

UNTIGHT PIPELINE VENTILATION SYSTEMS' CALCULATIONS

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ABSTRACT

A review of pressure and air volumes in un-tight pipelines predictive methods has been done. Two main approaches, utilized to work out distribution functions for h_x and Q_x , are compared. Reasons have been given for virtual substitution of integral model with algebraic system of equations for recurrent calculations. Paper present so called passports R_x-P_x for typical characteristics of pipelines. Such approach can avoid repeatable prediction of h_x and Q_x under different boundary conditions in calculation sectors. Pressure and air volumes distribution is defined under graphical and polynomial approximation, given in the passports. A comprehensive algorithm for the method, worked out by authors, has been presented. Its application is demonstrated on real examples.

INTRODUCTION

Fan operation in tight pipelines is described by exact mathematical model. The design of such pipeline systems is a routine work. In un-tight pipelines mathematical description is harden due to existence of air leakages towards and from pipes thus forming complex network from mutually interacted transit and filtration flows.

Mine ventilation pipelines are normally un-tight for heavy natural and technological conditions in the process of their construction and maintenance. Two physical models are utilized to describe their un-tightness:

- **Network** (fig. 1) – fixed along the pipeline un-tightness (flanges or other conjunctions);
- **Continuous** (fig. 2) – randomly distributed outlets along the pipeline walls.

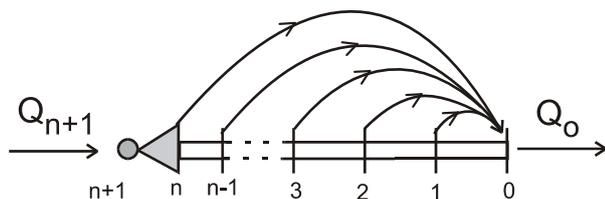


Figure 1. Network model of pipeline

Air distribution in such pipelines is described by mass and energy conservation equations, which are solved under following assumptions:

- Turbulent flow mode;
- Non changeable air density;
- Momentum conservation is not affected by filtration;
- Local resistances are taken into account by increased value of friction factor;
- Air resistance of main flow is neglected or added to pipeline friction factor.

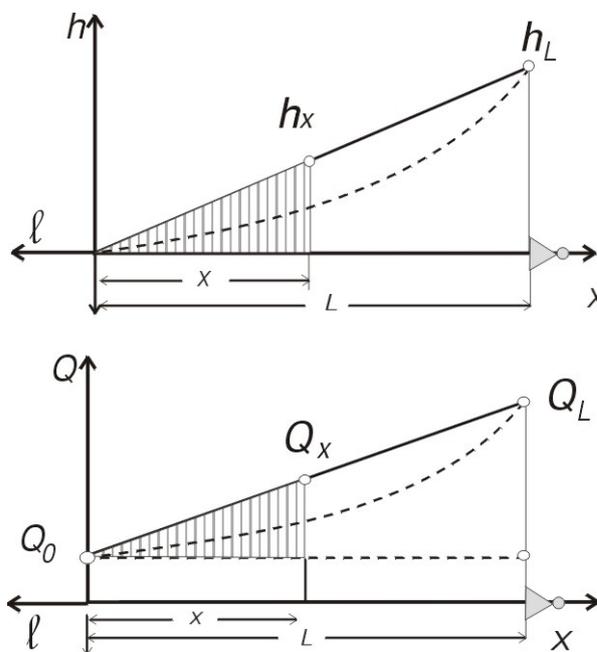


Figure 2. Q_x, h_x distribution functions

Conservation equations under above written assumptions are as follows:

1. **network distribution** (fig.1):

$$\begin{cases} Q_i = Q_{i-1} + k_f \sqrt{h_{i-1}} \\ h_i = h_{i-1} + r l_f Q_i^2 \end{cases} \quad (1)$$

where : $i = 1, 2, 3, \dots, n; n = L/l_f$ is junction number and its adjoining out flowing branch; l_f - distance between flanges, m; L - pipeline length, m.

Quantities Q_i and h_i represent air volumes (m³/s) and pressure (N/m²) distribution in separate junctions, where $Q_1 = Q_0$; $h_L = 0$; $Q_{n+1} = Q_L$; $h_n = h_L$.

2. continuous distribution (fig. 2):

$$\begin{cases} \frac{dQ_x}{dx} = -k_x \sqrt{h_x} & (2a) \\ \frac{dh_x}{dx} = -r Q_x^2 & (2b) \end{cases} \quad (2)$$

where Q_x and h_x are continuous functions along the transit flow direction x in boundaries:

$$Q_L \geq Q_x \geq Q_0; h_L \geq h_x \geq 0; 0 \leq x \leq L.$$

Functions Q_x and h_x are transformed for convenience into Q_ℓ and h_ℓ along reciprocate axe ℓ (fig.2), where: $x = L - \ell$; $Q_L \geq Q_\ell \geq Q_0$; $h_L \geq h_\ell \geq 0$.

Distribution functions, obtained from solutions of either (1) or from (2) can be applied in the following engineering calculations:

- Fan selection under given Q_0 ;
- Evaluation of initial air quantity Q_0 under given fan;
- Location of two and more fans with given characteristics $h_{Fi}(Q_{Fi})$ evaluation.

These problems motivated continuous interest in solution of models (1) or (2) and distribution functions evaluation.

DISTRIBUTION FUNCTIONS

Recurrent formulae (1) define exact numerical values of air volumes and pressure (Q_i, h_i) in the simplified model (fig. 1) under following input data - L, r, l_f, k_f и Q_0 . Such approach is applied more than hundred years to solve simple parallel networks. Stefanov T.P., V.V. Tomov, I.S. Velchev (1975) utilized iteration solution under H.Kross method, presenting local ventilation system as a complex diagonal network with ventilation tubes (transit flows), diagonal branches, arbitrary number and place of fans, different resistance factor of branches etc.

Model (2) utilization in mine ventilation is initiated in the works of Loisson R. и J.Ulmo, (1950); Holdsworth J.E., M.A. Pritchard и W.N.Walton, (1951); Воронин В.Н., (1956). During the second half of 20th century series of new solutions are published: Simode E., (1976) ; Pawinski J., J. Roszkowski и J.Strzeminski (1979); Robertson R. и P.B.Wharton (1980), Browning E.J., (1983); Vutukuri V.S. (1983), Kertikov (1994). This is a stage of analytical treatment of the model and trials for engineering expressions deduction. Different simplifications are applied in the process of solution of (2), leading afterwards to different Q_L and h_L , in some cases reaching serious

deviations from real values. Satisfying results give an integral solution (3), obtained under $h_x(m)$ approximation:

$$Q_L = Q_0 + \frac{2k_x L}{m+2} \sqrt{h_L(m)} \quad (3)$$

Voronin's (1956) formulae are very useful and give good agreement with reality for ($L < 750 m$):

$$h_L = r L Q_0 Q_L ; P_L = \frac{Q_L}{Q_0} = \left(\frac{k_x}{3} \sqrt{r L^3} + 1 \right)^2 \quad (4)$$

Similar is Browning's E.J. (1983) approach.

Authors of this paper apply sequent iterative integration of (2) to required accuracy via polynomial approximation (Vlasseva 2001). First approximation for h_x is: $h'_x = r L Q_0^2 \frac{\ell}{L}$. This expression is substituted into (2a), which solution is first approximation for Q'_x :

$$\int_{Q_0}^{Q'_x} dQ_x = -k \int_0^x \sqrt{h'_x} = Q'_x$$

This is a starting point for polynomial approximation, developed by the authors of this paper, namely: Q'_x is approximated by 3-rd degree polynomial (functions Q_x and h_x analysis show that such degree polynomial describes very well their behavior):

$$Q'_x \approx P_3(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3$$

This approximation is then substituted into (2b), giving:

$$\frac{dh_x}{dx} = -r (a_0 + a_1 x + a_2 x^2 + a_3 x^3)^2$$

Above written equation is the second iteration of h''_x .

Numerical values of $\sqrt{h''_x}$ are approximated by 3-rd degree polynomial, which polynomial is substituted into (2a):

$$\frac{dQ_x}{dx} = -k (b_0 + b_1 x + b_2 x^2 + b_3 x^3).$$

Solution os this equation is second iteration for Q''_x . Iteration procedure continue till preliminary given accuracy is reached, namely, 10⁻² in regard for Q .

Above described algorithm is transferred into computer code giving distribution functions h_x and Q_x under given input data – diameters, filtration factor, required air quantity.

As a result of above described procedure continuous functions for pressure h_x and air volumes Q_x are obtained. In this way the authors have achieved continuation of R.Loisson и J.Ulmo's (1950) solution, made analytically till the second iteration and is similar to the approach, applied by Vutukuri V.S. (1983) and Gillies, 1999

Insufficient information from empirical tests of solution to the model (2) lead to results comparison with proven calculation methods.

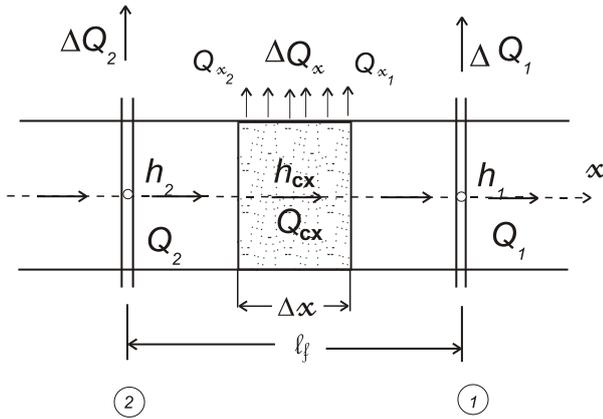


Figure 3. Filtration outflows

MODELS' COMPARISON

Difference between models (1) and (2) comes from filtration inflows determination (fig. 3). In model (1) each outflow is calculated separately by its friction factor $R_f = 1/k_f^2$, kg/m⁷ on the basis of averaged friction factor of holes (pores), located along the pipe wall surface $\pi l_p d$, namely:

$R_p = 1/(\ell_p k_x)^2$, kg/m⁷. Thus dimension of the two filtration factors is determined: concentrated k_f , (m⁷/kg)^{1/2} and distributed along surface k_x , (m⁵/kg)^{1/2}. According to (1) and (2) these factors are defined (fig. 3) as ratio between filtration flow (ΔQ) from the hole or from filtration surface to pressure (\sqrt{h}) in the pipeline:

$$k_f = \frac{Q_2 - Q_1}{\sqrt{h_1}} = \frac{\Delta Q_1}{\sqrt{h_1}}; \ell_p k_x = \frac{Q_{x2} - Q_{x1}}{\sqrt{h_{cx}}} = \frac{\Delta Q_x}{\sqrt{h_{cx}}} \quad (5)$$

where: $h_1 = h_f = R_f \Delta Q_1^2$ and $h_{cx} = R_p \Delta Q_x^2$, while h_{cx} and Q_{cx} are integral expressions under (2) for the sector $\ell_p = \Delta x$ (fig. 3).

Expressions (5) give ground to draw the following conclusions for pipelines with equal diameters ($d_1=d_2$) and with concentrated and distributed surface filtration:

1. when $\ell_f \rightarrow \ell_p$ and $k_f \rightarrow \ell_p k_x$, functions h_i, Q_i are close to h_x, Q_x ;

2. best approximation is achieved when $\ell_f = \ell_p$
3. full coincidence of distribution functions, obtained by the two models could not be achieved due to initial differences in the models – in tight (ℓ_f) and un-tight (ℓ_p) sector, when $\Delta Q_i < \Delta Q_x$ and $\Delta h_i > \Delta h_{ni}$;
4. the above unevenness become negligible when $\ell_f = \ell_p = \Delta x < 10m$.

Convergence criteria from model (1) to (2) can be presented in the following way:

$$\ell_v = \ell_p \text{ u } k_v = \ell_p k_x \quad (6)$$

where distance ℓ_v and factor k_v are virtual values of ℓ_f and k_f . Under these conditions recurrent calculations made by (1) can be taken into engineering calculations as equivalent to the integral model (2).

Vutukuri V.S. (1983) transforms model (2) into (1) by splitting of air flow in given sector ($\ell_p = \Delta x$) into two parallel flows – transit in tight pipe ($h = r \ell_p Q_d^2$) and filtration – conditional pore with resistance $R_p = 1/(\ell_p k_x)^2$, equivalent to filtration resistance along sector walls ($h = R_p Q_p^2$). Vutukuri A.S. solves the problem by introduction of R_p into (2), eliminates Q_x and integrates thus achieved second order differential equation by approximation proposed by Holdworth et al. (1951):

$$(h'_x)^{1/2} (h''_x)^2 = \left(\frac{r}{R_p} \right)^{1/2} 2 h'_x (h_x)^{1/2}$$

Table 1 presents comparative solutions, obtained by Vutukuri A.S. transformed model (2), Vlasseva E. – polynomial iteration approximation of (2) and virtual model (1). The problem example №3 in Vutukuri A.S. (1983) with the following input data: $d=1,00m$, $r=0,02464kg/m^8$; $k_x=0,00005(m^5/kg)^{1/2}$, $Q_0=10,00m^3/s$, $l_v=20m$, $L=2000m$.

Table 1. Comparative results

L	Vutukuri 1983		Vlasseva 2001		Virtual model	
	100	--	--	10.06	247.103	10.06
500	10.48	1258.35	10.58	1291.71	10.61	1290.75
1000	11.64	2785.29	11.71	2813.05	11.74	2813.87
1500	13.30	4765.39	13.23	4722.21	13.27	4722.10
1840	14.59	6416.90	14.49	6331.12	14.53	6328.30
2000	--	--	15.15	7195.41	15.19	7104.30

Factors k_x and k_f are of great importance to the results obtained under (1) or (2). Their real values can be experimentally proved by measurements of ΔQ and Δh in

control pipelines sectors as shown in Simode E., 1976; Seleznirov A.C., 1992; Gillies A.D.S., H.W.Wu, 1992.

Pipeline junction tightness (k_f) is defined by laboratory modeling and similarity.

Factor k_x results from un-tightness, locate along the whole pipeline length L . Its average value should reflect measured values ΔQ and Δh in comparatively long sector $\Delta L=L_1-L_2$. When utilizing same technology for tightness achievement and developed turbulence in it, location and length of control section (fig. 3) are chosen based only on accuracy of measurements and representatives of averization. Formulae for k_x evaluation is obtained on the basis of Q_1-Q_2 under expression (3):

$$k_x = \frac{Q_2 - Q_1}{2 \left(\frac{L_2}{m_2 + 1} \sqrt{h_2} - \frac{L_1}{m_1 + 1} \sqrt{h_1} \right)} \left[\frac{m^3 / s}{m \sqrt{N / m^2}} \right] \quad (7)$$

or via integration in boundaries ΔL (fig. 3) when $m=1$ (linear approximation):

$$k_x = \frac{3(Q_2 - Q_1)(h_2 - h_1)}{2 \Delta L (\sqrt{h_2^3} - \sqrt{h_1^3})} \quad (8)$$

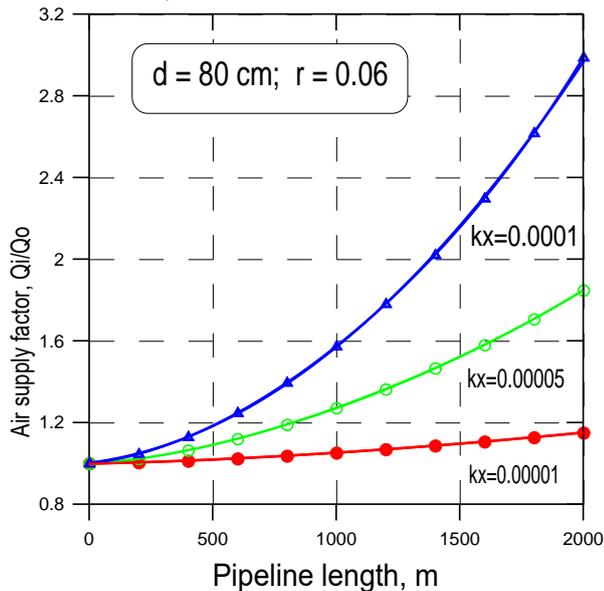


Figure 4a. Air supply factor (d=80 cm)

◀	$P = 1.00247 + 0.000151 X + 4.1491 E - 7 X^2$
○	$P = 0.9922 + 0.0001278 X + 1.5005 E - 7 X^2$
●	$P = 0.9974 + 3.1876 E - 5 X + 2.2565 E - 7 X^2$
d= 100 cm; r= 0.02	
◀	$P = 0.99241 + 0.000139 X + 1.82596 E - 7 X^2$
○	$P = 0.99376 + 8.40209 E - 5 X + 7.47475 E - 8 X^2$
●	$P = 0.9984 + 1.875895 E - 5 X + 1.260837 E - 8 X^2$

For the same purpose can serve expression (4). English equivalent of k_x is $L_c = k_x 100\sqrt{1000}$.

Above described measurements and calculations can be used to obtain real values for k_x and resistance R_p ,

reflecting pipe diameter, i.e. filtration surface $F=\ell \rho d$ and aero dynamical leakage conditions. When filtration intensity in equal by length sectors ($\ell_{p_1} = \ell_{p_2}$) with different diameters ($d_1 \neq d_2$) is equal ($FILQ_1 = FILQ_2$), the following expressions are obtained:

$$k_{x1} d_1 = k_{x2} d_2 \quad \text{or} \quad \frac{R_{p1}}{d_1^2} = \frac{R_{p2}}{d_2^2} \quad (9)$$

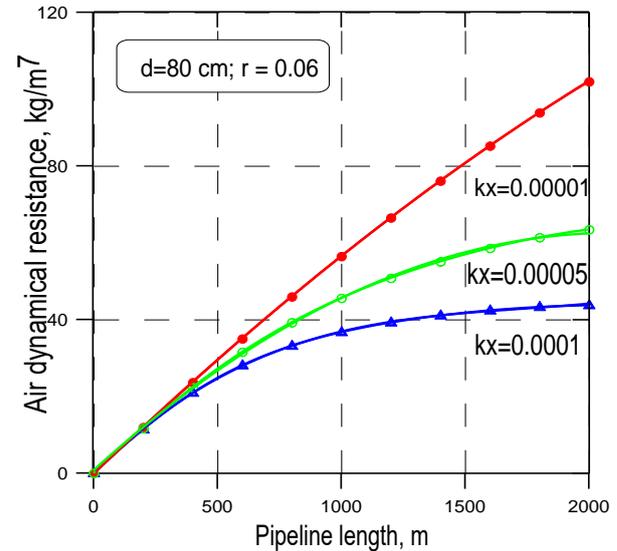


Figure 4b. Pipeline resistance (d=80 cm)

◀	$P = 0.26634 + 0.06223 X + 5.51496 E - 6 X^2$
○	$P = 0.680196 + 0.05889 X + 1.40185 E - 5 X^2$
●	$P = 0.24751 + 0.06559 X + 3.5308 E - 5 X^2 + 6.8006 E - 9 X^3$
d= 100 cm; r= 0.02	
◀	$P = 0.068201 + 0.02052 X - 1.15546 E - 6 X^2$
○	$P = 0.680196 + 0.05889 X + 1.40185 E - 5 X^2$
●	$P = 0.1336 + 0.02195 X - 8.34636 E - 6 X^2 + 1.17097 E - 9 X^3$

These are criteria for equal pipeline tightness degree dith different diameters. Following indexes can be written: $K_d = k_x d$ or $Z_d = L_c d$ and $R_d = R_p / d^2$, in order to compare pipelines in regard to tightness.

Table 2 presents classification based on Vutukuri V.S. (1983) of un-tight pipelines for different diameters but equal tightness conditions k_x and R_p for $\ell_p=100$ m.

Table 2. Comparison of tightness factors

d	kx	Rp	Kd	Ld	Rd	tightness
0.25	0.0002	2500	0.00005	0.158114	40000	Very good
0.50	0.0002	2500	0.0001	0.316228	10000	Good
0.75	0.0002	2500	0.00015	0.474342	4444.4	Average
1.00	0.0002	2500	0.0002	0.632456	2500.0	Poor
2.00	0.0002	2500	0.0004	1.264912	625.0	Very bad
5.00	0.0002	2500	0.001	3.162280	100.0	

Tight factors of E. Simode (1976) and Pawinski (1979) are for coefficient kx and refer to equal pipelines diameters.

SPECIFIC CHARACTERISTICS OF UN-TIGHT PIPELINES

Main purpose in design process of pipeline ventilation systems is to achieve advisable air flows and pressure distribution for variety of facilities and boundary conditions such as: length of pipeline (L), length of sectors (ΔL) and composition tubes (ℓ_i); diameters and resistances (d, r); degree of tightness (k_x, k_f); number, location (i) and fans' pressure characteristics (h_F-Q_F), different Q_0 etc. Calculations are conducted for each subset of data by utilization of distribution functions Q_i and h_i or Q_x and h_x , obtained either under (1) or (2).

Such repeatable calculations can be avoided by application of specific characteristics for the pipeline R_x and P_x , which depend only on its length (x), friction (r) and filtration (R_f or R_p) factors:

$$R_x = \frac{h_x}{Q_x^2} = R(x; r, k) \tag{10}$$

$$P_x = \frac{Q_x}{Q_0} = p(x, r, k) \tag{11}$$

Functions (10) and (11) are developed once by solution of (1) or (2) for arbitrary L and Q_0 (for instance $L=2000$ m $Q_0=1$ m³/s). They are permanent characteristic (passport) for the taken pipeline (r, k_x or k_f). Catalogue of $R-P$ passports and corresponding $h_F(Q_F)$ fan characteristics give sufficient information for engineering calculations in un-tight ventilation systems. Table 3 presents R-P passports for two widely used pipelines with three degrees of tightness. Figures 4a and 4b show in graphical way resistance and air supply coefficients for $d=80$ cm and $r=0.06$. Polynomials, approximating these characteristics for the two pipelines with three types of tightness are shown under the graph.

Table 3. P-R passports for two pipelines with different degrees of tightness

x	D = 80 cm; r = 0.06						D = 100 cm; r = 0.02					
	kx=0.00001		kx=0.00005		kx=0.0001		kx=0.00001		kx=0.00005		kx=0.0001	
	P	R	P	R	P	R	P	R	P	R	P	R
0	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
200	1.00	11.93	1.02	11.67	1.05	11.35	1.00	3.99	1.01	3.94	1.03	3.87
400	1.01	23.65	1.06	22.33	1.13	20.89	1.01	7.93	1.04	7.67	1.07	7.37
600	1.02	35.01	1.12	31.54	1.25	28.05	1.01	11.81	1.07	11.10	1.14	10.32
800	1.04	45.96	1.19	39.24	1.40	33.13	1.02	15.60	1.11	14.18	1.22	12.72
1000	1.05	56.47	1.27	45.58	1.57	36.68	1.03	19.30	1.15	16.93	1.32	14.65
1200	1.07	66.51	1.36	50.80	1.78	39.20	1.04	22.91	1.20	19.36	1.42	16.19
1400	1.09	76.11	1.47	55.10	2.02	41.03	1.05	26.42	1.26	21.51	1.55	17.43
1600	1.11	85.23	1.58	58.59	2.30	42.34	1.06	29.83	1.32	23.40	1.68	18.42
1800	1.13	93.88	1.71	61.37	2.62	43.23	1.07	33.13	1.39	25.04	1.83	19.18
2000	1.15	101.97	1.85	63.44	2.99	43.70	1.09	36.30	1.46	26.41	2.00	19.73

ENGINEERING CALCILATIONS

One fan in pipeline

Pipeline and fan are set by their specific characteristics $R-P$ and $h_F(Q_F)$. Calculations are performed for the whole pipeline length, divided into separate sectors ΔL (fig. 6), thus defining junctions \dot{i} – fans' location and place of intermediate calculations. To each of such junction are tied down sector's growths of ΔR_i and ΔP_i along the axes X и ℓ .

When fan is installed at the beginning ($x=0; \ell=L$) of transit flow (fig. 5), it operated in compressed regime along the whole pipeline length. On the contrary, when it is installed at the end of pipeline ($x=L; \ell=0$), its action is forced. Air current parameters in both cases are equal, but with opposite meaning. Air resistance overcome equals to R_L , filtration is one directional ($+FILQ_x$ or $-FILQ_\ell$) and maximal, no re-circulation is presented ($RECQ=0$). Водеща цел на проекта е да осигури достатъчно Project's main goal is to

ensure required air volume for the ventilated object Q_0 , pre-defined or calculated in advance on limiting factors.

Aero-dynamical calculations for such system are performed in two ways:

- under required Q_0 work regime of fan is evaluated by the following expressions:

$$Q_F = Q_L = Q_0 P_\ell \text{ и } h_F = h_L = R_\ell Q_0^2 \tag{12}$$

- fan or fan aggregate is selected $h_F(Q_F)$ and its resulting regime under R_L and air volumes distribution are then evaluated by the system of equations:

$$h_F(Q_F) \text{ и } h_L = R_L Q_L^2 \tag{13}$$

$$Q_0 = Q_L / P_L ; Q_i = Q_0 P_i ; h_i = R_i Q_i^2 \tag{14}$$

In case obtained value of Q_0 is unacceptable, solution is repeated with other fan or pipeline.

In case fan is located along the transit current (fig. 5), two pressure zones are formed in the pipeline: forced by x and compressed by ℓ with corresponding filtration ($+FILQ_x$ and $-FILQ_\ell$) and re-circulation ($RECQ_{cx}$). Aero-dynamical pipeline resistance is divided into two independent branches R_{ix} and $R_{i\ell}$, where:

$$R_i = R_{ix} + R_{i\ell}; h_i = R_i Q_i^2 \quad (15)$$

Fan work regime (h_i, Q_i) is evaluated under (15), while pressure and air volumes distribution – on the expressions written below:

$$Q_{0x} = Q_i / P_{ix}, h_{ix} = R_{ix} Q_{ix}^2 \quad (16)$$

$$Q_{0\ell} = Q_i / P_{i\ell}, h_{i\ell} = R_{i\ell} Q_{i\ell}^2 \quad (17)$$

The above described calculations are repeated for the selected $R-P$ pipeline for $L = L_{max}$ and for $L < L_{max}$. In this way need for one or more fans for pipeline installation construction and maintenance is estimated. Calculations might be repeated with other input data in case results doesn't satisfy either by technological or by economical reasons.

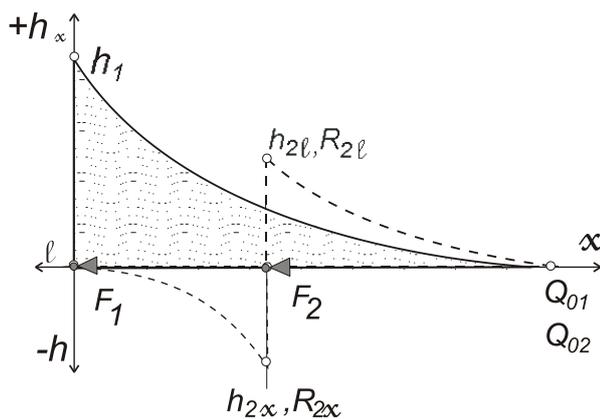


Figure 5. Fan in the beginning of pipeline

Two and more fans in the pipeline

Normally one of the fans is installed at one end of the pipeline – compressed along x or forced along ℓ (fig. 6). The rest of them are located along the air current. Their interaction is evaluated by summing up their individual functions h_{ix} and $h_{i\ell}$ for each pipeline junction:

$$\bar{h}_i = \sum h_{i\ell} - \sum h_{ix} \quad (18)$$

and by re-calculation of resulting air flow:

$$\bar{Q}_i = \sqrt{\bar{h}_i / R_i} \quad (19)$$

Resulting values \bar{h}_i and \bar{Q}_i describe pressure and air volumes variation along the transit flow direction (fig. 6). Function \bar{h}_i forms behind each fan junction with one of the following pressure:

- N – null ($\bar{h}_i = 0$);

- K – compressed ($\bar{h}_i > 0$);
- D – depressed ($\bar{h}_i < 0$);

Function \bar{Q}_i describes continuity of transit air current – descending by x and ascending by ℓ .

Between two adjacent junctions N-N zone is formed, where pressure loss is restored only by fan located within. Zone N-N result from individual regime of this fan (R_i, P_i, h_i, Q_i).

Compression in junction K defines the degree of sequential aggregating of interacting fans. Increase in the distance between them lead to appearance of junction N and then to D. Decrease in distance between fans lead to increase of compression to 100% (fans operate in one junction consecutively).

Depression sector N-D causes re-circulation in the pipeline, which should be avoided by default. It can be reduced and overcome by decreasing of distance between interacting fans.

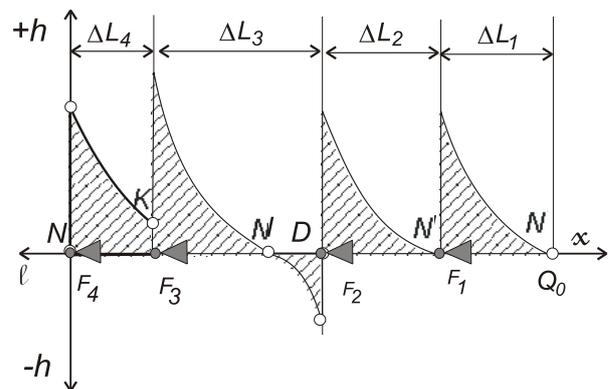


Figure 6. Two and more fans

Desired operation of given (available) fans is searched through variant calculations in order to find the best distance between fans.

Ventilation system without re-circulation is achieved assuming N-N scheme under required Q_0 (fig. 6) by the following procedure:

- Maximal pipeline length L is divided into sectors ΔL_i . Under required at the end of transit flow value Q_0 functions h_i and Q_i are evaluated either by P_i, R_i passport or under solution of (2).
- Selection of Fan №1 (of fan aggregate composed from smaller fans) is performed for the first N-N zone, which include several sectors. Thus selected fans should satisfied sectors' characteristics $h_i; Q_i$ for each pipeline lengthen. This could be achieved by increase of motor rotation or change of fans' blades angle.
- In the same way next fans (aggregates) №2, №3 etc. are selected for the following zones with required air quantity Q_0 ,

equals to fan operation efficiency in the preceding zone ($Q_{02} = Q_1, Q_{03} = Q_2$) etc.

- Project N-N should be achieved with 5-10% increase of calculated fan pressure for fans №2, №3 etc., which ensures reserves for avoiding re-circulation sectors. presents numerical

solution for 2000 m pipeline, composed from two consecutive sectors with characteristics written below:

$$\Delta L_1 = 1000; d_1 = 80; r = 0.060; k_x = 0.0001$$

$$\Delta L_2 = 1000; d_2 = 100; r = 0.020; k_x = 0.0001$$

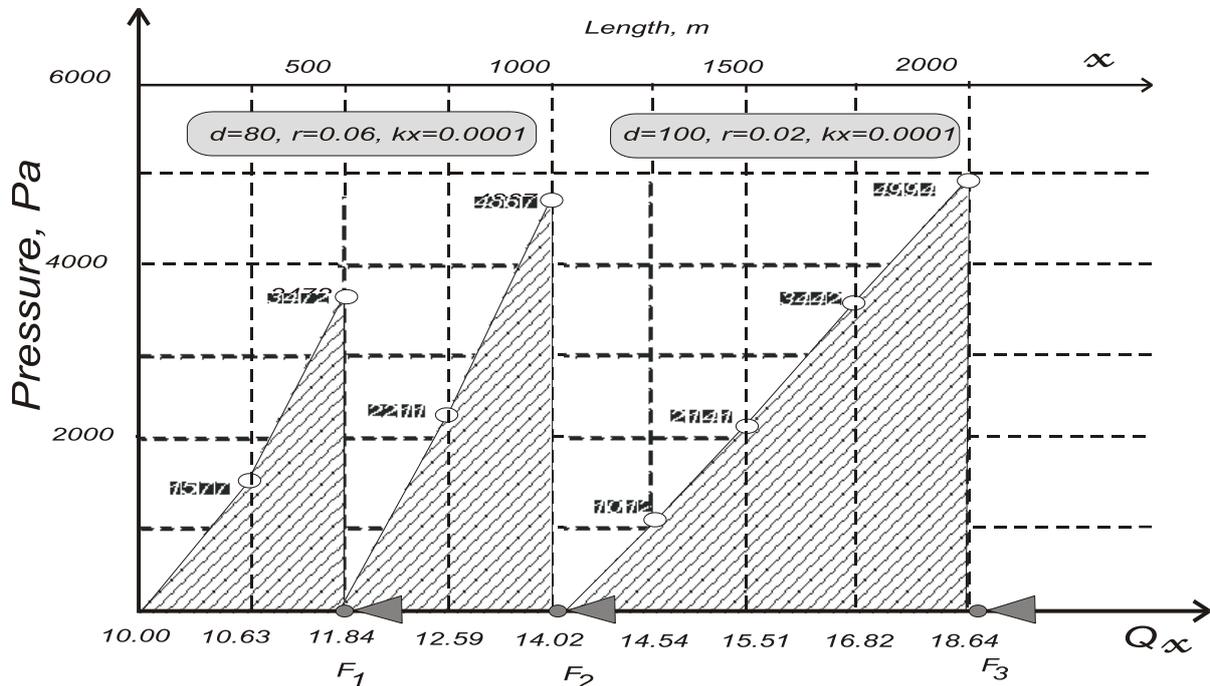


Figure 7. Numerical solution for 200 m pipeline

Final stage of designed forced ventilation system is shown on the figure. Fans selected are one type with possible changing of their blades' angel:

$$(F_1, \beta = 15^\circ; F_2, \beta = 25^\circ; F_3, \beta = 30^\circ).$$

Intermediate stages (regimes) after each pipeline lengthen are shown at each $\Delta L = 250m$. Total theoretical fans' power equals to 202,36 kW.

CONCLUSION

Comparative calculations for typical un-tight pipelines are performed based on known solutions and approaches. They give ground for the following conclusions and achievements:

- Computer program calculating distribution functions h_x and Q_x is developed. It reflects algorithm based on consecutive polynomial approximation and integration of (2);
- By utilization if the above described program passports $R-P$ for two types of pipelines with characteristic parameters are created and presented in graphical and numerical way;
- Numerical algorithm for "un-tight pipeline – fans" ventilation system design is presented which allows to optimize types and fans location.

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