Power Plant Waste Heat Utilization for Soil Heating using Subsurface Pipes

Dr. Salah Sabeeh Abed-Alkareem
Instructor
Dept. of Machines and Agricultural Equipment.
University of Baghdad - College of Agricultural

Abstract

Warm water is circulated through the soil medium in order to maintain the plant root zone above same critical temperature. In power plants reject heat from steam through the condenser, the waste heat, could be a suitable resource for soil heating. This work presents theoretical and numerical models. Two methods are applied with water temperature (20°C, 30°C, and .50°C) to give the temperature distribution in the soil around buried pipes carrying hot water. The Models used to calculate the required heated land area using the heat from power plants of Daura Steam Power Plant where the discharge 85000m3/hr at Tw = 20°C which is cover the land area (44.7Km2) with piping of (4cm) diameter and length of(10714m). The theoretical results are compared with experimental published work (Johnsion 1976) and showed good agreements.

KEY WORDS**:** Heat transfer, Analytical Solution, Numerical Solution, Soil Depth, Soil Surface

الخلاصة

من الممكن استخدام الحرارة الناتجة (الضائعة) من محطات توليد الطاقة الكهربائية لتدفئة التربة. تتم هذه العملية باستخدام أنابيب مدفونة تحت سطح التربة ويجري بداخلها الماء الحار الخارج من مكثفات محطات توليد الطاقة الكهربائية. لقد تم عمل نموذجين رياضيين لحساب توزيع درجات الحرارة في التربة حول الأنابيب المدفونة تحت سطح التربة والتي يجري بداخلها الماء الحار باستخدام الحاسوب والنموذجان هما استخدام طريقة التحليل الرياضي (Analytical) والتي طبقت بدرجة حرارة محطة كهرباء الدورة البخارية في بغداد ($Tw = 20\ ^0C$) ودرجات حرارة أخرى ($Tw = 30\ ^0C,50\ ^0C$) . وطريقة الفروق المحددة (Finite-Difference) والتي تعطي توزيع درجات الحرارة في التربة مع التغير الزمن وباستخدام الشروط الابتدائية (Initial Conditions) والشروط الحدية (Boundary Conditions) والتي تمثل درجة حرارة سطح التربة (Ts) ودرجة حرارة عمق التربة (Tso) على مسافة ١ متر وبواسطتها يتم ايجاد توزيع درجات الحرارة في التربة بدقة حول الأنابيب المدفونة . ويمكن استخدام هذا الموديل في الأراضي القريبة من محطات توليد الطاقة الكهربائية كأن تكون محطة كهرباء الدورة البخارية والتي يتم خلالها حساب المساحة المراد تدفئتها ($44.7\ Km^2$) علما ان درجة حرارة الماء الخارج من المكثفات (20 0C) وكمية الماء الداخل

في الأنابيب هي (85000 m3/hr) وبأطوال (10714m) . قورنت النتائج المستحصلة مع النتائج المختبرية المنشورة وتبين بأن النتائج قريبة التطابق مع النتائج المنشورة .

Introduction

Soil heating is an important modern technique in high production controlled-environment agriculture. Warm water is circulated through the soil medium in plastic or steel pipes in order to maintain the plant root zone temperature above same critical level. These can provide a considerable economic benefit for the producers who use a soil heating system. In cold climate the warm soil provides an improved environment for plant growth and in the light of present high energy costs can result in considerable savings in heating cost. The power plant waste heat could be used to provide soil warming for agricultural purposes, Shapiro(1975), Shapiro and Roller (1975) as mentioned in Elwell et al. [1] (1985). Very large quantities of low temperature reject or waste heat are potentially available today as a by-product of various industrial processes. In steam electrical power plants much energy is rejected through the condenser cooling water. In most cases, however, the rejected thermal energy is contained in large quantities of relatively low temperature water. On the other hand, this can constitute a suitable resource for soil heating. The waste heat could be a suitable resource for soil heating. The feasibility of using power plant waste heat in a system which would provide soil warming for agricultural purposes which are very important to maintain the plant root zone temperature. Gosse[2] (1990) applied One-dimensional heat transfer in semi- infinite body solving about equation by analytical method which is giving temperature distribution in soil. The heating effect due to buried pipes uniformly distributed through-out the root zone in order to benefit crop growth. Alpert and Dewalle[3](1976) determined both experimentally and theoretically the temperature distributions around the buried pipes and heat flow from the buried network Mahrer and Avissar(1985) examined Two - dimensional heat transfer in soils with ridged and furrowed surfaces. Kluitenberg and Hoton (1990) considered a problem in which surface temperature is specified as a known function of time and horizontal position . They specified this function by calculating surface temperatures with the numerical model of Chung and Horton[4](1987). Farberov et al. [5](1991) showed that at present waste heat from nuclear and thermal electric power plants used for heating the soil .Nassar and Horton[6](1992) compares predicted and laboratory observed values of temperature from Horton [7] 1989).

The Present work deals with analytical and finite-difference methods to solve the unsteady-state partial differential equation to determine the temperature distribution in the soil around buried pipes assuming constant thermal conductivity of the soil following, Kendrick and Havens[8] (1973). The model is concerned with the waste heat of power plants (Daura power station or any other power station) for heating the soil for agricultural application. A computer program was written to solve these equations to give temperature distribution in the soil.

Analytical Solution

Figure(1) shows diagram of a system of buried pipes at the same depth below the surface of homogenous soil . Figure(2) shows a portion of the soil warming system considered , Fig(3) shows soil warming model and Fig(4) shows configuration of heat source to calculate the temperature distribution at any point in the soil from equation by images method is given as in Jakob[9] (1957) ;

$$T(x,y)-T_s=\frac{(T_w-T_s)}{\left\{\ln\left(\frac{2h-R}{R}\right)+\sum_{n=1}^{N}\ln\left[\frac{(ns)^2+(2h-R)^2}{(ns)^2+R^2}\right]\right\}}\times\left[\ln\sqrt{\frac{x^2+(h-y)^2}{x^2+(h+y)^2}}+\sum_{n=1}^{N}\ln\sqrt{\frac{(ns-x)^2+(h-y)^2}{(ns-x)^2+(h+y)^2}}\right]+\sum_{n=1}^{N}\ln\sqrt{\frac{(ns+x)^2+(h-y)^2}{(ns+x)^2+(h+y)^2}} \quad (1)$$

The temperature water inside the pipe is given as :

$$Tw=T_S+(T_I+T_S)\times\exp\left\{\frac{-2\pi KZ}{incp\left[\ln\left(\frac{2h-R}{R}\right)+\sum_{n=1}^{N}\ln\left(\frac{(ns-x)^2+(2h-R)^2}{(ns)^2+R}\right)\right]}\right\} \quad (2)$$

The necessary length of pipe is given as:

$$Z=\frac{1}{2\pi K}\ln\left(\frac{T_I-T_S}{T_w-T_S}\right)\times\dot{m}cp\left\{\ln\left(\frac{2h-R}{R}\right)+\sum_{n=1}^{N}\ln\left[\frac{(ns)^2+(2h-R)^2}{(ns)^2+R^2}\right]\right\} \quad (3)$$

The cooling water flow rate from the condensers is given as:

$$\dot{m}=Q\rho_W \quad (4)$$

The total number of pipes in the system is given as:

$$(2N+1) = \frac{\text{Total water flow rate}}{\text{Water flow rate per pipe}} \tag{5}$$

N is no. of pipes at right or left center pipe .

The mass flow rate of water through a single pipe is given as:

$$\dot{m} = \left(\frac{Q}{2N+1}\right)\rho_w \tag{6}$$

The total area heated is given as:

$$\text{AREA} = 2\text{NSZ} \tag{7}$$

Numerical Method

The transient partial differential equation cover the temperature distribution in the soil is given as in Holman[10] (1989) ;

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = \frac{1}{\alpha}\left(\frac{\partial T}{\partial \tau}\right) \tag{8}$$

Where:

T is the temperature

x, y are the distance from the buried pipe in two perpendicular directions

τ is the time

α is the diffusivity.

The alternating-direction implicit method (A.D.I.) was used, Salah[11](1998). Equation (8) may be written in form For **x;**

Let $r = \frac{\alpha \Delta t}{(\Delta x)^2} = \frac{\alpha \Delta t}{(\Delta y)^2}$

And $\Delta x = \Delta y$

$$\frac{T_{i,j,n+1} - T_{i,j,n}}{\alpha \Delta t} = \left[\frac{T_{i,j-1,n+1} - 2T_{i,j,n+1} + T_{i,j+1,n+1}}{(\Delta y)^2}\right] + \left[\frac{T_{i-1,j,n} - 2T_{i,j,n} + T_{i+1,j,n}}{(\Delta x)^2}\right] \tag{9}$$

The Final equation for **X- DIRECTION** is

$$-r\,T_{i,j-1,n+1} + (1+2r)\,T_{i,j,n+1} - r\,T_{i,j+1,n+1} =$$

$$T_{i-1,j,n} + (1-2r)\,T_{i,j,n} + r\,T_{i+1,j,n} \tag{10}$$

For **Y** , Equation (8) may be written in form ;

$$\frac{T_{i,j,n+1}-T_{i,j,n}}{\Delta t}=\frac{\alpha}{(\Delta y)^2}\left[T_{i,j-1,n}-2T_{i,j,n}+T_{i,j+1,n}\right]+ \frac{\alpha}{(\Delta x)^2}\left[T_{i-1,j,n+1}-2T_{i,j,n+1}+T_{i+1,j,n+1}\right] \quad (11)$$

The Final equation for **Y- DIRECTION** is :

$$-r\,T_{i-1,j,n+1}+(1+2r)\,T_{i,j,n+1}-r\,T_{i+1,j,n+1}=$$

$$r\,T_{i,j-1,n}+(1-2r)\,T_{i,j,n}+r\,T_{i,j+1,n} \quad (12)$$

For solving the equations (10) and (12) with appropriate conditions the distance between pipes (S),
Depth (h) and time domains of the soil are divide into a number of equally spaced intervals ($\Delta x=\Delta y$) and time intervals (Δt) was shown in figure(5) were (i) refers to depth (h), (j) refers to space between pipes (S) and (n) refers to time (t). The step sizes chosen in this work are ($\Delta x=\Delta y=0.05$m) and $\Delta t=1$ hour.

Result and Discussion

Figure (6) shows the steady state temperature distribution around buried pipes in the soil, carrying hot water at (T_w = 20^{o}C) and at depth of (h = 30cm) from soil surface. The pipes are separated by distances (s = 20cm) and temperature of soil surface (T_s = 5^{o}C). The pipes heat flux are sufficient to form a cylindrical dry core region. This produced a very considerable reduction of the soil thermal conductivity in the dry region and hence very steep temperature gradients around the pipes in the soil. The lines of temperature contours above the buried pipes are closed to each other. Therefore the distance between the lines of temperature down the pipes are comparatively more than the above lines. This is due to the temperature at soil surface is less than the temperature at (1 m) depth from the soil surface. Figure (7) shows the steady state temperature distribution around buried pipes in the soil carrying hot water at 50 ^{o}C (T_w = 50 ^{o}C) and at the same depth of figure (6). The pipes are separated from each other at the same distance of Figure (6) and at the same temperature of soil surface. The pipes heat flux, sufficient to form a cylindrical dry core region is greater than that show in Figure (6) because the source of heat is at 50 ^{o}C. This again produces a very considerable reduction of the soil thermal conductivity in the dry region. Figure (8) and Figure (9) shows the temperature distribution around the buried pipes at the same conditions (T_s = 12^{o}C, s =0. 2m, h = 0.3m) except carrying hot water in the pipes at different values (T_w = 20^o, T_w = 50^{o}C) .We notice that in these figures that the accumulated increases around the buried pipes , due to reduce heat loss getting to the surface .Figure (10) represent pipes carrying hot water at 20 oC and at depth (h = 30cm). The pipes are separated by distances 30 cm and temperature of soil surface 5 ^{o}C . Figure (11) for other case of hot water (Tw = 50 ^{o}C) and same condition of Figure (10) in this case the distance between pipes is 30 cm. It can be noticed from the figure that more heat transfer to soil. Figure (12) shows temperature distribution around buried pipes in the soil, carrying hot water at 20^{o}C and at depth of 40 cm from soil surface. The pipes are separated by distances 30 cm (S = 30 cm) and temperature of soil surface 5^{o}C.Figure (13) shows the temperature distribution around buried pipes in the soil, carrying hot water at 50^{o}C and other parameters at same conditions in Figure (13). Figure (14) shows the temperature distribution around the buried pipes in the soil, carrying hot water at 20^{o}C and at depth of 30 cm (h = 30 cm) from soil surface. The pipes are separated by distances 40cm and temperature of soil surface 5^{o}C. Figure (15) shows the temperature distribution around buried pipes in the soil carrying hot water at 50oC and others parameters at same conditions in the Figure (14).Figure (16) shows the temperature distribution around buried pipes carrying hot water at 20^{o}C and at depth of 40 cm. The pipes are separated by distances at the same in the Figure (15), also the temperature of soil surface same in the last Figure. Figure (17) shows the temperature distribution around the buried pipes carrying hot water at 50^{o}C, and other parameters are the same in the figure (16). Figure (18) shows the experimental steady state temperature based on Johnson (1976) compared to the present work.

Conclusions

It can be concluded that the method of heating soil is of benefit for plant growth in cold season and this method could be used instead of covering the plant with plastic covers. The waste heat of power plants is good source for heating soil, such as Daura steam power plant. The depth of buried pipes at 40 cm is more convenient for heating the root plants. Even the low temperature of waste power plants could maintain the required root temperature because temperature during day time is about (18^{o}C) and at right time is about (16^{o}C). The soil warming has two benefits in agriculture: extension of the growing season for crops and acceleration of plant growth. When the waste heat is removed from hot water circulation, it can either be returned to its natural origin with out harm to environmental or recycled again.

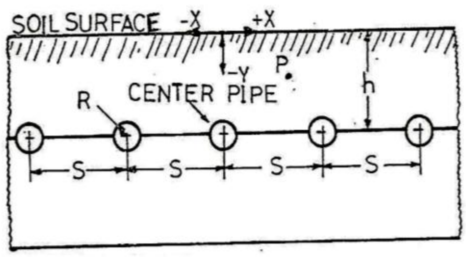


Fig.(1) **Cross-sectional view of soil warming system with water flowing in the same direction in neighboring pipes**

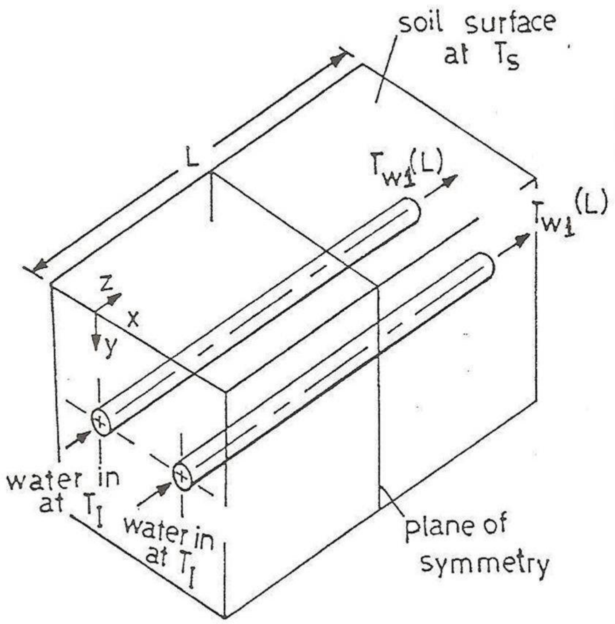


Fig.(2) **Soil Warming Model**

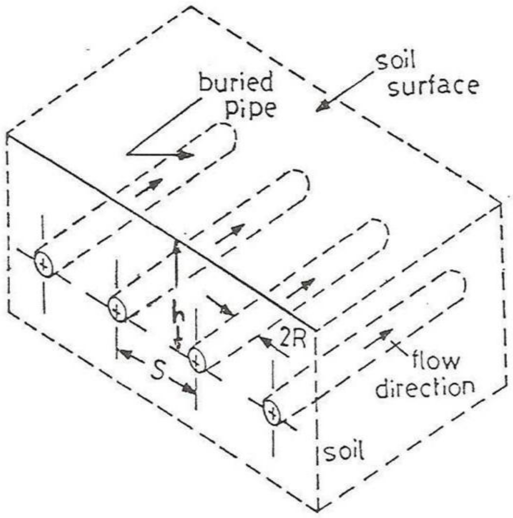


Fig.(3) **Layout of a Soil Warming System**

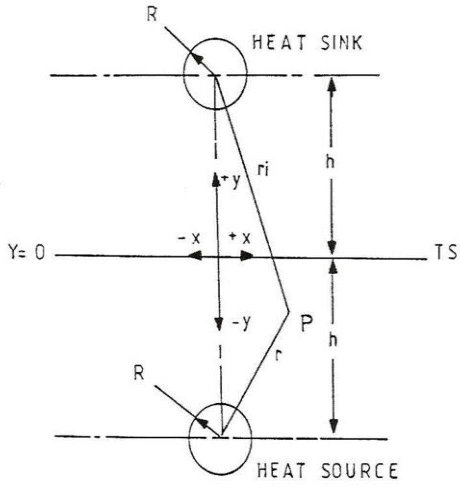


Fig.(4) **Configuration of heat source and fictitious heat sink (image) for determination of temperature distribution around a buried pipe by method of images**

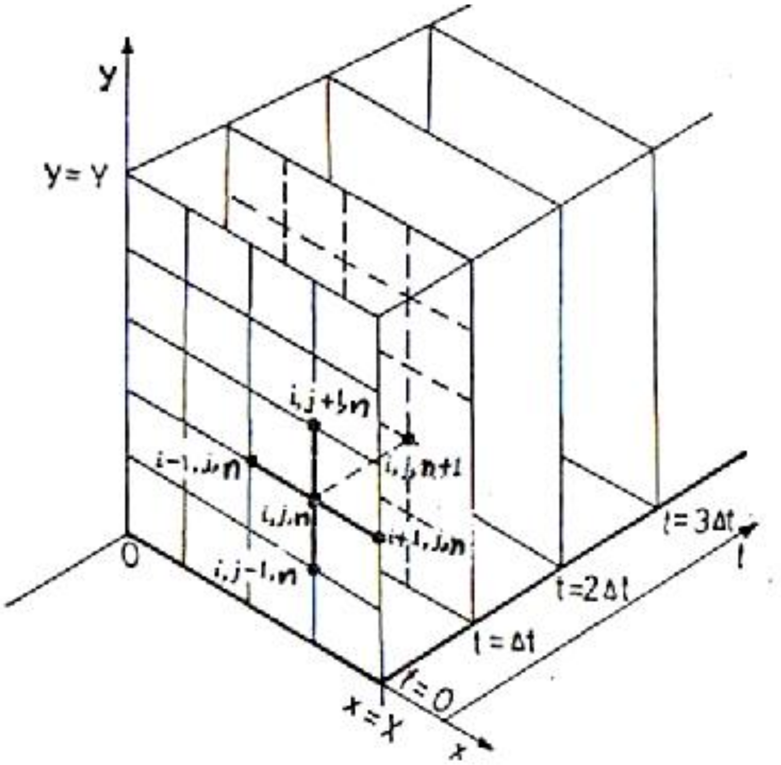


Fig. (5) Graphical Representation of two – Dimensional Transient Conduction.

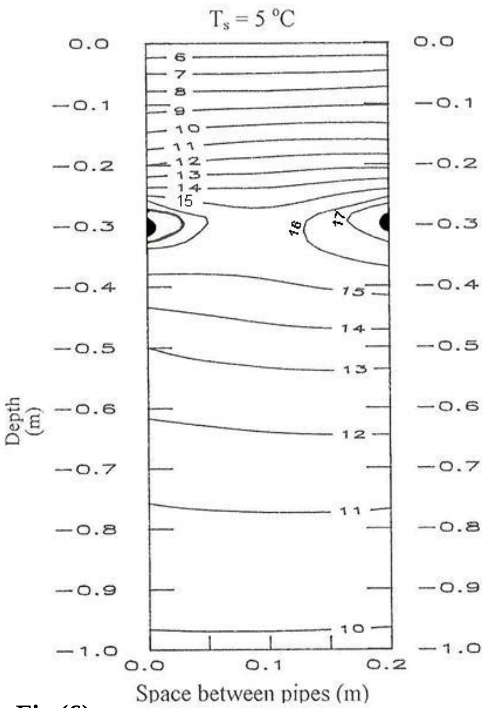


Fig.(6) **Temperatur distribution ar ound buried pipes.**
For parameters:- (T_w = 20 °C , S = 0.2 m, h = 0.3 m)

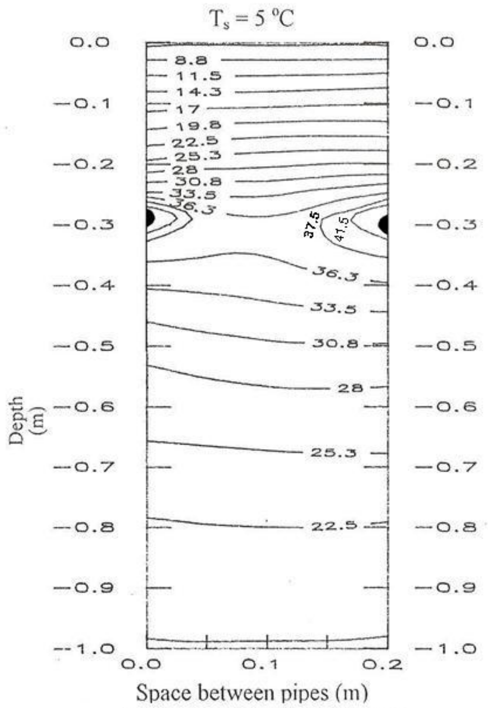


Fig.(7) **Temperature distribution und buried pipes.**
For parameters:- (T_w = 50 °C , S = 0.2 m , h = 0.3 m)

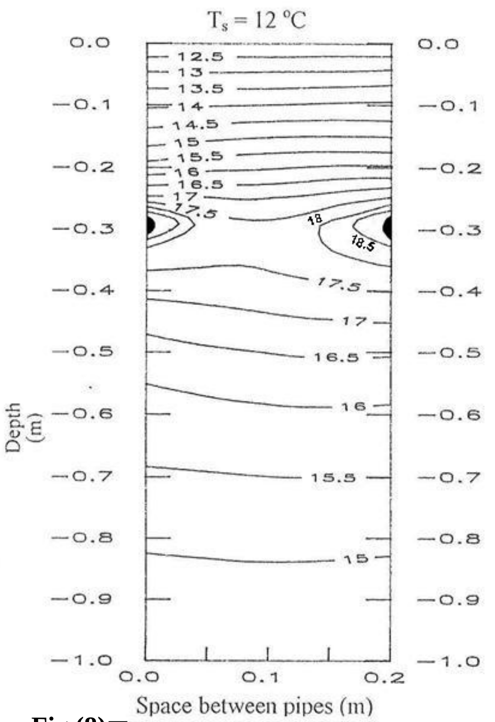


Fig.(8) **Temperatur distribution ar ound buried pipes.**
For parameters:- (T_w = 20 °C, S = 0.2 m, h = 0.3 m)

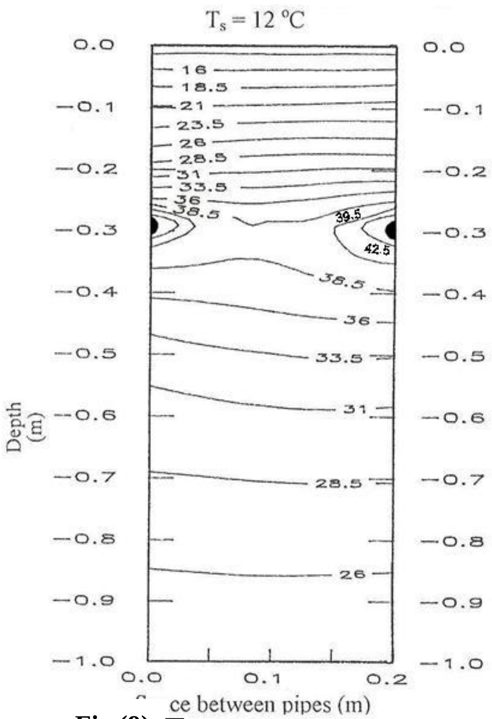


Fig.(9) **Trature distribution around buried pipes.**
For parameters:- (T_w = 50 °C, S = 0.2 m , h = 0.3 m)

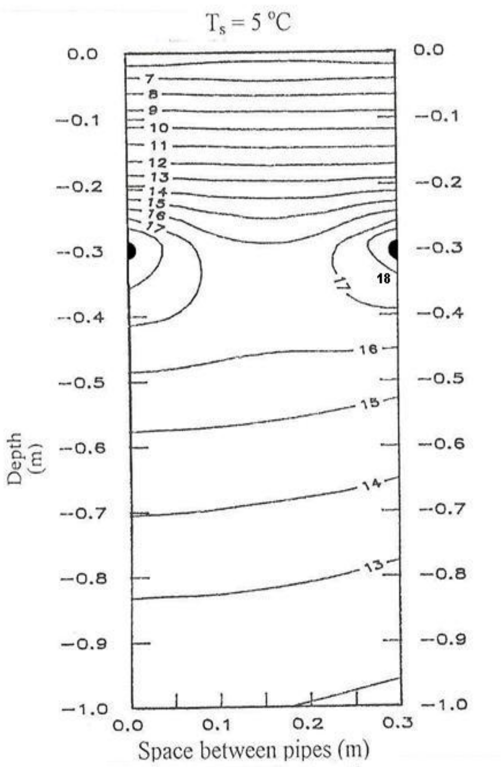


Fig.(10) Temperatur distribution ar ound buried pipes.
For parameters:- ($T_w = 20\ ^oC$, S = 0.3 m, h = 0.3 m)

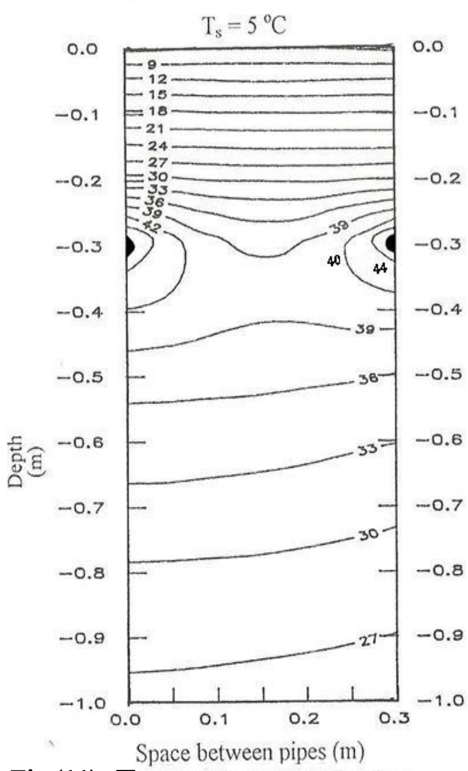


Fig.(11) Temperature distribution around buried pipes.
For parameters:- ($T_w = 50\ ^oC$, S = 0.3 m , h = 0.3 m)

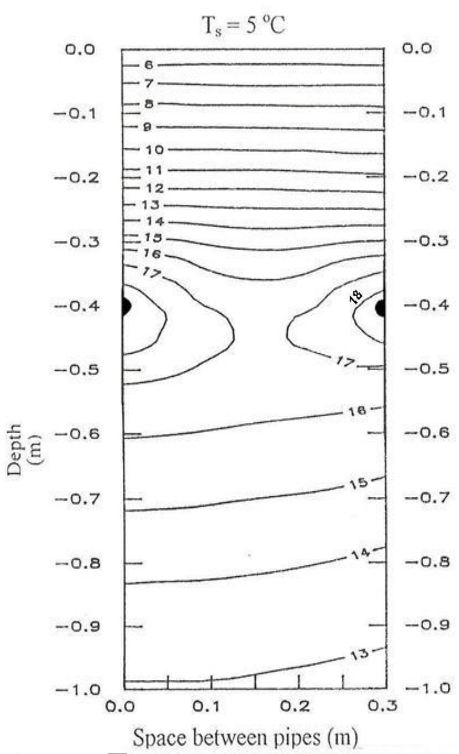


Fig.(12) Temperatur distribution ar ound buried pipes.
For parameters:- ($T_w = 20\ ^oC$, S = 0.3 m, h = 0.4 m)

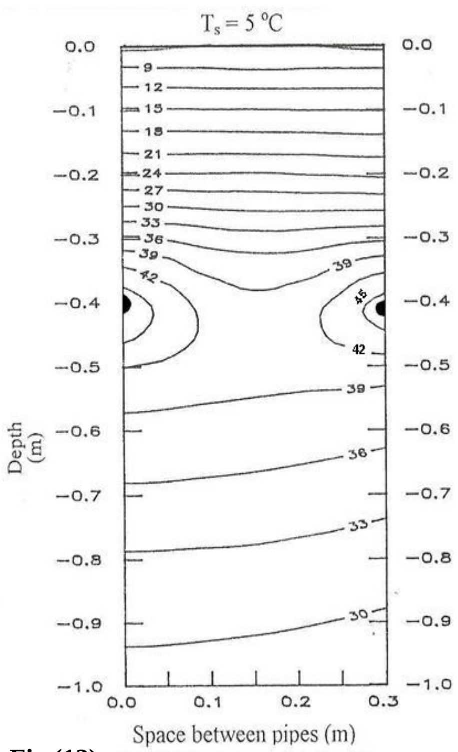


Fig.(13) Temperature distribution around buried pipes.
For parameters:- ($T_w = 50\ ^oC$, S = 0.3 m , h = 0.4 m)

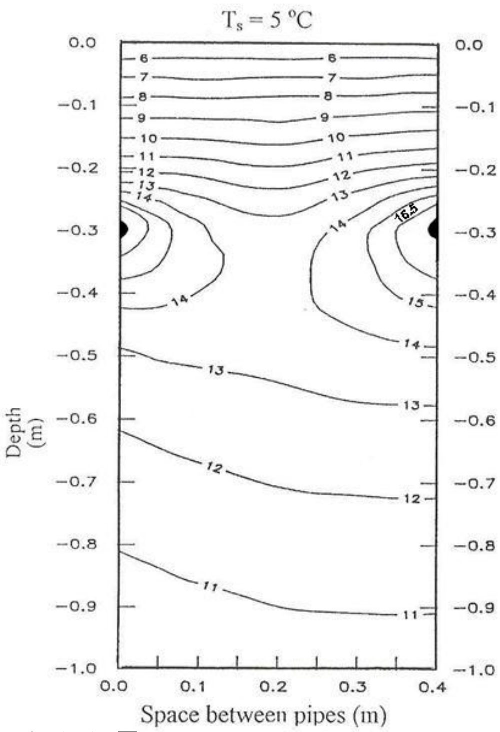


Fig.(14) **Temperatur distribution around buried pipes.**
For parameters:- (T_w = 20 °C , S = 0.4 m, h = 0.3 m)

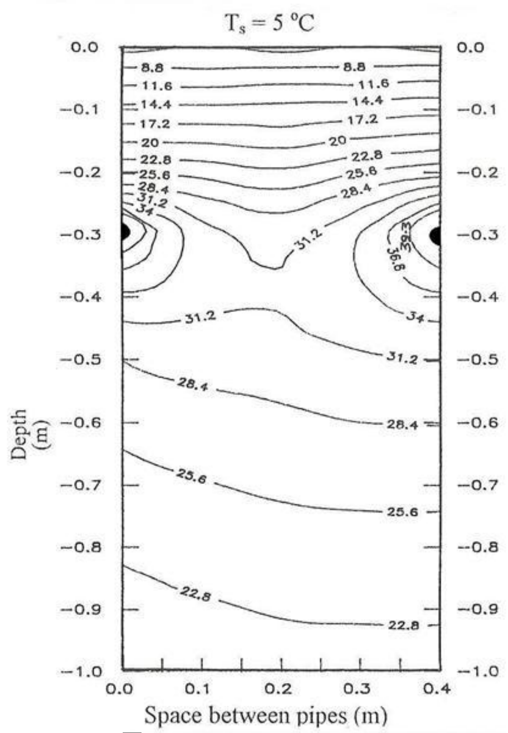


Fig.(15) **Temperature distribution around buried pipes.**
For parameters:- (T_w = 50 °C , S = 0.4 m , h = 0.3 m)

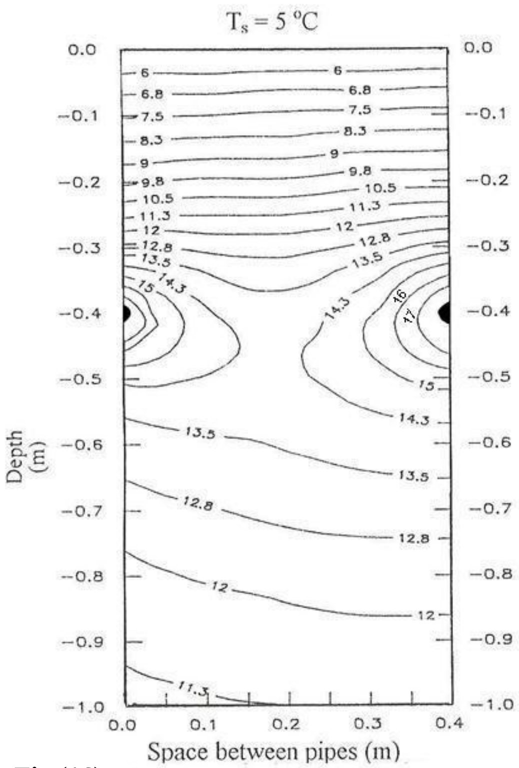


Fig.(16) **Temperatur distribution around buried pipes.**
For parameters:- (T_w = 20 °C , S = 0.4 m, h = 0.4 m)

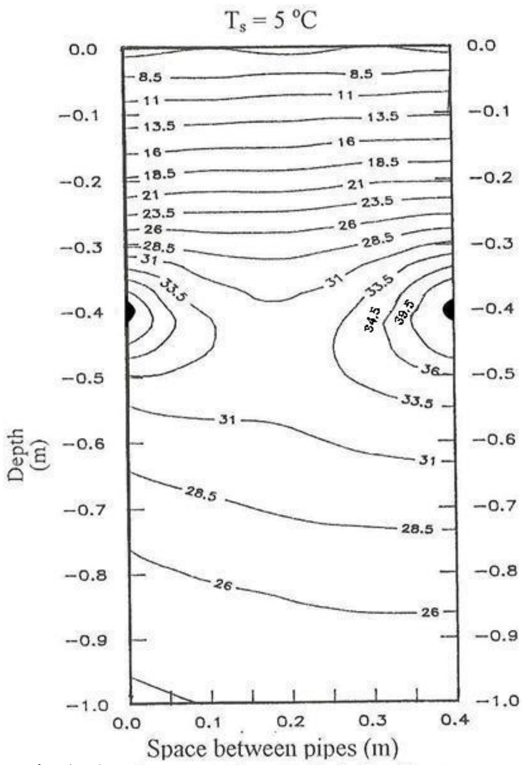
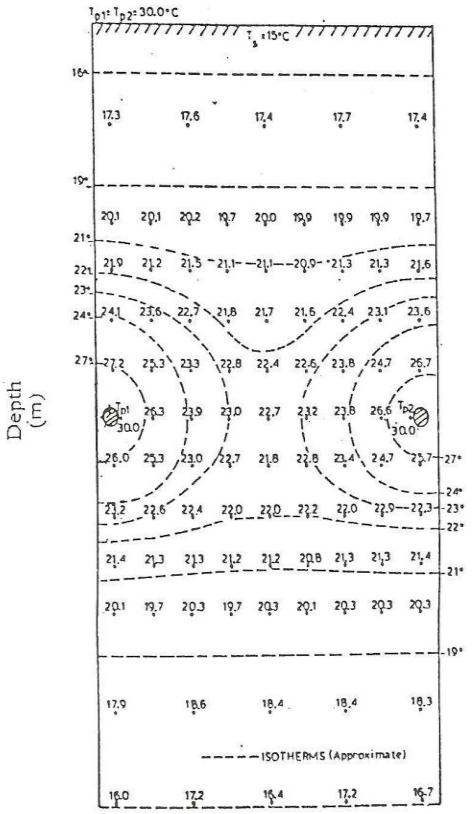
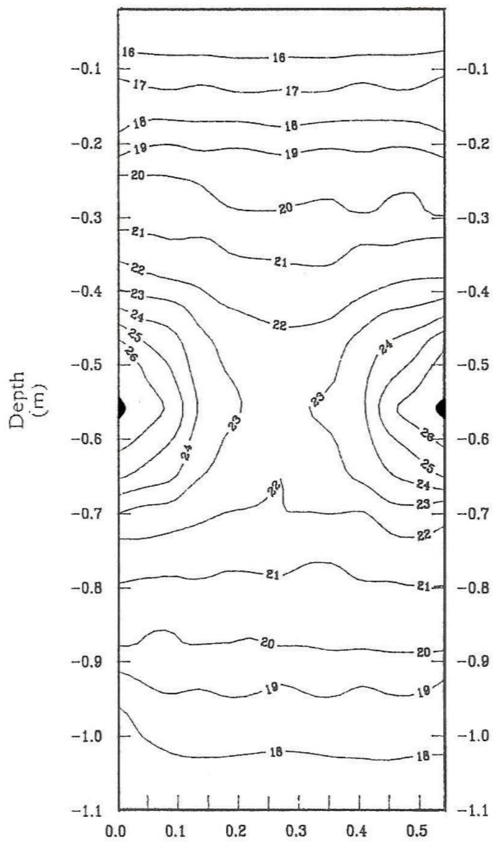


Fig.(17) **Temperature distribution around buried pipes.**
For parameters:- (T_w = 50 °C , S = 0.4 m , h = 0.4 m)



a. Jhonson (1976).



b. Present results.

Fig.(18) Comparison of present results with the experimental work of Jhonson (1976) .

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Nomenclature

Symbol	Definition	*Unit*
C_p	Heat capacity of water.	[J/Kg.°C]
h	Depth pipe is buried, measured to pipe center.	[m]
k	Thermal conductivity of soil.	[W/m^2. °C]
$\dot{m}$	Mass floe rate of water through a single pipe.	[kg/sec]
n	Counter numbering from center pipe.	
N	Number of pipes on either side of center pipe.	
Q	Discharge.	[m^3/sec]
$\dot{q}$	low rate per linear length unit of pipe at longitudinal coordinate (z).	[W/m^2]
r	Radial distance from pipe center.	[m]
r_i	Radial distance from image heat sink.	[m]
R	Outside radius of pipe	[m]
S	Lateral distance between pipes.	[m]
t	Time.	[sec]
T	Temperature of medium at any radial distance r.	[°C]
T_F	Final water temperature.	[°C]
T_I	Initial water temperature.	[°C]
T_S	Temperature of soil surface.	[°C]
T_w	Temperature of water in a pipe at coordinate Z.	[C]
X	Horizontal distance from source of sink , Cartesian coordinate.	[m].
Y	Cartesian coordinate .	[m].
Z	Necessary length of pipe to drop the water temperature a required amount	[m]
i , j , n	Refers to grid point.	

Greek Symbols

Symbol	Definition	Unit
α_s	Thermal diffusivity of soil	[m2/sec]
ρ_w	Density of water	[kg/m3]
ρ_s	Density of soil	[kg/m3]