ANALYSIS AND DETERMINATION OF OPTIMAL DEPTH OF SETTING PIPELINE WITH COLD WATER

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Abstract: In system of centralized supply of coolant energy (cold water) important place takes pipeline network of coolant energy, by which cooled water is delivered to consumer (air condition). Transport of cooled water is usually performed by two-pipe system. As experiments have found, depth of setting pipelines for cooled water is a minimal value of total year investiture costs, loses of heat and costs of pumping cooling water.

Keywords: Coolant energy. Cold water, Investiture costs

1. INTRODUCTION

System of centralized supply of cooling water energy is a complex system in which are involved cooling station, many consumers of cold water for needs of air condition and technology – consumers, which are located in various distances from cooling stations and pipelines of cool water from coolant station to consumer.

In SCSRE important place takes pipeline of coolant water. Transport of cooling energy is usually performed through two-pipeline system.

Optimal dept of setting pipelines of cooling water for concrete geographical region is determined from conditions of minimal energy loses with taking into consideration thermo physical characteristics of earth. Never the less, by proper processed climate data, a change curve is drawn of mean season temperature of earth in dependence with depth, $t_{ZE} = f(H)$. Then based on temperature of cold water t_{HW}, can be determined depth of setting pipelines with cold water, so that there are no heat loses, $t_{HW} = t_{ZE}$.

In values of coolant water (for example $t_{HW} = 10 \div 15^0 C$), which is rarely applied in conditioning, that kind of determined depth of setting H_{GRA}, can be smaller that minimal allowed depth of setting pipelines with coolant water $H_{\min} = 0{,}8 \div 1{,}2m$.

With most commonly applied temperatures of coolant water, order $4 \div 8^0 C$, depth H_{GRA}, which soots conditions of zero energy loses almost for all climate zone is large. In some hot regions isotherm, t_{HW}, do not intersect with curve $t_{ZE} = f(H)$ and in that cases this way can be applied for determination H_{GRA}.

In all cases optimal depth of setting pipelines of coolant water should be determined based on minimum year costs.

2. DETERMINATION OF EARTH TEMPERATURE IN FUNCTION OF DEPTH

Temperature on surface of earth is constantly changed through a year. Full cycle of change equals $n = 8760(h/god)$. Difference between temperature and its mean value on earth surface in any moment of time, can be determined by formula:

$$\theta_F^\tau = \theta_F^{\max} \cos\left(2\pi \frac{\tau}{\tau_0} + \varphi\right) \tag{1}$$

Where with $\theta_F^{\max}$ is determined maximal difference temperature and its middle value on surface of earth.
Change of temperature of outer air is calculated by formula:

$$\theta_{SV} = \theta_{SV}^{\max} \cos\left(2\pi \frac{\tau}{\tau_0}\right) \tag{2}$$

Temperature variation on surface of earth is spread into the deep of the earth and weakens with increase of distance X and its value. Maximal difference between temperature of earth on depth X and its mean value can be determined by formula:

$$\theta_X^{\max} = +\theta_F^{\max} \exp\left(-\sqrt{\frac{\pi}{a \cdot \tau_0}} \cdot X\right) \tag{3}$$

Results of analysis by formula (1), (2) and (3) presented in form of graph on figure 1. As we can see from graph maximal temperature of earth, on depth X, is given by expression:

$$t_{OK}^{\max} = t_X^{\max} = t_{ZE}^{SR} + \theta_F^{\max} \exp\left(-\sqrt{\frac{\pi}{a \cdot \tau_0}} \cdot X\right) \tag{4}$$

Based on diagram, presented on figure 1., for coolant water temperature $10^0 C$, pipeline needs to be set on depth of 2m. By temperature of water $13 \div 15^0 C$, depth of setting pipelines needs to be smaller than 1m, which is opposite with norms. On depth $10 \div 15m$ from surface of earth, season variation of temperature practically does not exist and is approx. $5^0 C$, so coolant water temperature $5^0 C$ can theoretically be transported without energy loses. However, because of large depth of pipeline setting, it is unjustified to set pipeline on such large depths. So, for example, by middle temperature of earth from $+13^0 C$ (figure 1b) and temperature of water from $+13^0 C$ from diagram we get very large depths for setting pipeline for water coolant. By temperature of water coolant of $+16^0 C \div 20^0 C$ we get usual depths of setting pipelines. However, for needs of air conditioning, in practice this temperature of water has been proved to be very rarely applied. From this reasons we approach to determination of optimal depth of setting pipelines using technological economical analysis.

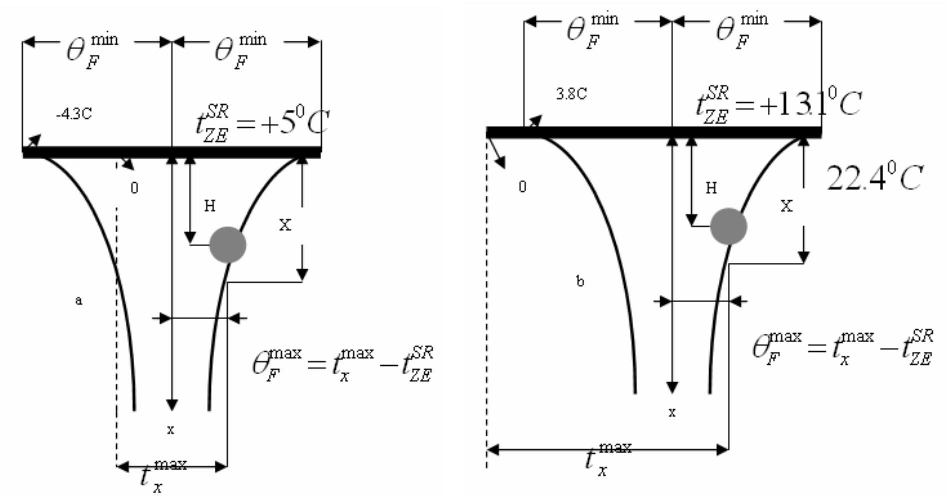

Figure 1. Change of earth temperature in function of its depth, for a) $t_{ZE}^{SR} = +5^0 C$ and b) $t_{ZE}^{SR} = +13{,}1^0 C$ in both cases $\theta_F^{max} = 9{,}3^0 C$

3. DETERMINATION OF OPTIMAL DEPTH OF SETTING PIPELINES OF COOLANT WATER BY CRITERIA OF MINIMUM YEAR COSTS

Water coolant pipeline is usually set into previously prepared canal or non-canal, that is, directly onto the ground. In this analysis is given procedure of determination optimal depth of setting non-canal two-pipe lines, as shown in figure 2.

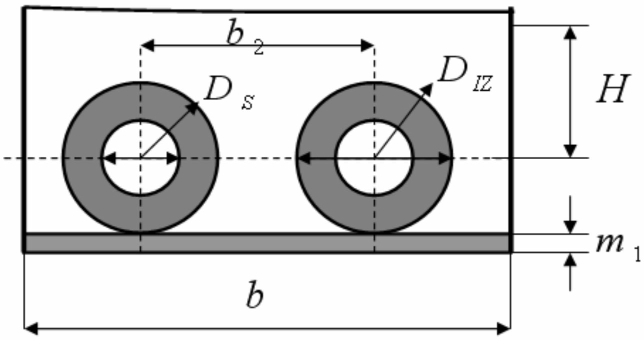

Figure 2. Non-canal set two-pipe cool line

Total costs by length meter of set pipeline are given by example:

$$T_{UK} = r \cdot T_{IN} + T_{EK} \tag{5}$$

Investiture costs T_{IN}, consist from costs of architecture ((digging, leveling and canal filing) and mechanical (delivery , mounting and finishing work on setting pipeline) work in function of pipeline diameter, can be presented by equation:

$$T_{IN} = C_{GRA}\left[b\left(H + \frac{D_{IZ}}{2} + m_1 \right) + bm_1 + b\left(H + \frac{D_{IZ}}{} \right) - 1{,}517 D_{IZ}^2 \right] + A_1 + B_1 D_{IZ} + C_1 D_{IZ}^2 \tag{6}$$

Exploitation costs consist costs of “losses” of heat energy and costs of pumping cold water. It is assumed that costs of pumping do not depend upon depth of setting water coolant pipeline, that is, it can be considered constant value. Taking this into consideration, exploitation costs by length meter of water coolant pipeline, can be presented by equation:

$$T_{EK} = Q_{GU}C_{RE} = 3{,}6 \cdot \pi \cdot 10^{-6}(1+\alpha)\cdot \tau_h \cdot D_S\left(t_{OK} - t_{HW}^{SR}\right)K \cdot C_{EE} + CON \tag{7}$$

Featuring that the coefficient of heat passing K for two-pipelines near set into earth is given by expression [1]:

$$K = \frac{1}{R_{IZ} + \frac{1}{2\pi\lambda_{ZE}}\ln\sqrt{1+4\frac{H^2}{b_2^2}}} \tag{8}$$

By which heat resistance of isolation is given by example:

$$R_{IZ} = \frac{1}{2\pi\lambda_{IZ}}\ln\frac{D_{IZ}}{D_S} \tag{9}$$

That after expression swap (4) and (8) in expression (7) and after arrangement of expression (5) , implementation of suitable measurements B_1, B_2, B_3, B_4 costs by length meter have shape:

$$T_{UK} = B_1 + HB_2 + B_3\frac{t_{ZE}^{SR} + \theta_F^{\max}e^{-SH} - t_{HW}^{SR}}{R_{IZ} + B_4\ln\sqrt{1+4\frac{H^2}{b_2^2}}} \tag{10}$$

From condition $\partial T_{UK}/\partial H = 0$ we get form of equation $Y_1 = Y_2$, so optimal depth of setting pipeline with water coolant is found in function intersection, figure 3.

$$Y_1 = R_1 + B_4\ln\sqrt{1+B_5H^2} \tag{11}$$

$$Y_2 = \frac{B_3}{B_2}\left[\frac{S\theta_F^{\max}}{e^{SH}} + B_4B_5\frac{H}{1+B_5H^2}\,\frac{t_{ZE} + \theta_F^{\max}e^{-SH} - t_{HW}^{SR}}{R_1 + B_4\ln\sqrt{1+B_5H^2}}\right] \tag{12}$$

In order for function given by equation (10) to really have minimum, there must be second partial epitome of function T_{UK} by H larger that zero $\partial^2 T_{UK}/\partial H^2 > 0$, and that is by analysis confirmed. After swap of concrete values for suitable physical measurements:

$\lambda_{ZE} = 1{,}75(W/mK); \rho_{ZE} = 1600(kg/m^3); c_{ZE} = 1{,}44(KJ/kgK); \lambda_{IZ} = 0{,}035(W/mK); \alpha = 0{,}25;$
$\tau_h = 2201(h/god); C_{RE} = 40(evra/GJ); C_{GR} = 12(Evra/m^3); r = 0{,}08(1/god); S = 0{,}3623(1/m);$
$\theta_F = t_{PZE} - t_{ZE}^{SR} = 22{,}4 - 13{,}1 = 9{,}3^0C; t_{HW}^{SR} = 10^0C;$ function (11) and (12) have shape:

$$Y_1 = 4{,}55\ln\frac{D_{IZ}}{D_S} + 0{,}091\ln\sqrt{1+4\frac{H^2}{b_2^2}} \tag{13}$$

$$Y_2 = 194375 \frac{D_S + 2\delta_{IZ}}{b} \frac{C_{RE}}{C_{GA}} \left[\frac{S\theta_f^{\max}}{e^{SH}} + \frac{0,364}{b_2^2} \frac{H}{1 + 4\frac{H^2}{b_2^2}} \cdot \frac{t_{SR} + e^{-SH}\theta_F^{\max} - t_{HW}^{SR}}{Y_1} \right] \tag{14}$$

Function flow Y_1 and Y_2 shown on figure 3, and in dependance from depth of setting and diameter of coolant water pipeline. In intersection of functions Y_1 and Y_2 we get by given diameter D_S optimal depth of setting pipeline of water coolant H_{OP}.

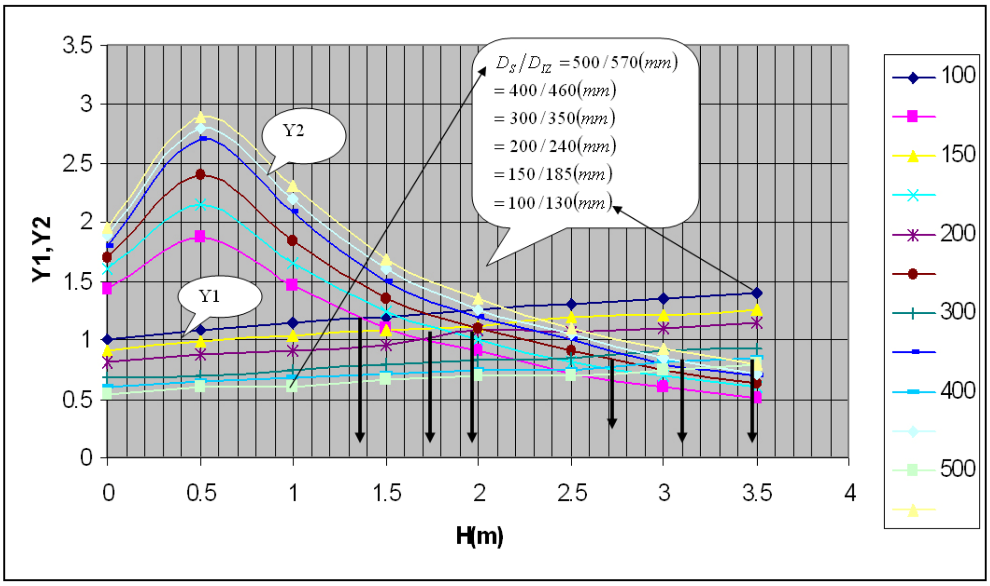

Figure 3. Depended Y_1 and Y_2 from depth of pipeline seting and their outer diameter

4. CONCLUSION

Shown method enables that, depending of geographical region (climate conditions), mode of setting water coolant pipeline, thermo physical characteristics of earth, price of coolant water energy, architectural work and characteristics of network can accurately determine depth of setting water coolant pipeline.

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MARKS

a -coefficient of earth heat diffusion $(a = \lambda/c\rho)$, m^2/h
A_1 - coefficient of unit price of water coolant pipeline, $€/m$
B_1 - coefficient of unit price of water coolant pipeline, $€/m^2$
b_2 -axis reach of pipeline, m
b -canal width of two-pipeline of water coolant, m
C_1 -coefficient of unit price of water coolant pipeline , $€/m^3$
c -specific heat, KJ/kgK
C_{GR} -price by cubic meter of earth dug $€/m^3$
C_{RE} -price of cool energy $€/GJ$
D -pipeline diameter, m
H -depth of setting water coolant pipeline, m
K -coefficient of heat transport, W/mK
m_1 -height of bank intersection
Q -loss of heat energy by length meter in a year, GJ/kgK
r -factor of investment return, $1/god$
R -heat layer resistance, mK/W
S -mark $(= 0{,}3623)$, m
t -temperature of work environment, ${}^0C$
T -costs by length meter of water coolant pipeline in a year, $€/m \cdot god$
α -coefficient of local heat loss,,
φ -delay by phase of temperature variation on earth surface compared to -variation of air temperature, rad
λ -coefficient of heat conductivity, $W/m \cdot K$
δ -layer depth, m
ρ -thickness of work environment, kg/m^3
τ -work duration, h/god
τ_0 -time from one temperature period, h

INDEX

S	-outer	SR	-mean
Sv	-outer air	ZE	-earth
OP	-optimal	UK	-total

PU	-pumping	EK	-exploitation
RE	-cool energy	hw	-cold water
GU	-loss	IN	-investiture
GR	-architectural	GRA	-border
IZ	-isolation	PZE	-earth surface
OK	-enviorment		

ENSIGN

$$R_{IZ} = \frac{1}{2\pi\lambda_{IZ}} \ln \frac{D_{IZ}}{D_S}$$

$B_1 = C_{GR} r\left(2m_1 b + bD_{IZ} - 1{,}517 D_{IZ}^2\right) + r\left(A_1 + B_1 D_{IZ} + C_1 D_{IZ}\right)$; $B_2 = 2 \cdot r \cdot b \cdot C_{GR}$

$B_3 = 3{,}6 \cdot \pi \cdot 10^{-6}(1+\alpha)\tau_h D_{IZ} C_{RE}$; $B_4 = 1/2\pi\lambda_{ZE}$; $B_5 = 4/b_2^2$; $CON = T_{PU}$