ANALYSIS AND CALCULATION OF NEEDED PARAMETERS OF AIR FOR CONDITIONING AND VENTILATION OF ROOM FOR CERTAIN USE

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Abstract: Ventilation of the air is necessary due to complacence of human need for air, for dilution of polluted air, amount of fresh air which depends from allowed level of harmful components in room air (polluting component can be CO_2, which is produced by human breathing, technological process), for enabling air circulation in a room, which is the one of components for comfort conditions. To satisfy human needs for fresh air, it is necessary new amount of outer air. Relevant moment in determination of needed amount of fresh air is calculation of dilution of harmful component (for example, CO_2 and human breath) or appeared in technological process. Based on such determined amount of fresh air we can approach to a choice of system for ventilation and conditioning of certain work recycled or technological rooms or establishments. In that context in paper is shown calculation methodology of air amount for ventilation of static and variable sources of appearance harmful components in work and manufacturing rooms.

Keywords: Technical system, technological process, ventilation

1. APPEARANCE OF MOISTURE AND HARMFUL COMPONENTS IN ROOMS

Additional amount of outer air is necessary to enable necessary mobility of air inside a room. Outer air in larger amount is necessary in rooms with significant heat source, in absence of cooling facilities. Need for outer air depend on characteristics of human work.

Source of moisture appearance in production rooms are humans, evaporation of water from open water and moist surfaces, some chemical reactions (for example, combustion), material drying, water steam which penetrate through non-captive parts of appliances and pipelines, and also moister with infiltration of outer air, and if its level of moisture percent is higher that level of air moisture in a room.

Separation of moisture by present people, depends upon temperature and hardness of work.

Moisture amount which evaporates from open and wet surfaces is determined by known expressions which are given in literature [1].

Due to technological processes in manufacturing facilities harmful gasses and dust appear, and also CO_2 from breathing. Amount of CO_2, which appears from one man depends from type of job which he performs. In table T1 are given data for amount of heat, moisture and CO_2 with adult persons in dependence of type of work and air temperature in a room [4].

Appearance of heat, moisture and CO_2 in adult persons [4] Table 1.

Indicators	**Air temperature in a room $\left({}^0C\right)$**					
In state of stagnancy						
Heat,W						
Sensible	140	116	87,2	68	40,7	11,6
Latent	23	29	28,8	35	52,3	81,4
Total	163	145	116	93	93	93
Moist,10(g/s)	8,3	8,3	11,1	13,9	20,8	32
CO_2 ,10(g/s)	6,4	6,4	6,4	6,4	6,4	6,4
Easy work						
Heat ,W						
Sensible	151	122	98,8	63,5	40,8	5,8
Latent	29	35	52,2	31,5	104,5	139,5
Total	180	157	151	145	145	145,3
Moist,10(g/s)	11,1	15,3	20,8	32	41,7	55,6
CO_2 ,10(g/s)	7,0	7,0	7,0	7,0	7,0	7,0
Middle hard work						
Heat,W						
Sensible	143	134,5	105	70	40,8	5,8
Latent	52,5	75,6	99	128	157,2	192,2
Total	195,5	210	204	198	198	198
Moist,10(g/s)	19,5	30,6	39	51,6	64	78
CO_2 ,10(g/s)	9,7	9,7	9,7	9,7	9,7	9,7
Hard work						
Heat,W						
Sensible	198	163	128	93	52,5	11,6
Latent	93	128	163	198	238	279,4
Total	291	291	291	291	291	291
Moist,10(g/s)	37,5	51,5	66,8	82	98,8	115,4
CO_2 ,10(g/s)	12,5	12,5	12,5	12,5	12,5	12,5

Appearance of harmful gasses and steam comes from existence of chemical reactions, with fluid evaporation in open reservoir, which contain chemical materials, by penetration of harmful materials through non-captive equipment elements, in time of accident, where in the room enter harmful components etc.
When in an reaction comes chemically pure material, amount of produced component can be determined analytically.
Amount of harmful materials, who are produced in work rooms, $G_{ŠM}$, is equal to expression [4]:

$$G_{ŠM} = \dot{V}\left(K_{KO} - K_{PO}\right) \tag{1}$$

Amount of fluid which evaporates, G_{IS} , which contains chemical components, can be approximately determined by:

$$G_{IS} = 10^{-6} \cdot M \cdot p_{TE} \cdot \left(0{,}733 + 1{,}635 \cdot W\right) \cdot F \tag{2}$$

Mass consumption of gas and steam G_{GP} , through non-captive aperture and pipelines for pressure to $4MPa$ can be determined by formula Repin N.N.:

$$G_{GP} = 50 \cdot 10^{-6} \cdot \eta_{RE} \cdot V_{AP} \cdot \sqrt{\frac{M}{T}} \tag{3}$$

Amount of harmful components through captivate of pumps can be determined by formula:

$$G_{GP} = 27{,}8 \cdot 10^{-6} \cdot d \cdot C\sqrt{p} \tag{4}$$

In terms of air conditioning of manufacturing rooms, where is a place of appearing harmful materials, it is necessary to predict maximal hermetization of technological equipment and local system of ventilation.

2. CALCULATION OF NECESSARY AMOUNT OF AIR FOR VENTILATION OF ROOMS IN STATIC SOURCES OF APPEARANCE OF HARMFUL MATERIAL

For solving questions of necessary amount of air ventilation we consider the room, in which is brought outer air and where air pollution happens from people and technological processes and also increase of temperature and humidity. Concentration of harmful components constantly grows. With increase of concentration so do temperature and humidity. On figure 1 is shown conditional scheme of ventilation of closed room in time interval $d\tau$ [2].

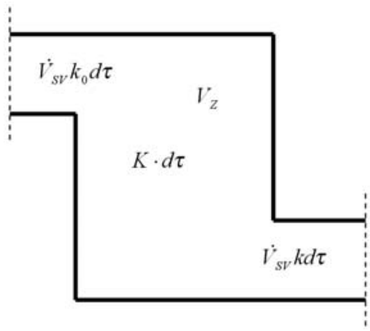


Figure 1. Conditional scheme of room

For time interval $d\tau$, general content of harmful component is $\left(\dot{V}_{SV} \cdot k_0 + K\right)d\tau$. For that time from the room is removed harmful components, that is, air in amount $\left(\dot{V}_{SV} k\right)d\tau$. This means that in the room for time interval $d\tau$ amount of harmful component is:

$$\left(\dot{V}_{SV} \cdot k_0 + K\right) \cdot d\tau - V_{SV} \cdot k \cdot d\tau \tag{5}$$

Equation (5), expressing concentration dk by room volume unit has a form:

$$dk \cdot V_Z = \left(\dot{V}_{SV} k_0 + K\right) \cdot d\tau - \dot{V}_{SV} \cdot k \cdot d\tau \tag{6}$$

That is

$$\frac{dk}{d\tau} + \frac{V_{SV} k}{V_Z} = \frac{\dot{V}_{SV} k_0 + k}{\dot{V}_Z} \tag{7}$$

Equation (7) has a form of differential first order equation and has general form integral:

$$k = e^{-\int \frac{\dot{V}_{SV}}{V_Z} d\tau} \cdot \left[C + \int \left(\frac{\dot{V} k_0 + K}{V_Z} \right) \cdot e^{\int \frac{\dot{V}}{V_Z} d\tau} d\tau \right] \tag{8}$$

If we adopt that $V_{SV} / V_Z = n$ is a number of air changes in a room, by integrating equation (8) by which border conditions for $\tau = 0, k = k_i$ concentration of harmful components in time interval τ is equal to expression:

$$k = \left(k_o + \frac{K}{\dot{V}_{SV}} \right)\left(1 - e^{-n\tau}\right) + k_i e^{-n\tau} \tag{9}$$

According to expression (9), there are possible cases which are seen in practice:

1. outer air does not contain harmful components $k_0 = 0$ and in the room are no people, that is there are no technological pollutions $K = 0$, equation (9) has a form:

$$k = k_i \cdot e^{-n\tau} \tag{10}$$

2. if starting concentration of air equals zero, $k_i = 0$, and in the room are no people, that is there are no technological pollutions $K = 0$, equation (9) has a form:

$$k = k_0\left(1 - e^{-n\tau}\right) \tag{11}$$

3. if starting concentration of air equals zero, $k_i = 0$, and in the room are no people, that is there are no technological pollutions $K \neq 0$, equation (9) has a form:

$$k = \left(k_0 + \frac{K}{\dot{V}_{SV}} \right)\left(1 - e^{-n\tau}\right) \tag{12}$$

4. amount of harmful components K produced in a room during time is changing, that is, $K = K(\tau)$. Law of change K in time function can be linear, exponential and similar. These cases are mostly seen in different technological processes in chemical, food, pharmaceutical and similar industries. Equations (9),(10),(11) and (12) are graphically shown on figure 2.

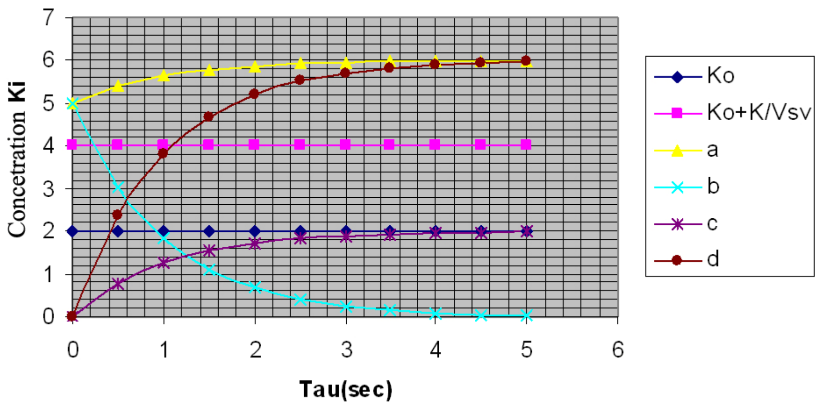


Figure 2. Graphical presentation of equations :a) equation (9); b) equation (10); c) equation (11); d) equation (12)

Amount of ventilation air, starting from equation (9) can be calculated by expression:

$$V_{SV} = \frac{K \cdot \left(e^{n\tau} - 1\right)}{e^{n\tau} \cdot (k - k_0) + k_0 - k_i} \tag{13}$$

If in the room are N people and each one produces by breathing $K_1 = 4{,}719 \cdot 10^{-6} \left(m^3/s\right)$ CO_2 by which content of CO_2 in fresh air $k_0 = 0{,}0003\%$, concentration of harmfull components in the room must not exceed value in time $\tau = 1sat$ from $k = 0{,}001\%$; amount of fresh air for ventilation of room, in dependence of number of air change (n), is expressed by equation:

$$V_{SV} = \frac{K_1 \cdot N \cdot \left(e^{n\tau} - 1\right)}{e^{n\tau} \cdot (k - k_0) + k_0 - k_i} \tag{14}$$

By which: $k_i = k_0 = 0{,}0003$; $k = 0{,}01$; $K_1 = 4{,}719 \cdot 10^{-6} \left(m^3/s\right)$ CO_2; After sorting expression (14) we have that:

$$V_{SV} = \frac{4{,}71 \cdot 10^{-6} \cdot N \cdot \left(e^{n\tau} - 1\right)}{e^{n\tau} \cdot (0{,}001 - 0{,}0003)} = 6{,}73 \cdot 10^{-3} \cdot N \cdot \left(1 - e^{-n\tau}\right)$$

That is, in form:

$$\left(\frac{\dot{V}_{SV}}{N}\right) = 6{,}73 \cdot 10^{-3}\left(1 - e^{-n\tau}\right) \tag{15}$$

Equation (15) is shown on figure 3.

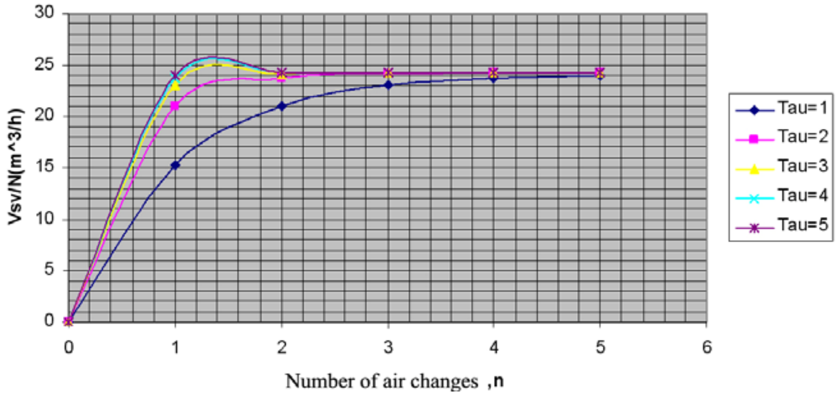


Figure 3. Amount of fresh air per person

3. CALCULATION OF NEEDED AMOUNT OF AIR FOR VENTILATING ROOMS WITH VARIABLE (DINAMIC) SOURCES OF APPEARANCE OF TOXIC MATTER

In industry (chemical, food, pharmaceutical etc) there are often cases of appearance of harmful components which depend from time of appearance, that is, amount of components is being changed in function of time. Course of appearance of harmful components is shown on figure 4.

Starting from equation (8), concentration k for shown changes of appearance of harmful matter K (Figure 4, a-e), has a form:

$$k_a = k_0\left(1 - e^{-n\tau}\right) + \frac{K_a}{\dot{V}_{SV}} \tag{16}$$

$$k_b = k_0\left(1 - e^{-n\tau}\right) + \frac{K_a}{\dot{V}_{SV}} + \frac{a_1}{\dot{V}_{SV}} e^{-n\tau}\left(\frac{1}{n} + \tau \cdot e^{n\tau} - \frac{1}{n} e^{n\tau}\right) \tag{17}$$

$$k_c = k_0\left(1 - e^{-n\tau}\right) + \frac{K_c}{\dot{V}_{SV}} - \frac{a_2}{\dot{V}_{SV}} e^{-n\tau}\left(\frac{1}{n} + \tau \cdot e^{n\tau} - \frac{1}{n} e^{n\tau}\right) \tag{18}$$

$$k_d = \frac{K_d}{\dot{V}_{SV}} e^{-n\tau} + \frac{K_d}{\dot{V}_{SV}} \frac{n}{n-b_1}\left(e^{-b_1\tau} - e^{-n\tau}\right) + k_0 \cdot \left(1 - e^{-n\tau}\right) \tag{19}$$

$$k_e = \frac{K_e}{\dot{V}_{SV}}\left[e^{-n\tau} + \frac{n}{b_2+n}\left(e^{b_2\cdot\tau} - e^{-n\tau}\right)\right] + k_0 \cdot \left(1 - e^{-n\tau}\right) \tag{20}$$

Amount of ventilation air can be shown by following equations:

$$\dot{V}_{SV}^{a} = \frac{K_a}{k_a - k_0\left(1 - e^{-n\tau}\right)} \tag{21}$$

$$\dot{V}_{SV}^{b} = \frac{K_b + a_1 \cdot e^{-n\tau}\left(\frac{1}{n} + \tau \cdot e^{n\tau} - \frac{e^{n\tau}}{n}\right)}{k_b - k_0\left(1 - e^{-n\tau}\right)} \tag{22}$$

$$\dot{V}_{SV}^{c} = \frac{K_c - a_2 \cdot e^{-n\tau}\left(\frac{1}{n} + \tau \cdot e^{n\tau} - \frac{e^{n\tau}}{n}\right)}{k_c - k_0\left(1 - e^{-n\tau}\right)} \tag{23}$$

$$\dot{V}_{SV}^{d} = \frac{K_d\left[e^{-n\tau} + \frac{n}{n-b_1}\left(e^{-b_1\tau} - e^{-n\tau}\right)\right]}{k_d - k_0\left(1 - e^{-n\tau}\right)} \tag{24}$$

$$\dot{V}_{SV}^{e} = \frac{K_e\left[e^{-n\tau} + \frac{n}{n-b_2}\left(e^{-b_2\tau} - e^{-n\tau}\right)\right]}{k_d - k_0\left(1 - e^{-n\tau}\right)} \tag{25}$$

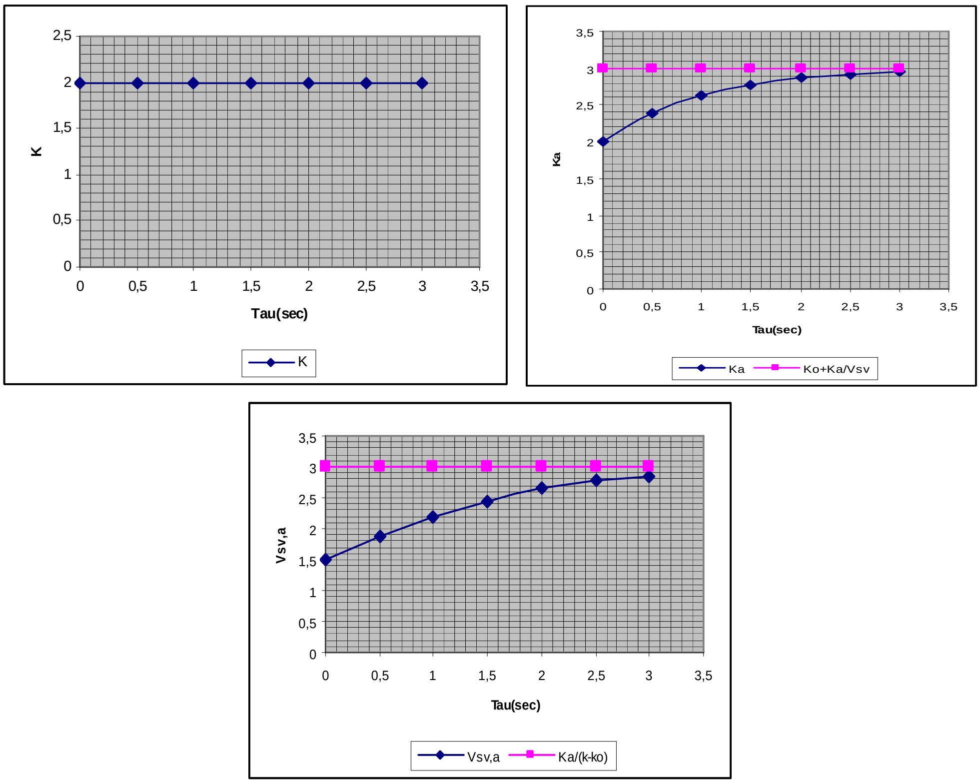
Course of concentration change and amount of ventilation air in function τ and n is shown on figure 4

4. CONCLUSION

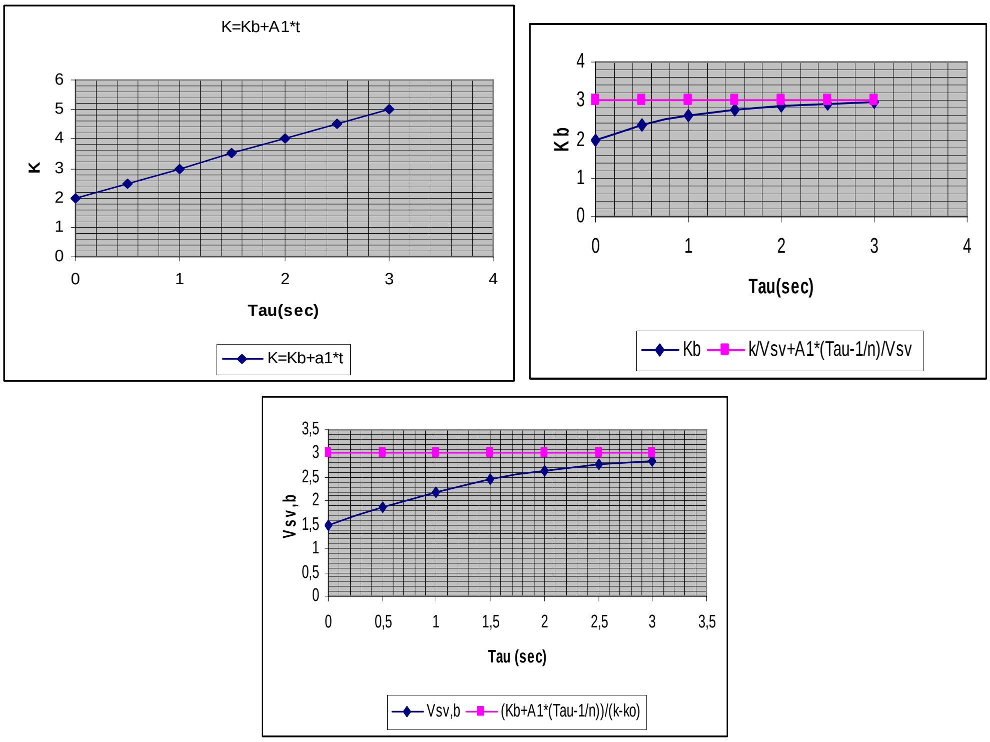
Amount of concentration of harmful components and air ventilation, in much depends from volume of harmful components in a room (K), number of air changes (n), room size (V_Z), concentration of harmful components in supplied air (k_0) and starting concentration in room air (k_i) in time $(\tau = 0)$. By increasing number of air changes amount of ventilation air per person in one hour grows. That increase gets to constant value between $n = 3 \div 4$. By increasing number of changes n, ratio $\dot{V}_{SV}/N$ gets constant value.

By prolonging time τ for removing harmful components, ratio $\dot{V}_{SV}/N$ grows, but with value $n = 1 \div 3$, this ratio gets constant value. In technological processes, where appearance of harmful components in function of time, $K = K(\tau)$, concentration k and amount of fresh air $\dot{V}_{SV}$ depend from function of appearance of harmful components and coefficients K, a, b, τ. Formula (1) can be used not only for determination of necessary amount of outer air, but for solving other tasks, related to transitional (unbalanced) work regime.

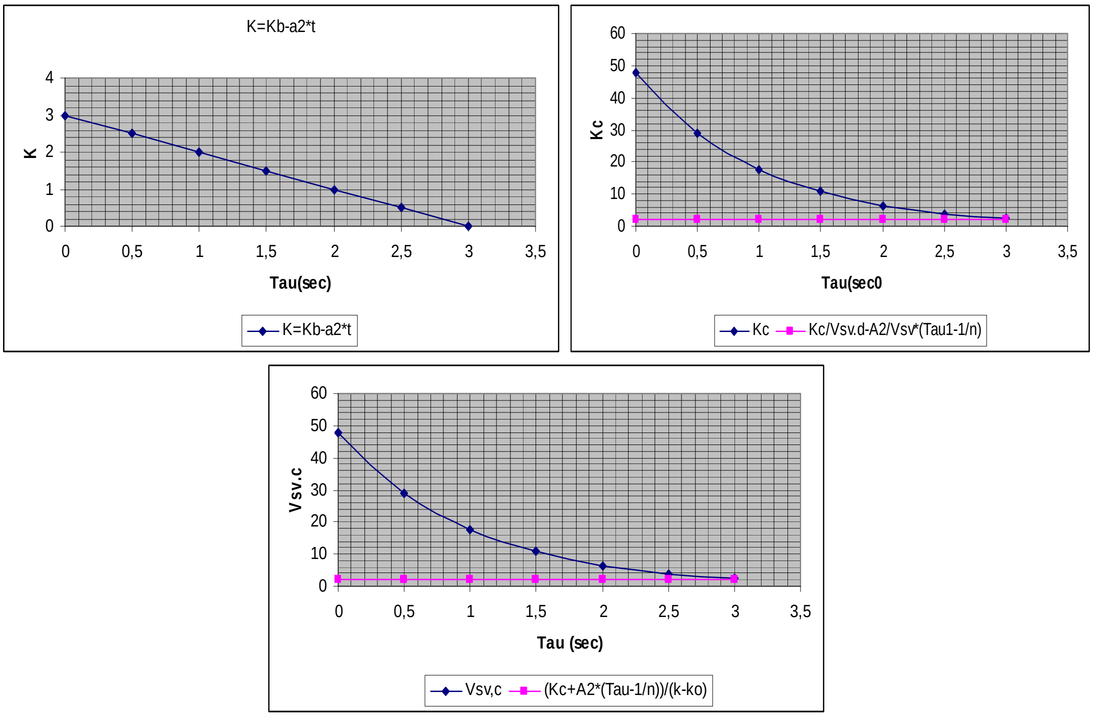
Formula (9) can be presented in form: $X = \left[X_0 + X(\tau)\right] \cdot \left[1 - e^{-N\cdot\tau} + X_i \cdot e^{-N\cdot\tau}\right]$.


K
Tau(sec)
K
Ka
Tau(sec)
Ka
Ko+Ka/Vsv
Vsv,a
Tau(sec)
Vsv,a
Ka/(k-ko)

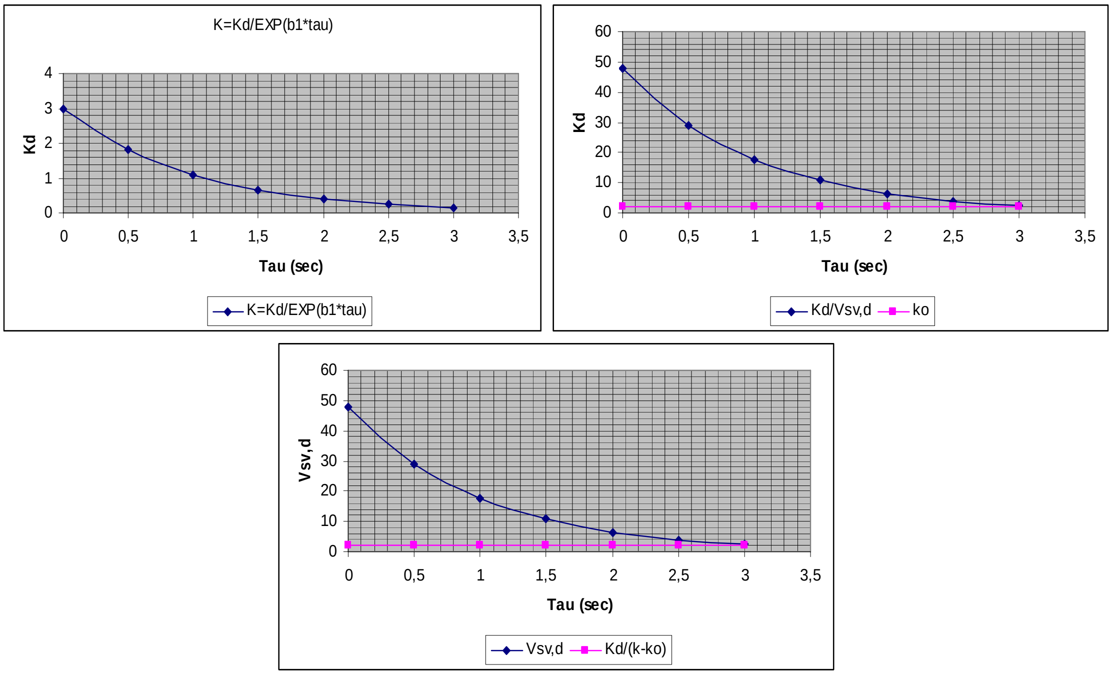
a)


K=Kb+A1*t
K
Tau(sec)
K=Kb+a1*t
K b
Tau(sec)
Kb
k/Vsv+A1*(Tau-1/n)/Vsv
Vsv,b
Tau (sec)
Vsv,b
(Kb+A1*(Tau-1/n))/(k-ko)

b)



c)



d)

Figure 4. Course of function of change of appearance harmful component K, concentration k_i and amount of ventilation air $\dot{V}_{SV}$

REFERENCES

[1] Bogoslovskij,V.N.:Otopljenije i ventilacija, Strojizdat, Moskva, 1976.

[2] Krum,D., B.Roberts: Kondicinirovanije vazduha i ventilacija zdanija, Strojizdat, Moskva, 1980.
[3] Talijev,V.N.: Aerodinamika ventilacii, Strojizdat, Moskva, 1979.
[4] Golubkov,B.N., T.M.Pomanova,V.A.Gusev: Proektirovanije i eksploatacija ustanovok kondicionirovanija voyduha i otoplenija, Moskva, Energoatomizdat, 1988.

MARKS

a_1, a_2 -coefficients

b_1, b_2 -coefficients

C -coefficients, takes into consideration state of gasket and level of toxicity, $(= 0{,}2 \div 0{,}3) \cdot 10^{-3}$

η_{RE} -coefficients of reserve, takes condition of equipment and harmful components $(= 1{,}5 \div 2{,}0)$

d -axle diameter, mm

k_i -starting concentration of harmful components in room air in moment of time $\tau = 0$, m^3/m^3

k_x -concentration of harmful components in air room air in moment of time

k_0 -concentration of harmful components in supplied air, m^3/m^3

$\dot{V}_{SV}$ -volume of supplied fresh air, m^3/s

K -volume of appeared harmful component in a room, m^3/s

V_Z -volume of room per person, m^3

F -plane surface of evaporation, m^2

$G_{ŠM}$ -amount of harmful matter which was produced in technological process, mg/h

G_{ISP} -amount of fluid which evaporates, kg/s

n -number of air change,

$\dot{V}_{VA}$ -amount of air through a room,

V_{AP} -inner volume of aperture, m^3

M -relative molecular fluid mass, kg/mol

p_t -partial pressure of liquid evaporation, by fluid temperature, kPa

p -over pressure created by pump, kPa

W -speed of air flow above liquid surface, m/s

$X(\tau)$ -parameter of air in a room (for example. temperature, content of moisture or enthalpy in time function)

X_0 -value of parameter of fresh air,

X_i -Starting size of this parameter in room air

N -size is proportional with time of relaxation of considered process and it depends on system manufacturing