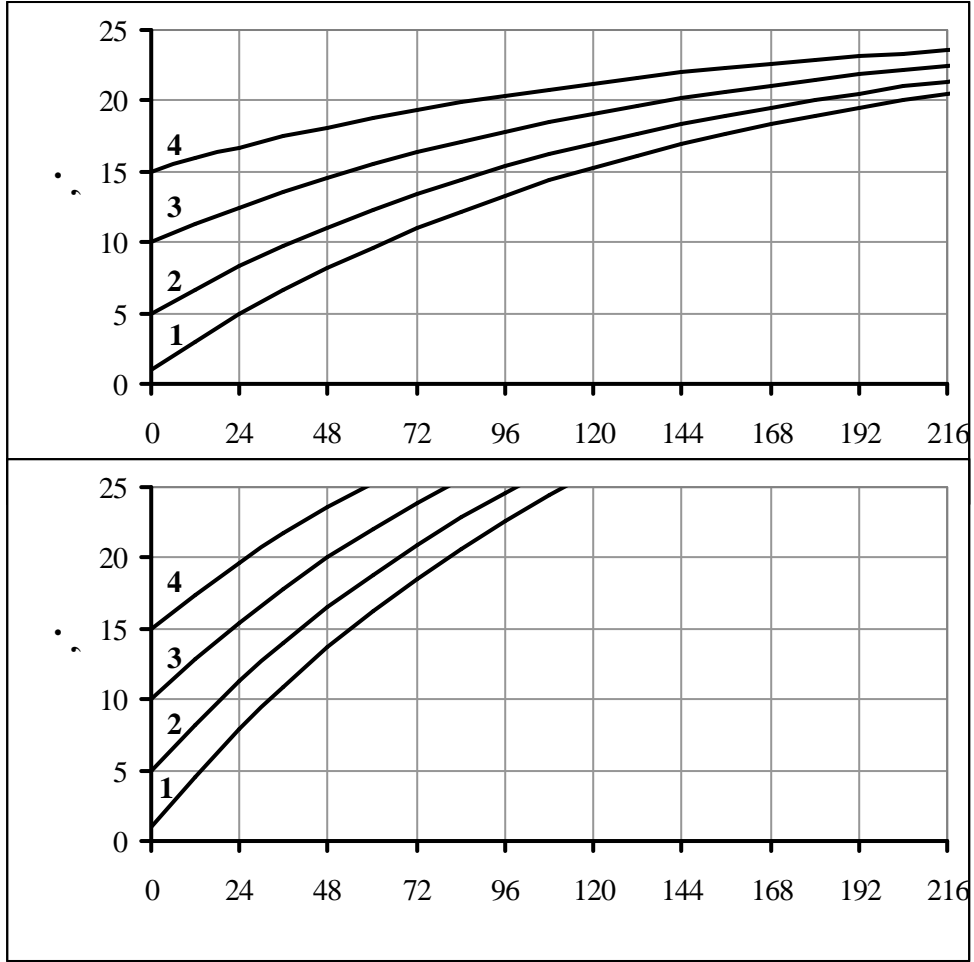
$$Q = 22,6 \dots / , \dots$$

18° . 3.16 ,

1, 5, 10, 15° .

5° 20° 7,5 (3.16 ,

2) [102].



3.16 -

()

() [102]. 1-4

1, 5, 10 15° .

15° .

,

« + » ,

, : 22,6 + 10,4 = 33,0 . / .

(3.45),

(3.16).

(3.35),

3.

18

25° .

25°

()

18°

3.17

(1 3.14)

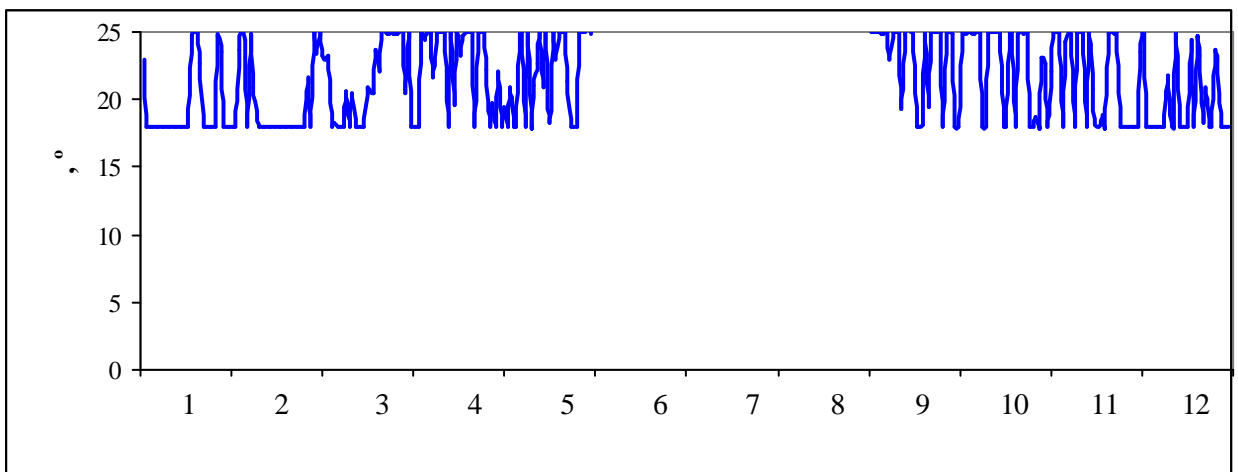
()

3.18

2.16.

3.19,

0,25 0,17.



3.17 -

2.

3.

4.

5.

25 18°

18 25°

2-5%.

4.

4.1

(,) [1].

(

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,

,

2022

70000

23000

[1].

,

1,5

105000 /

35000 /

72000 25000 / . . [1].

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,

,

.

: 0.02, 0.1, 0.5, 1.0, 2.0 5.0 / .

,

2022 ,

,

,

2022

[1].

... ,
 ... (/)
 , , [1].

0,143 -
 :

$$= (0,143 \cdot Q \cdot h) / (\cdot), \tag{4.1}$$

, ./ ; --
 , / ; h -
 , ; --
 () , .; = 0,95 -
 , , -
 , . [105].

...
 : 25000 72000
 / ...

3000-4000 . 3500 .
 0,6; 0,65; 0,7; 0,7 0,75 ,
 0,02, 0,1, 0,5, 1,0, 2,0 5,0 / [106].

...

$$= n \cdot Q \cdot \cdot 12, \tag{4.2}$$

n - , ./ (/); -
 , / .; 12
 - , .

4.1 -

[107]

	0,02	0,1	0,5	1,0	2,0	5,0
/(/)	150	40	12	7	4	2,8

115000 ,
2022 .

:
= k · Q , (4.3)
= 0,1 -
, ; k -
, /(/).

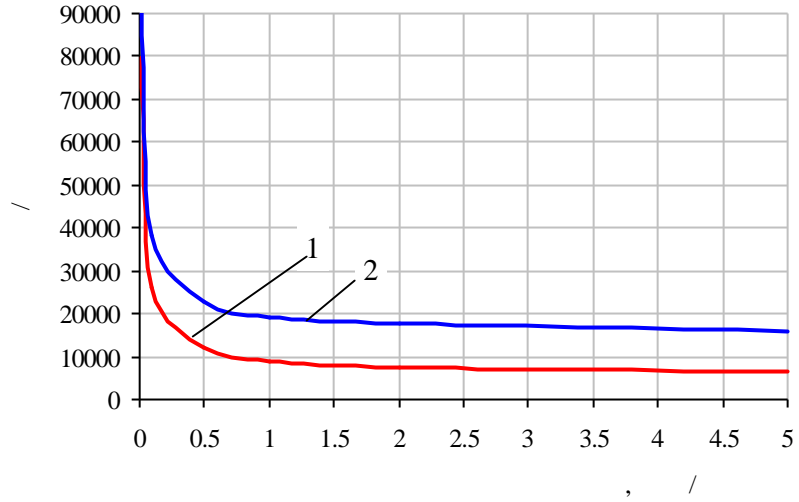
0,02, 0,1, 0,5, 1,0, 2,0 5,0 / 78,8; 31,6; 14,1; 10,6;
7,9 5,2 . /(/).

:
=0,2·(+), (4.4)
0,2 -
20%

=(+ + +)/(Q · h), / . (4.5)

4.1

1 / 20000 /
90000 / .



4.1 -

: 1 - 25000 2 - 72000 / ..

4.2

[1].

(= 1).

(< 1),

(4.1)

$$+ = (0,143 \cdot Q \cdot h \cdot \cdot) / (\cdot \cdot). \tag{4.6}$$

[30]

$$x = \exp \left[-3,2 \cdot \left(\frac{V}{V} \right)^2 \cdot s \right], \tag{4.7}$$

V -

, / ; V -

, / ; =Q /Q -

, ..

(4.7) (4.6),

$$+ = (0,143 \cdot Q \cdot h \cdot \exp\left[-3,2 \cdot \left(\frac{V}{V}\right)^2 \cdot s\right]) / (\dots) \quad (4.8)$$

$$= 690000 \quad (57500)$$

),

2022 .

$$= k \cdot Q \quad (4.9)$$

= 0,07 -

, ; k - , / (/), Q

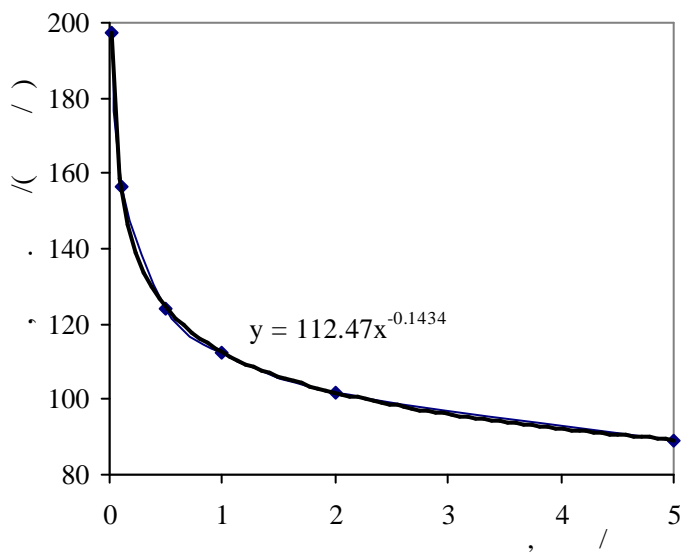
, / .

0.02 5.0 /

200 90 . / (/)

(4.2):

$$k = 112,47 \cdot Q^{-0,1434} \quad (4.10)$$



4.2 -

$$= \frac{(112,47 \cdot Q^{-0,1434}) \cdot Q}{1-5\%}, \quad (4.11)$$

[108]:

$$= 0,05 \cdot (\dots), \quad (4.12)$$

0,05 –
5%

[1]:

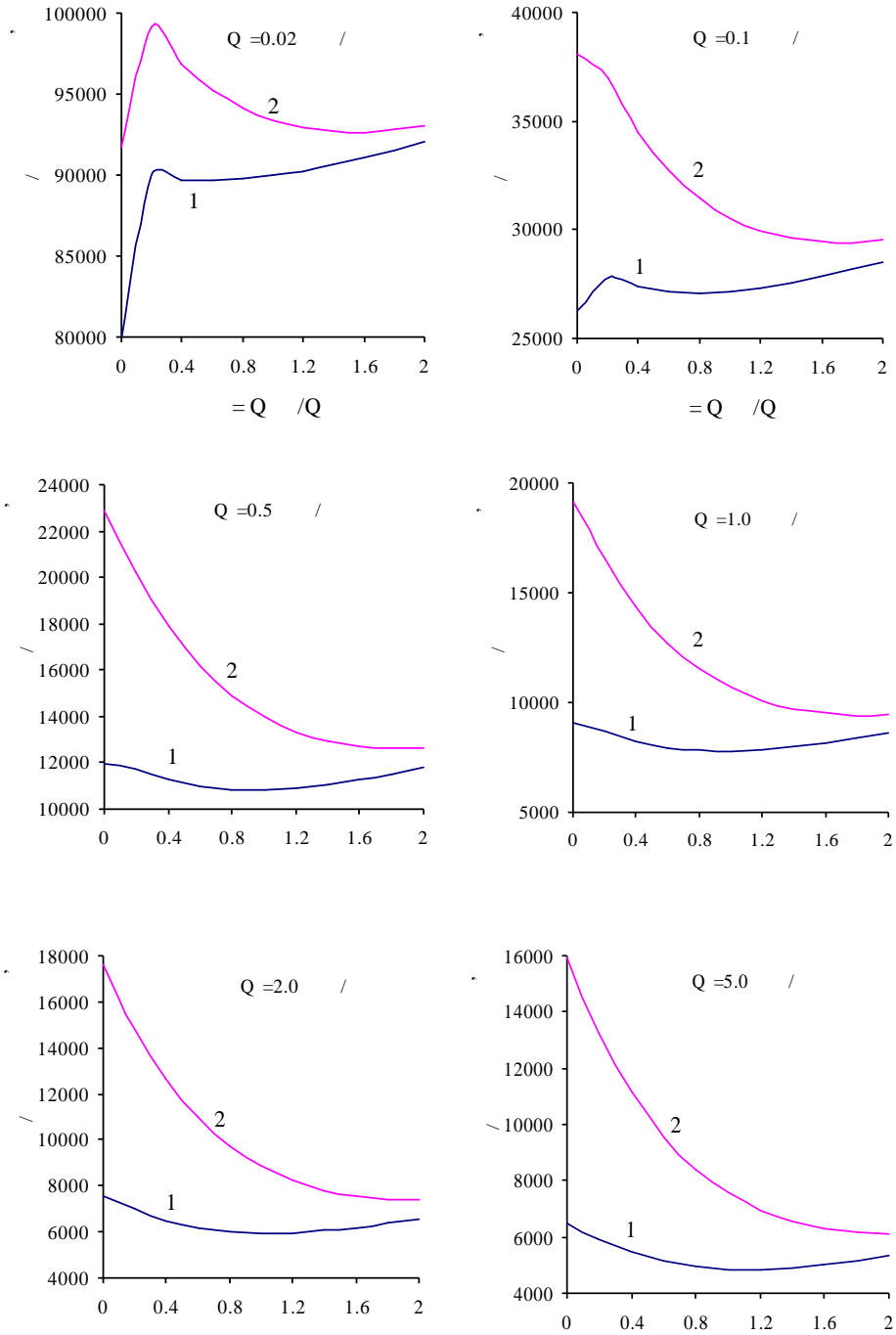
$$+ = (\dots) / (Q \cdot h). \quad (4.13)$$

4.3.

25000 / ... 0,1

[1].

72000 / ...
0,02 / (4.3, 2).
4.3 (2),
1,2 – 2 (Q = 0,1
38000 30000



4.3 -

0.02 5.0 /

: 1 2 -

25000 72000 / ... [1].

4.3 4.3

0,5 / .

25000 / ...

(> 0 , $Q = \text{const}$)

25000 / ... 0,5 /
 0,7-1,25 1,0, 2,0 5,0
 / 0,7-1,3, 0,8-1,35 0,9-1,45. 72000
 / ...
 0,1, 0,5, 1,0, 2,0 5,0 /
 1,6-2,0.
 60-90%
 10-60%.

4.3 -

« + »
 (),
 [107, 109].

[110]:

$$= \left[\sum_{i=1}^n \frac{B_i}{(1+r)^i} \right] - I_0, \tag{4.14}$$

i=1, 2, .., n - « + »; n -
 « + », ; B_i -
 « + » i- , ; r -

, . . . ; $I_0 -$
 « + », , .
 , -
 .
 :
 . . . ,
 , . . . ,
 .

$$r = \frac{n_r - J}{1 + J}, \tag{4.15}$$

$n_r -$, . . . ; $J -$
 , . . .

« + » $i -$
 :

$$B_i = W \cdot f_i - i, \tag{4.16}$$

$W = Q \cdot h -$, ; $f_i -$
 $i -$, / ; $i -$
 « + » $i -$, .
 i

$$i = + i + /n + i + i + i, \tag{4.17}$$

.- « + »
 , ; + i , $i -$
 $i -$, ; $i -$
 « + » $i -$, .
 :

$$= + \cdot (k \cdot Q + k \cdot Q), \tag{4.18}$$

+ = 2,5% -
 « + ».

:

$$i=0,2 \cdot (\frac{1}{n} + i), \tag{4.19}$$

0,2 –
20%

[71, 87].

[111-113]

(,).

« + »

(4.3),

« + »

()

f_0 1 , f_0

4.1. 2 f_0 ,

4.3. 3 f_0 ,

1 2.

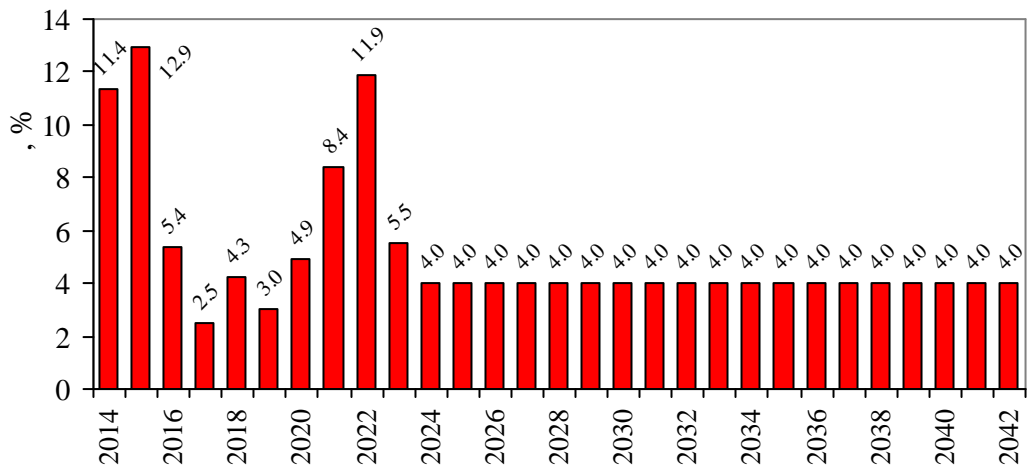
2014 – 2022

12,9 2,5%

2023-2024

: 5,5% (2023) 4%

(4.4).



4.4 -

4.3

0.5, 1.0, 2.0 5.0

/ ,
 25000 / .. 0,7-1,45 .
 72000 / .. 0.1, 0.5, 1.0, 2.0 5.0 /
 , 1,6-2,0 .
 0,7 1,6
 25000 / .. 72000 / ..

« + »

4.5 4.6.

: 0.1, 0.5, 1.0, 2.0 5.0 / .

$r = 0,12$ (12%). , ,

« + » ()

I_0 . « +

»

« + »

4.5 4.6, 2,

4.1

4.3.

25000 / ..

« + » 13-14 ,

- 17-26%

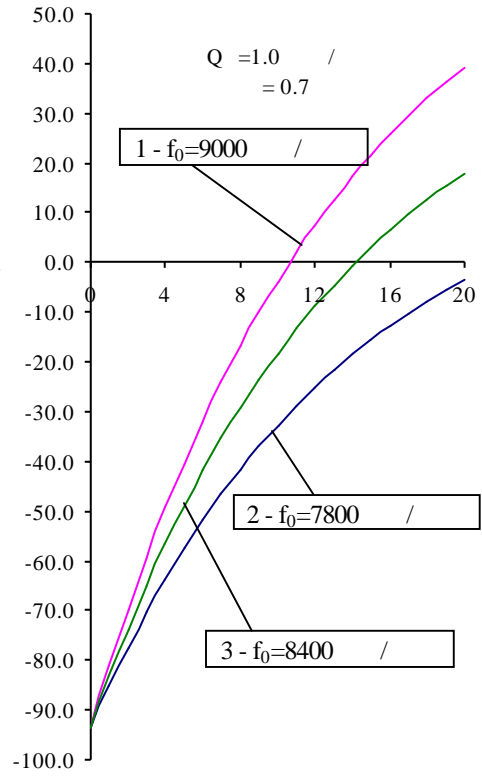
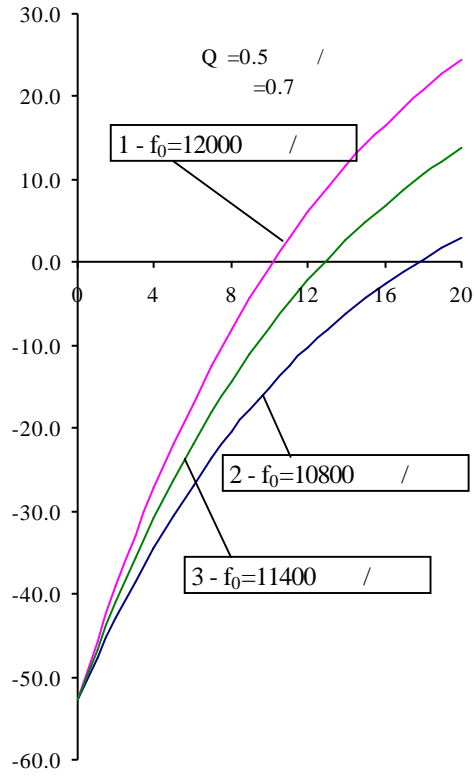
20 (4.5, 2). 72000 / ..

6 8 ,

20 76-105%

4.6, 2.

« + »



4.5 -

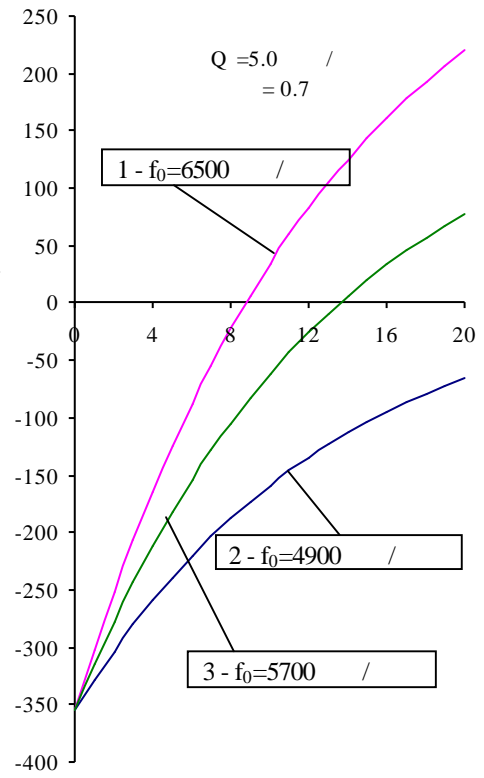
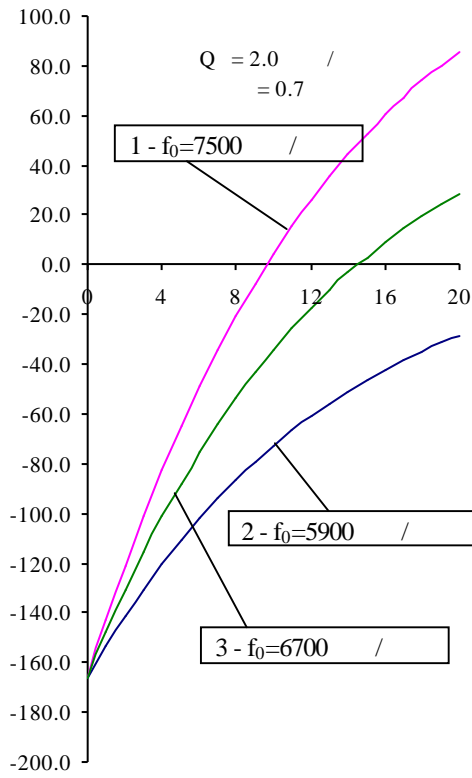
0.5 5.0 / 25000 /

: 1 - f_0 ,

4.1; 2 - f_0 ,

4.3; 3 - f_0 ,

1 2.



4.5 -

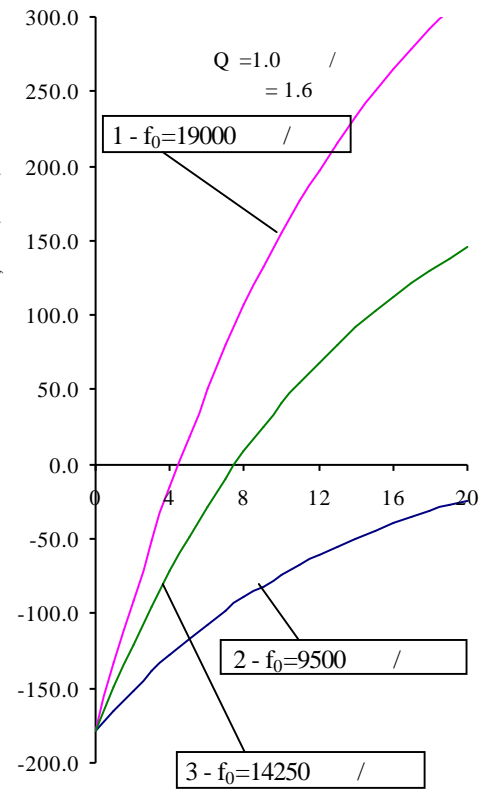
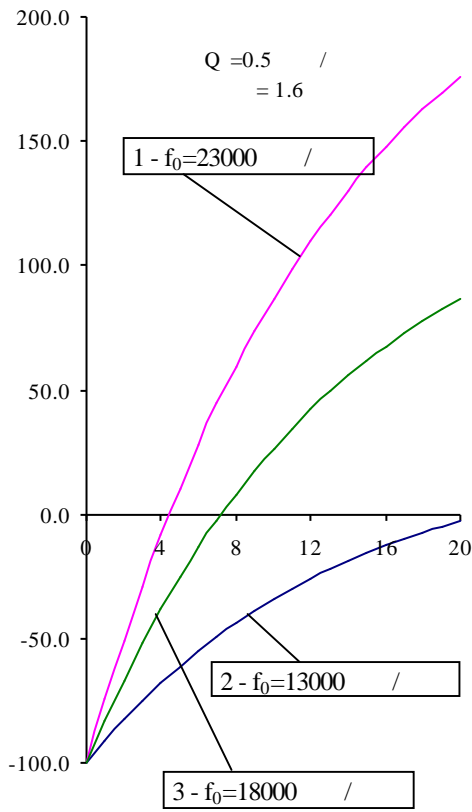
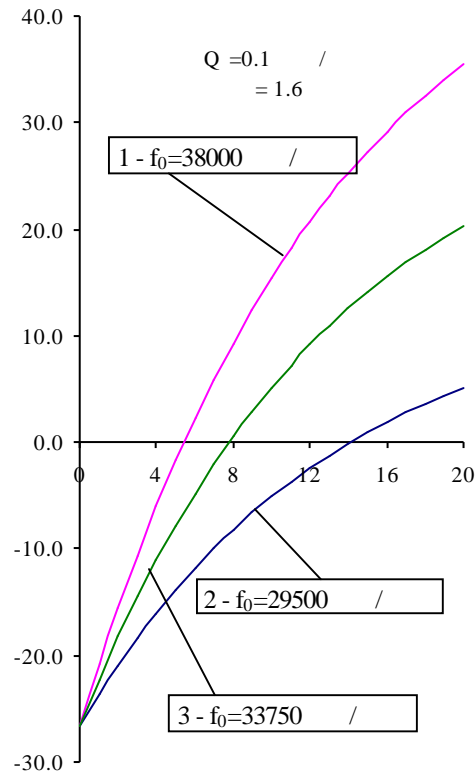
0.5 5.0 / 25000 /

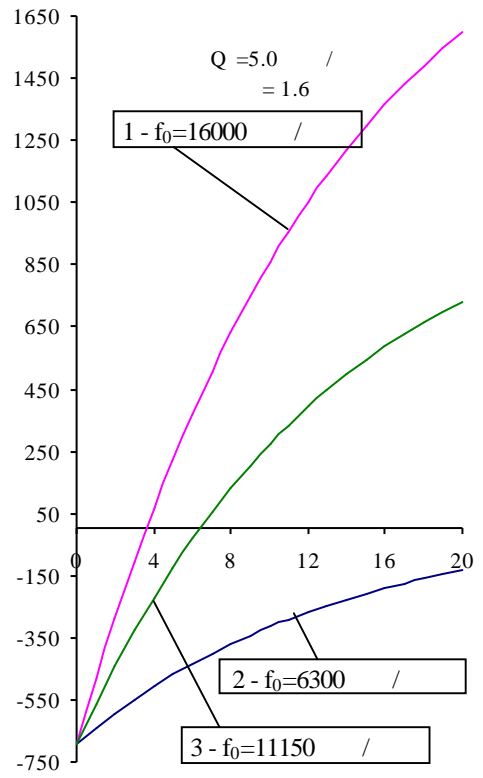
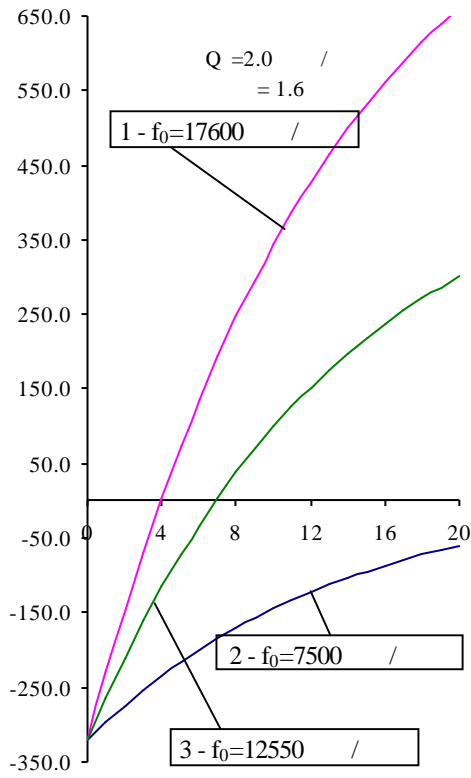
: 1 - f_0 ,

4.1; 2 - f_0 ,

4.3; 3 - f_0 ,

1 2 ().





4.6 -

0.1 5.0 / 72000 /

: 1 - f_0 ,

4.1; 2 - f_0 ,

4.3; 3 - f_0 ,

1 2.

4.4

1.

0,1 /

60-90% 25000-72000

/ ... 10-60% [1].

· ,
« + »
,
« + » 17-105%
, 6-14 .
2. , , ,
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1.

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2.

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4.

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90%

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10-60%,

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« + »

17-105%

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6-14 .

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РОССИЙСКАЯ ФЕДЕРАЦИЯ



СВИДЕТЕЛЬСТВО

о государственной регистрации программы для ЭВМ

№ 2023664293

**Программа для расчета зависимости параметров
теплового аккумулятора по времени**

Правообладатель: *Федеральное государственное бюджетное
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2.

МИНИСТЕРСТВО НАУКИ И ВЫСШЕГО ОБРАЗОВАНИЯ
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«08» сентября 2023 г.



АКТ

использования результатов диссертационной работы

Настоящий акт составлен о том, что результаты исследования Бежан Алексея Владимировича полученные при подготовке диссертационной работы «Повышение эффективности систем теплоснабжения районов арктической зоны путем внедрения энергокомплексов на базе ветроэнергетических установок (на примере Мурманской области)» используются в учебном процессе кафедры «Промышленная теплоэнергетика и системы теплоснабжения» ФГБОУ ВО «Казанский государственный энергетический университет» при проведении занятий по дисциплине «Источники и системы теплоснабжения».

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