المعهد التقني النجف

قسم ميكانيك القدرة

فرع التبريد والتكييف

المرحلة الثانية

محاضرات مادة انتقال الحرارة

انتهاء راضي الحمامي

الفصل الاول

أهمية انتقال الحرارة

طرق انتقال الحرارة

HEAT TRANSFER
انتقال الحرارة

HEAT TRANSFER :-it is the science العلم that studyيدرس the heat transferred الحرارة انتقال between بين material bodies الاجسام المادية as a result نتيجة of temperatures difference اختلاف درجات الحرارة .

** When a temperature gradient exists عندما يكون هناك تدرج حراري it causes يسبب the heat to transfer انتقال الحرارة from high temperature region من الحيز ذو درجة الحرارة العالية to الى the low temperature region الحيز ذو درجة الحرارة الواطئة,

Table for quantities and units

Quantity الكمية	Symbol الرمز	Unit الوحدة
Density الكثافة	ρ	Kg/m^3
Force	F=m.g	$N=kg.m/sec^2$
Work الشغل	W	(Joule) جول =J=N.m
Acceleration التعجيل	a	m/sec^2
Time الزمن	t	hr , min , sec
Temperature درجة الحرارة	T	℃,°K
Power القدرة	P	1Watt=1J/sec
Heat الحرارة	Q	Joule
Dynamic Viscosity لزوجة دينامية	μ	Pa*sec
Kinematic viscosity لزوجة كينماتية	ν	m^2/sec
British thermal unit وحدة حرارة بريطانية	Btu	1Btu=1055J 1Btu=252cal
Calorie سعرة حرارية	Cal	1Cal=4.1868J
Ton refrigeration طن تبريد	T.R	12000Btu/hr=3520w

**Heat (Q) is measured in Joule (J)=N.m الطاقة او الحرارة وتقاس بوحدة الجول

*Heat transfer rate(q) is measured in watt(w)= المعدل الزمني للطاقة يقاس بوحدة و الواط

METHODS OF HEAT TRANSFER

- CONDUCTION — التوصيل
- CONVECTION — الحمل
- RADIATION — الاشعاع

CONDUCTION HEAT TRANSFER :- conduction heat transfer occur يحدث in a solid bodies في الاجسام الصلبة because بسبب they contain a number of free electronsاحتواء ذراتها على عدد من الالكترونات الحرة.

The basic law for conduction heat transfer is Fourier's law:-

القانون الاساسي للتوصيل يسمى قانون فورير

$$q = K \times A \times \frac{\Delta T}{\Delta X}$$

قانون فورير للتوصيل

q :heat transfer rate in watt المعدل الزمني لانتقال الحرارة بوحدة الواط

k :thermal conductivity of material in w/m.°k الموصلية الحرارية للمادة بوحدة

A : area in m^2 المساحة للسطح بوحدة

ΔT: temperature difference in °k اختلاف درجات الحرارة بوحدة

Δx : wall thickness in m سمك الجدار بوحدة

CONVECTION HEAT TRANSFER :- convection heat transfer occur يحدث between بين fluids molecules جزيئات المائع and a solid surfaces contact to fluidsالاسطح الصلبة الملامسة للموائع due to molecules motionنتيجة حركة جزيئات المائع.

The basic law for convection heat transfer is newton's law:-

القانون الاساسي للحمل هو قانون نيوتن

$$q = h * A * \Delta t$$

قانون نيوتن للحمل

q : heat transfer rate in watt .المعدل الزمني لانتقال الحرارة بوحدة الواط

h : convection heat transfer coefficient in $w/m^2.^oK$. معامل المواصلة السطحية بالحمل

A: area in m^2 المساحة للسطح بوحدة

At: temperature difference in $^oK = t_w - t_\infty$ اختلاف درجات الحرارة بين السطح والمائع

t_w : wall temperature in ^oK. درجة حرارة السطح

t_∞ : fluid temperature in ^oK. درجة حرارة المائع

RADIATION HEAT TRANSFER:-radiation heat transfer occur يحدث in vacuum في الفراغ as an electromagnetic waves بشكل موجات كهرومغناطيسية, it needs no medium ولايحتاج لوسيط.

The basic law for radiation heat transfer is Stefan –Boltzman's law:–

القانون الاساسي للاشعاع هو قانون ستيفان بولتزمان

$$q = \epsilon \times \sigma \times A \times T^4$$

قانون ستيفان بولتزمان للاشعاع

q : heat transfer rate in watt.المعدل الزمني لانتقال الحرارة بوحدة الواط

Є: emissivity of body < 1 معامل الانبعاث للسطح المشع

σ :Stefan –Boltzmann constant $=5.67*10^{-8}$ $w/m^2.{}^oK^4$ ثابت ستيفان

A: area in m^2 المساحة للسطح المشع

T: absolute temperature in ^oK. درجة الحرارة المطلقة للسطح المشع

HEAT TRANSFER

Problems for Radiation(chapter six)

==========

Q1- A plane received radial energy at a rate of (120)w/m^2.it absorb (80) w/m^2, transmiss(10) w/m^2 and reflect the other. calculate the value of :

1-absorbtion factor 2-reflection factor 3-transmissivity factor

Solution

---------:-

ϴ=(120)w/m^2

ϴα=80 w/m^2 , ϴτ =10 w/m^2

ϴρ=reflect energy=120−(80+10)=30 w/m^2

1-absorbtion factor α

$$\alpha=\frac{\theta_\alpha}{\theta}=\frac{80}{120}=(0.66)$$

2-reflection factor

$$\rho=\frac{\theta\rho}{\theta}=\frac{30}{120}=(0.25)$$

3-transmissivity factor

$$\tau=\frac{\theta\tau}{\theta}=\frac{10}{120}=(0.083)$$

Q2-Athermal radial energy at a rate of 300 w/m^2 set on a radial grey body where it reflect 200 w/m^2 and transmiss 60 w/m^2.calculate the absorbtion factor for the body.

Solution

---------:-

ϴ=(300)w/m^2

ϴ ρ=reflect energy=200 w/m^2

ϴ τ = transmiss energy=60 w/m^2

ϴ α =absorb energy=300−(200+60)=40 w/m^2

absorbtion factor α

$$\alpha=\frac{\theta_\alpha}{\theta}=\frac{40}{300}=(0.13)$$

Q3- A cylindrical black body has a radius of 20 cm and a high of 3m ,if the temperature of A cylindrical wall is 1100℃ .calculate the radial energy from outside surface.

Solution

---------:-

R=20cm , d=40cm ,L=3m

$A=\pi*d*L=3.14*0.4*3=3.76\ m^2$

$T=1100+273=1373°k$

$q_b = б*A*T^4$

$q_b = 5.67*10^{-8}*3.76*1373^4$

$q_b =5.67*3.76*(\frac{1373}{100})^4=757622.82w=757.622kw$

Q4- A spherical grey body has a radius of 30cm and a temperature of 1300℃. calculate the radial energy from outside surface if the emmissivity factor is 0.85

Solution

---------:-

R=30cm , d=60cm =0.6m

$A \text{ for spherical body}=\pi*d^2 =3.14*0.6^2=1.13m^2$

$T=1300+273=1573°k$

$q_{gr} = Є* б*A*(T^4)$

$=0.85*5.67*10^{-8}*1.13*(1573)^4$

$=0.85*5.67*1.13*(\frac{1573}{100})^4$

$q_{gr}=333422.81w=333.422kw$

Q5- calculate the radial energy per square meter between two infinite black bodies if the temperatures of bodies are 500℃ ,200℃

Solution:-

$A=1m^2$

For infinite black body $F_{1\to2}=1$

$T_1=500+273=773°k$

$T_2=200+273=473°k$

$q_{1\to2}=б*A*F_{1\to2}(T_1^4-T_2^4)$

$q_{1\to2}=5.67*1*1*(7.73^4-4.73^4)$

$q_{1\to2}=17406.11w=17.406kw$

Q6-Two black parallel discs have same area each one of 60cm diameter placed so that the distance between them is 30cm ,the temperatures of discs are 250℃,150 ℃.calculate the net radial energy exchanged between the two discs per square meter.

Solution:-

d =60cm=0.6m ,L=30cm

$\frac{d}{L}=\frac{60}{30}=2$

$A=1m^2$

From chart of F we find

$F_{1\to2}= 0.38$

$T_1=250+273=523°k$

$T_2=150+273=423°k$

$q_{1\to2}=б*A*F_{1\to2}(T_1^4-T_2^4)$

$q_{1\to2}=5.67*1*0.38*(5.23^4-4.23^4)$

$q_{1\to2}=922.223w$

Q7- Two black square bodies ,each one of 1.2 m side placed so that the distance between them is 0.3m ,the temperature of first body is 90℃,and the second body is 220℃.calculate the net radial energy exchanged between them.

Solution:-

S =1.2m ,L=0.3m

$\frac{d}{L}=\frac{1.2}{0.3}=4$

$A=1.2*1.2=1.44m^2$

From chart of F we find

$F_{1\to2}=0.632$

$T_1=90+273=363°k$

$T_2=220+273=493°k$

$q_{1\to2}=б*A*F_{1\to2}(T_1^4-T_2^4)$

$q_{1\to2}=5.67*1.44*0.632*(4.93^4-3.63^4)$

$q_{1\to2}=2152.28w$

Q8- calculate the radial energy exchanged between two black square bodies placed so that the distance between them is 60cm and each one of 200cm side if the temperature of first body is 220℃ and the second body is 330 ℃.

Solution:-

S =200cm=2m ,L=60cm

$\frac{S}{L}=\frac{200}{60}=3.33$

A=2*2=4m^2

From chart of F we find

$F_{1\to2}=0.569$

$T_1=220+273=493°k$

$T_2=330+273=603°k$

$q_{2\to1}=б*A*F_{2\to1}(T_2^4-T_1^4)$

$q_{2\to1}=5.67*4*0.569*(6.03^4-4.93^4)$

$q_{2\to1}=9438.48w$

Q9-rectangular black bodies have dimensions of 2m , 2.4m at a distance of 4m if the temperatures of bodies are 260℃ ,160℃ .calculate the net radial energy exchanged between them.

Solution:-

X =2m ,Y=2.4m ,Z=4m

$\frac{X}{Z}=\frac{2}{4}=0.5$

$\frac{Y}{Z}=\frac{2.4}{4}=0.6$

From chart of F we find for rectangular

$F_{1\to2}=0.08$

A=2*2.4=4.8m^2

$T_1=260+273=533°k$

$T_2=160+273=433°k$

$q_{1\to2}=б*A*F_{1\to2}(T_1^4-T_2^4)$

$q_{1\to2}=5.67*4.8*0.08*(5.33^4-4.33^4)$

$q_{1\to2}=991.847w$

Q10- calculate the radial energy exchanged between two bodies contact with reradiating bodies , the dimensions of each body is 2m*2m placed at a distance of 6m assume the temperature of first body is 810℃,and the second body is 420℃. The emissivity factor of hot body is 0.9 and for cold body is 0.6.

Solution:-

S =2m , L=6m

$\frac{S}{L}=\frac{2}{6}=0.33$

From chart of F we find for square

$F_{1R2}=0.262$

$\in_1=0.9$, $\in_2=0.6$

$$(F_{1R2})_{gr}=\frac{1}{\frac{1}{F1R2}+\left(\frac{1}{\epsilon1}-1\right)+\frac{A1}{A2}\left(\frac{1}{\in2}-1\right)}=\frac{1}{\frac{1}{0.262}+\left(\frac{1}{0.9}-1\right)+\frac{4}{4}\left(\frac{1}{0.6}-1\right)}$$

$(F_{1R2})_{gr}=(0.217)$

$A=2*2=4m^2$

$T_1=810+273=1083°k$

$T_2=420+273=693°k$

$(q_{1\to2})gr=б*A_1*(F_{1R2})gr*(T_1^4-T_2^4)$

$(q_{1\to2})gr=5.67*4*0.217*(10.83^4-6.93^4)$

$(q_{1\to2})gr=56353.31w$

Q11- calculate the radial energy exchanged between the bottom and celling of furnace , each one has square shape of 4m*4m placed at a distance of 1.5m and each one contact with reradiating surfaces ,assume The emissivity factor of bottom and celling are 0.7 , 0.92 respectively, if the temperatures of bottom and celling are 1050 ℃,420 ℃ respectively.

Solution:-

S =4m , L=1.5m

$\frac{S}{L} = \frac{4}{1.5}$ **=2.66**

From chart of F we find for square

F_{1R2}**=0.746**

$\in_1$**=0.92 , ** $\in_2$**=0.7**

$$(F_{1R2})_{gr} = \frac{1}{\frac{1}{F1R2}+\left(\frac{1}{\epsilon 1}-1\right)+\frac{A1}{A2}\left(\frac{1}{\epsilon 2}-1\right)} = \frac{1}{\frac{1}{0.746}+\left(\frac{1}{0.92}-1\right)+\frac{16}{16}\left(\frac{1}{0.7}-1\right)}$$

$(F_{1R2})_{gr}$**=(0.538)**

A=4*4=16m^2

T_1**=1050+273=1323°k**

T_2**=420+273=693°k**

$(q_{1\to 2})gr = \sigma * A_1 * (F_{1R2})gr * (T_1^4 - T_2^4)$

$(q_{1\to 2})gr = 5.67 * 16 * 0.538 * (13.23^4 - 6.93^4)$

$(q_{1\to 2})gr$**=1384.74w**

EXAMPLE(1):-calculate the heat transfer rate by free convection from a vertical hot surface with (15cm) high and (23cm) width at a temperature of (124℃) to the air at (38℃).

Solution:-

$q = h * A * \Delta t$

$A = 0.15 * 0.23 = 0.0345\ m^2$

$\Delta t = tw - t\infty = 124 - 38 = 86℃$

$T_f = \frac{(tw + t\infty)}{2} = \frac{(124+38)}{2} = 81℃ + 273 = 354°k$

From chart of Z for air we find:-

$Z = 38.2 * 10^6 + (57.2 - 38.2) * 10^6 * \frac{2}{7} = 43.6 * 10^6 = 4.36 * 10^7\ 1/m^3.℃.$

$N_{Ra} = N_{Gr} * N_{pr} = L^3 * \Delta t * Z = (0.15)^3 * 86 * 4.36 * 10^7 = 1.26 * 10^7$

$10^9 > N_{Gr} * N_{pr} > 10^4$, **the flow is laminar**

$N_{NU} = 0.59(N_{Gr} * N_{pr})^{0.25} = 35.15$

$N_{NU} = \frac{h * L}{k}$

k for air from tables of air at $t_f = 81℃$ is 0.0302 $w/m.^0k$

$35.15 = \frac{h * L}{k}$

$h = \frac{N_{NU} * K}{L}$

$h = \frac{35.15 * 0.0302}{0.15}$

$h = 7.07\ w/m^2.^0k$

$q = h * A * \Delta t = 20.99\ w$

EXAMPLE(2):- calculate the heat transfer rate by free convection from a unit area of outside surface of a horizontal tube with 10cm diameter having vapor to the air of room if the temperatures of tube and air are 213℃,41℃ respectively.

Solution

---------- :-

$q''=h*\Delta t$

$\Delta t=tw-t\infty=213-41=172℃$

$T_f=\frac{(tw+t\infty)}{2}=\frac{(213+41)}{2}=127℃$

From tables of air and at Tf we find:-

من جداول الهواء وعند Tf نوجد الخواص التالية:-

$\beta=\frac{1}{41+273}=0.00318 \quad 1/^0k$, $N_{pr}=0.689$

$\nu=0.254*10^{-4}\ m^2/sec$, $K=0.0336\ w/m.^0k$

$N_{Ra}=(N_{Gr}*N_{Pr})=\frac{g*\beta*\Delta t*D3}{\nu^2}*N_{pr}$

$N_{Ra}=\frac{9.8*0.00318*172*(0.1)^3}{(0.254*10^{-4})^2}*0.689$

$N_{Ra}=5.73*10^6$

$10^9 > N_{Ra} > 10^4$, The flow is laminar

$N_{NU}=0.53(N_{Gr}*N_{pr})^{0.25}=0.53(5.73*10^6)^{0.25}=25.92$

$N_{NU}=\frac{h*d}{k}$

$25.92==\frac{h*0.1}{0.0336}$

$h=\frac{NNU*k}{d}=\frac{25.92*0.0336}{0.1}=8.63\ w/m^2.^0k$

$q''=h*\Delta t=8.63*172$

$q''=1484\ w/m^2$

خطوات حلول مسائل الفصل الثالث(الحمل الحر)

---------- :-

١- يتم حساب درجة حرارة الطبقة الحدودية T_f.

٢- يتم استخراج الخواص للمائع حسب نوعه اما ماء او هواء من الجداول وهذه الخواص هي β و ν و K و N_{pr}.

اذا كان المائع هواء فهناك طريقتان للحل اما باستخدام خارطة z او باستخدام الجداول واما اذا كان المائع ماء فيجب استخدام الجداول فقط.

٣- يتم حساب عدد رايليه من ضرب حاصل عددي كراشوف وبراندتل لتحديد نوع الجريان

٤- يتم تحديد نوع الجريان اما طباقي او اضطرابي من قيمة عدد رايليه.فاذا كان الجريان طباقي تستخدم معادلة عدد نوسلت للجريان الطباقي وحسب نوع السطح افقي او عمودي او مربع اسطواني او مربع او مستوي.

٥- من قيمة عدد نوسلت يتم حساب h ثم يتم حساب قيمة q

هذه طريقة الجداول وتستخدم للماء والهواء

اما طريقةZ فتستخدم للهواء فقط وخطواتها هي:-

١- يتم حساب درجة حرارة الطبقة الحدودية T_f من القانون الخاص بها وبوحدة كلفن

٢- نذهب الى خارطة Z ونستخرج قيمة Z

٣- يتم حساب عدد رايليه من المعادلة $N_{Ra}=D^3*\Delta t*Z$

٤- يتم تحديد نوع الجريان من عدد رايليه ونختار معادلة عدد نوسلت حسب نوع الجريان ونوع السطح.

٥-من قيمة عدد نوسلت يتم حساب h ثم يتم حساب قيمة q

HEAT TRANSFER

Problems for forced convection (chapter four)

==========

Q1- calculate the mean coefficient of heat transfer for water flowing through a tube of 5cm inside diameter .water inter at 21°C and leave at 54°C if the mean velocity of water is 6.1 m/sec.

Solution

---------- :

$t_m = \frac{t_i + t_o}{2} = \frac{21+54}{2} = 37.5°C$

From water tables and at 37.5°C we find:-

$\nu = 0.00691 * 10^{-4}\ m^2/sec$

$K = 0.628\ w/m.^0k$

$N_{pr} = 4.55$

$(N_{Re}) = \frac{u*d}{\nu} = \frac{6.1*0.05}{0.00691*10^{-4}} = 4.4*10^5$

$(N_{Re}) > 2300$, **The flow is turbulent**

$N_{Nu} = 0.023(N_{Re})^{0.8}(N_{pr})^{0.4} = 0.023(4.4*10^5)^{0.8}(4.55)^{0.4} = 1379.41$

$N_{Nu} = \frac{h*d}{k}$

$1379.41 = \frac{h*0.05}{0.628}$

$h = 17325.43\ w/m^2.^0k$

Q2-water flow with flow rate of 2192 kg/hr in a tube with inside diameter of 5cm if the interring and leaving temperatures of water are 27°C and 49°C respectively.calculate the heat transfer coefficient beside water.

Solution

---------- :

$\dot{m} = \frac{2192}{3600} = 0.608\ kg/sec$

$\dot{m} = \rho * u * A$

$t_m = \frac{t_i + t_o}{2} = \frac{27+49}{2} = 38°C \sim 40°C$

From water tables and at 40^0c we find:-

$\rho = 992.71 kg/m^3$, $\nu = 0.00692 * 10^{-4}\ m^2/sec$

$N_{pr} = 4.5$, $K = 0.624\ w/m.^0k$

$u = \frac{\dot{m}}{\rho * A} = \frac{0.608}{992.71 * \frac{\pi}{4} * d^2} = 0.311\ m/sec$

$(N_{Re}) = \frac{u * d}{\nu} = \frac{0.311 * 0.05}{0.00692 * 10^{-4}} = 2.25 * 10^4$

$(N_{Re}) > 2300$, **The flow is turbulent**

$N_{Nu} = 0.023 (N_{Re})^{0.8} (Npr)^{0.4} = 0.023 (2.25 * 10^4)^{0.8} (4.5)^{0.4} = 127.3$

$N_{Nu} = \frac{h * d}{k}$

$127.3 = \frac{h * 0.05}{0.624}$

$h = 1588.75\ w/m^2.^0k$

Q3- water heated from 28°C to 50°C during flow in atube with inside diameter of 0.5cm .the mean surface temperature of tube is 60°C ,the flowrate of water flowing is 44 kg/hr .calculate the heat transfer coefficient and the heat transfer rate per square meter from inside surface .

Solution

---------- :

$\dot{m} = \frac{44}{3600} = 0.012\ kg/sec$

$\dot{m} = \rho * u * A$

$t_m = \frac{t_i + t_o}{2} = \frac{28+50}{2} = 39°C \sim 40°C$

From water tables and at 40^0c we find:-

ρ=992.1kg/m^3 , ν =0.00658$*10^{-4}$ m^2/sec

N_{pr}=4.35 , K=0.627 w/m.^{0}k

$$u=\frac{\dot{m}}{\rho * A}=\frac{0.012}{992.71*\frac{\pi}{4}*(0.005)^2}=0.61 \text{ m/sec}$$

$$(NRe)=\frac{u*d}{\nu}=\frac{0.61*0.005}{0.00658*10^{-4}}=4.68*10^3$$

$(N_{Re}) > 2300$, The flow is turbulent

$$N_{Nu}=0.023(N_{Re})^{0.8}(Npr)^{0.4}=0.023(4.68*10^3)^{0.8}(4.35)^{0.4}=35.75$$

$$N_{Nu}=\frac{h*d}{k}$$

$$35.75=\frac{h*0.005}{0.627}$$

h =4483.5 w/m^2.^{0}k

$$q''=h*\Delta t=4483.5*20=89670.12 \text{ w/m}^2$$

Q4-calculate the mean coefficient of heat transfer for oil flowing through a heated tube of 2.5 m long and inside diameter of 2.5 cm at mean velocity of 0.5 m/sec ,if the interring and leaving temperatures of oil are 53.9°C , 54.9°C respectively ,the mean surface temperature of tube is 70°C ,the specific gravity of oil is 0.88 and specific heat is 3.35 kJ/kg.^{0}k ,the thermal conductivity of oil is 0.138 w/m.°k,dynamic viscosity varies with temperature as follow:-

T°C	49	54.5	60	65.5	71
μ kg/m.sec	0.0019	0.0016	0.0013	0.0010	0.0009

Solution

---------- :

$$t_m=\frac{t_i+t_o}{2}=\frac{53.5+54.9}{2}=54.4°C$$

$$S_{oil}=\frac{\rho \text{ oil}}{\rho \text{ water}}$$

ρ_{oil} =0.88$*$1000=880kg/m^3 , μ=0.0016kg /m.sec

$(N_{Re})=\frac{\rho\ oil*u*d}{\mu_{oil}}=\frac{880*0.5*0.025}{0.0016}=6875$

$(N_{Re}) > 2300$, The flow is turbulent

$Npr=\frac{\mu*cp}{k}=\frac{0.0016*3350}{0.138}=38.84$

$N_{Nu}=0.027(N_{Re})^{0.8}(Npr)^{0.3}(\frac{\mu}{\mu_s})^{0.14}=0.027(6875)^{0.8}(38.84)^{0.4}(\frac{0.0016}{0.0009})^{0.14}$

$N_{Nu}=102.67$

$N_{Nu}=\frac{h*d}{k}$

$h=566.78\ w/m^2.^0k$

Q5- calculate the mean coefficient of heat transfer beside water for a single bath steam condenser with 6cm inside diameter ,cooling water interring at 15℃ and leaving at 22℃ .mean velocity of water is 2 m/sec and mean surface temperature is 101℃ also calculate the heat transfer rate from one meter length of tube.

Solution

---------- :

$t_m=\frac{t_i+t_o}{2}=\frac{15+22}{2}=18.5℃\sim20℃$

from tables of water and at 20℃

$\nu=0.01006*10^{-4}\ m^2/sec=1.006*10^{-6}\ m^2/sec$

$N_{pr}=7.03$, $K=0.598\ w/m.^0k$

$(N_{Re})=\frac{u*d}{\nu}=\frac{2*0.06}{1.006*10^{-6}}=1.19*10^5$

$(N_{Re}) > 2300$, The flow is turbulent

$N_{Nu}=0.023(N_{Re})^{0.8}(N_{pr})^{0.4}=0.023(1.19*10^5)^{0.8}(7.03)^{0.4}=576.69$

$N_{Nu}=\frac{h*d}{k}$

$h=\frac{NNu*k}{d}=\frac{576.69*0.598}{0.06}=5747.76\ w/m^2.^0k$

$q = h * A * \Delta t = 5747.76 * \pi * 0.06 * 1 * (101-20) = 87756.33$ w

Q6- a cylinder with outside diameter of 5cm placing normally in a duct of air ,the mean temperatures of air and cylinder are 37.8°C ,148.8 °C respectively .calculate the heat transfer coefficient beside air if the mean velocity of air is 60.7 m/sec.

Solution

---------- :

$t_f = \frac{t_w + t_m}{2} = \frac{148.8+37.8}{2} = 93.3°C$

from tables of air and at 93.3°C

$\nu = 0.229 * 10^{-4}\ m^2/sec = 2.29 * 10^{-5}\ m^2/sec$

$N_{pr} = 0.71$, $K = 0.0302\ w/m.^0k$

$(N_{Re}) = \frac{u * d}{\nu} = \frac{60.7 * 0.05}{2.29 * 10^{-5}} = 1.325 * 10^5$

$(N_{Re}) > 2300$, **The flow is turbulent**

$N_{Nu} = 0.3(N_{Re})^{0.57} = 0.3(1.325 * 10^5)^{0.57} = 249.37$

$N_{Nu} = \frac{h * d}{k}$

$h = \frac{NNu * k}{d} = \frac{249.37 * 0.0302}{0.05} = 150.61\ w/m^2.^0k$

Q7- air at atmospheric pressure flowing through banks of tubes with outside diameter of 5 cm ,mean surface temperature of tube is 65.3 °C .air heating from 15.6 °C to 37.8°C .the air flowing at velocity of 5 m/sec through minimum cross-sectional area for free surface between tubes. Calculate the mean coefficient of heat transfer beside air also find the heat transfer rate if the summation of surface tube area is 0.692 m^2.

Solution

---------- :

$t_m = \frac{t_i + t_o}{2} = \frac{15.6+37.8}{2} = 26.7°C \sim 27°C$

from tables of air and at 27°C

$\nu = 0.154 * 10^{-4}\ m^2/sec$

$N_{pr} = 0.708$, $K = 0.0263\ w/m.^0k$

$$(N_{Re}) = \frac{u*d}{\nu} = \frac{5*0.05}{0.154*10^{-4}} = 1.623*10^4$$

$(N_{Re}) > 2300$, The flow is turbulent

$$N_{Nu} = 0.3(N_{Re})^{0.57} = 0.3(1.623*10^4)^{0.57} = 75.33$$

$$N_{Nu} = \frac{h*d}{k}$$

$$h = \frac{NNu*k}{d} = \frac{75.33*0.0263}{0.05} = 39.62\ w/m^2.^0k$$

$$q = h*A*\Delta t = 39.62 * 0.692*(65.3-27) = 1050.07\ w$$

Q8-calculate the mean coefficient of heat transfer beside water that heated during flow normally on banks of tubes with outside diameter of 5 cm ,assuming the mean velocity through minimum cross-sectional area for free spaces between tubes is 0.5 m/sec if the mean film temperature is 49 ℃.

Solution

---------- :

from tables of water and at 49℃

$\nu = 0.00567*10^{-4} = 5.67*10^{-7}\ m^2/sec$

$N_{pr} = 3.62$, $K = 0.645\ w/m.^0k$

$$(N_{Re}) = \frac{u*d}{\nu} = \frac{0.5*0.05}{0.567*10-7} = 4.4*10^5$$

$$N_{Nu} = 0.33(N_{Re})^{0.6}(N_{pr})^{0.3} = 0.33(4.4*10^5)^{0.6}(3.62)^{0.3} = 1180.85$$

$$N_{Nu} = \frac{h*d}{k}$$

$$h = \frac{NNu*k}{d} = \frac{1180.85*0.645}{0.05} = 15232.96 w/m^2.^0k$$

Q9-water flowing on banks of tubes with outside diameter of 10 cm at flow rate of 2.42 kg/sec. the mean interring and leaving water temperatures are 17°C and 69°C respectively.the mean surface tube temperature is 86°C .the minimum cross-sectional area for free spaces between tubes is 0.186 m^2. Calculate the convection heat transfer coefficient.

Solution

---------- :

$$t_m=\frac{t_i+t_o}{2}=\frac{17+69}{2}=43°C$$

$$t_f=\frac{t_w+t_m}{2}=\frac{86+43}{2}=64.5°C$$

from tables of water and at 64.5°C

$\nu=0.00453*10^{-4}\ m^2/sec$, $\rho=980.5\ kg/m^3$

$N_{pr}=2.83$, $K=0.655\ w/m.^0k$

$\dot{m}=\rho*u*A$

$$u=\frac{\dot{m}}{\rho*A}=\frac{2.42}{980.5*0.186}=0.013\ m/sec$$

$$(N_{Re})=\frac{u*d}{\nu}=\frac{0.013*0.1}{0.00453*10^{-4}}=2.92*10^3$$

$$N_{Nu}=0.33(N_{Re})^{0.6}(N_{pr})^{0.33}=0.33(2.92*10^3)^{0.6}(2.83)^{0.33}=55.82$$

$$N_{Nu}=\frac{h*d}{k}$$

$$h=\frac{NNu*k}{d}=\frac{55.82*0.655}{0.1}=365.621\ w/m^2.^0k$$

HEAT TRANSFER

Problems for combined effect of Conduction & Convection(chapter five)

==========

Q1- Asteel plane wall with 1.25cm thick and km=43.32 w/m.°k where two fluids flowing on both sides with two coefficient of heat transfer are 5676,2838 w/m^2.°k .calculate the heat transfer rate between two fluids through 1.86m^2 from wall surface if the mean temperatures difference is 93°C.

Solution

---------- :

$$U = \frac{1}{\frac{1}{h_i}+\frac{\Delta x}{k_w}+\frac{1}{h_o}}$$

$$U = \frac{1}{\frac{1}{5676}+\frac{0.0125}{43.32}+\frac{1}{2838}} = 1223.97 \text{ w/m}^2.^0\text{k}$$

$$q = U*A*\Delta t = 1223.97*1.86*93 = 211702 \text{ w} = 211.702 \text{ Kw}$$

Q2- calculate the overall heat transfer coefficient based on outside surface of condenser tubes with mean thermal conductivity of 104 w/m.^{0}k if the outside and inside diameters are (2.5cm),(2.3cm) respectively .assuming the heat transfer coefficient beside steam is 5676 w/m^2.^{0}k and beside water is 4541 w/m^2.^{0}k

Solution

---------- :

Do=2.5cm ,ro=1.25cm=0.0125m

Di=2.3cm ,ri=1.15cm=0.0115m

$$U_O = \frac{1}{\frac{r_o}{r_i h_i}+\frac{r_0 ln\frac{r_o}{r_i}}{k_w}+\frac{1}{h_o}} =$$

$$U_O = \frac{1}{\frac{0.0125}{0.0115*4541}+\frac{0.0125 ln\frac{0.0125}{0.0115}}{104}+\frac{1}{5676}} = 2349.8 \text{ w/m}^2.^0\text{k}$$

Q3- calculate the overall heat transfer coefficient based on inside tube surface with mean thermal conductivity of 109 w/m.^{0}k if the outside diameter is (6cm) and inside diameter is(5cm) .assuming the steam

condensed on outside tube surface and the coefficient heat transfer beside steam is 5108 $w/m^2.^0k$ and inside tube is 5368 $w/m^2.^0k$.Draw the heat distribution.

Solution
---------- :

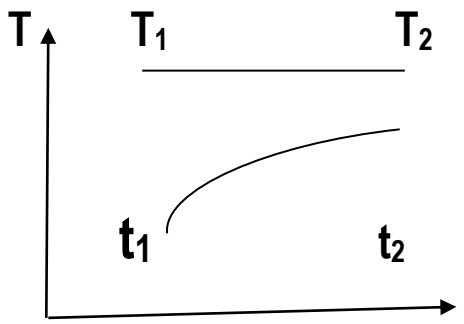
Do=6cm , ro=3cm=0.03m

Di=5cm , ri=2.5cm=0.025m

$$U_i = \frac{1}{\frac{1}{h_i} + \frac{r_i \ln\frac{r_o}{r_i}}{k_w} + \frac{r_i}{r_o h_o}} =$$

$$U_i = \frac{1}{\frac{1}{5368} + \frac{0.025 \ln\frac{0.03}{0.025}}{109} + \frac{0.025}{0.03*5108}}$$

U_i =2556.12 $w/m^2.^0k$



H.D for condenser

Q4- calculate the overall heat transfer coefficient based on inside area of glass tube with mean thermal conductivity of 0.866 $w/m.^0k$ if the inside and outside diameters are (7.5cm),(9cm) respectively .and the inside and outside heat transfer coefficients are 5676,2838 $w/m^2.^0k$ respectively.

Solution
---------- :

Do=9cm ,ro=4.5cm=0.045m

Di=7.5cm ,ri=3.75cm=0.0375m

$$U_i = \frac{1}{\frac{1}{h_i} + \frac{r_i \ln\frac{r_o}{r_i}}{k_w} + \frac{r_i}{r_o h_o}}$$

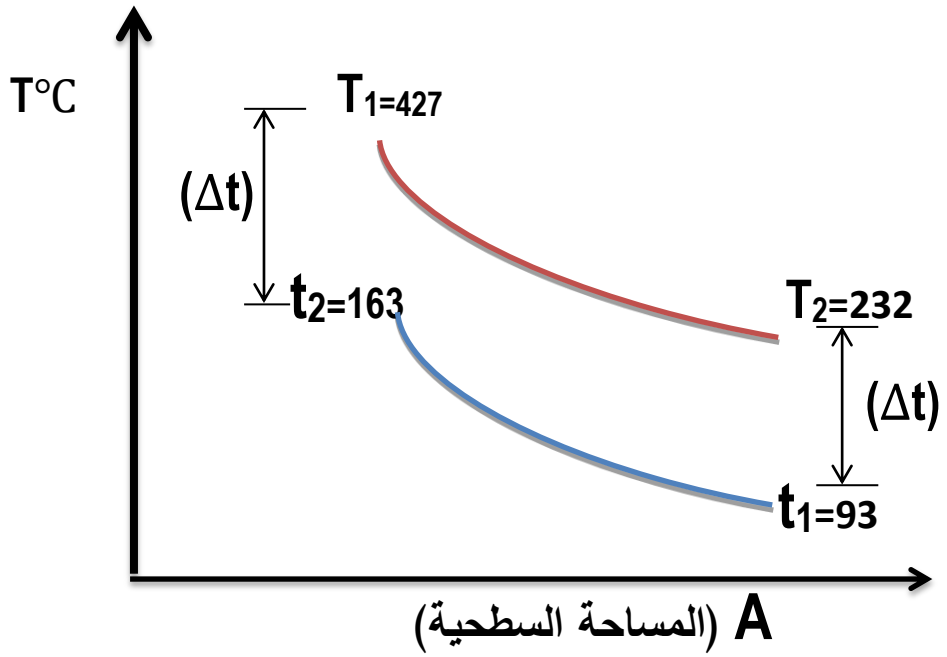
$$U_i = \frac{1}{\frac{1}{2838} + \frac{0.037 \ln\frac{0.045}{0.037}}{0.866} + \frac{0.037}{0.045*5676}}$$

U_i =120.67 $w/m^2.^0k$

Q5- water with flow rate of 136200 kg/hr heated in a counter-flow heat exchanger from 93°C to 163°C.the heated gases used in heating water inter the heat exchanger at 427°C and leaved at 232°C.calculate the overall heat transfer coefficient if the surface area equall to 2787m^2.

Solution

---------- :



$\dot{m}_w$= 136200 kg/hr $=\frac{136200}{3600}$= 37.83 kg/sec

c_w=4.19 kJ/kg.°k=4190 J/kg.°k الحرارة النوعية للماء

q received= q rejected =q exchanged

q received= q exchanged

$\dot{m}_w * c_w * \Delta t_w = U * A * (\Delta t)_{ln}$

$(\Delta t)_{max} = 427 - 163 = 264°C$

$(\Delta t)_{min} = 232 - 93 = 139°C$

$$(\Delta t)_{ln} = \frac{\Delta t_{max} - \Delta t_{min}}{ln\frac{\Delta t_{max}}{\Delta t_{min}}} = \frac{264-139}{ln\frac{264}{139}} = 194.86\ °C$$

$37.83 * 4190 * (163 - 93) = U * 2787 * 194.86$

$U = 20.43\ w/m^2.^0k$

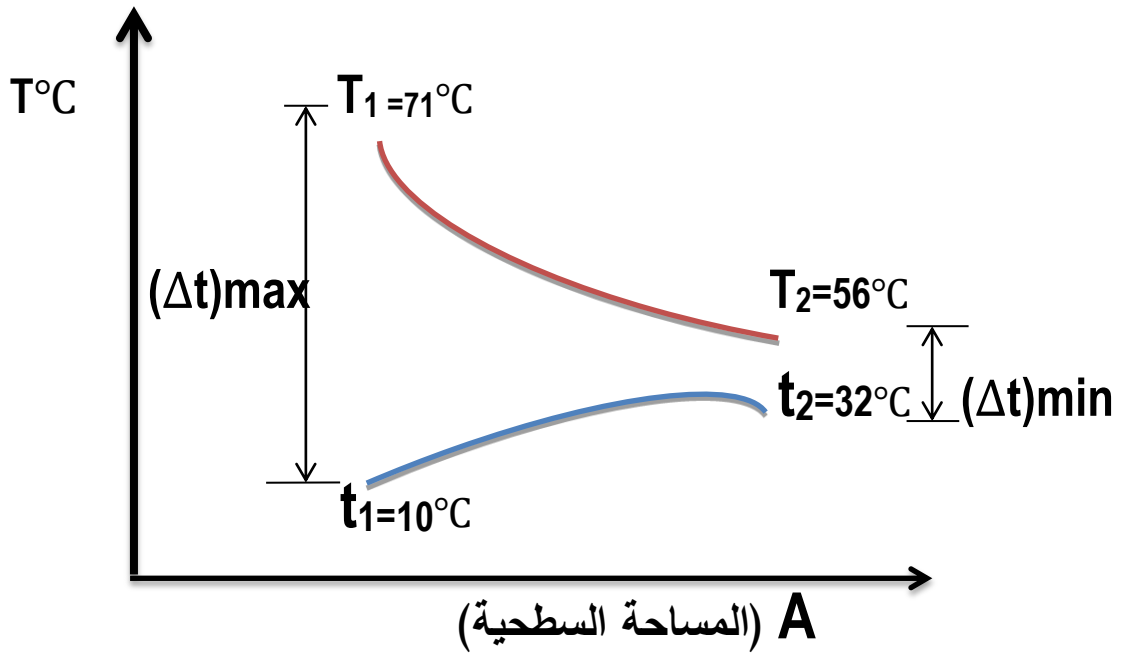
Q6-Air inter to heat exchanger at 71°Cand leave at 56°C,Another fluid inter at 10°C and leave at 32°C .calculate the log-mean temperature difference in case of

1- **Parallel-flow heat exchanger.**
2- **Counter-flow heat exchanger.**

Solution

---------- :

1-for parallel-flow heat exchanger للمتوازي

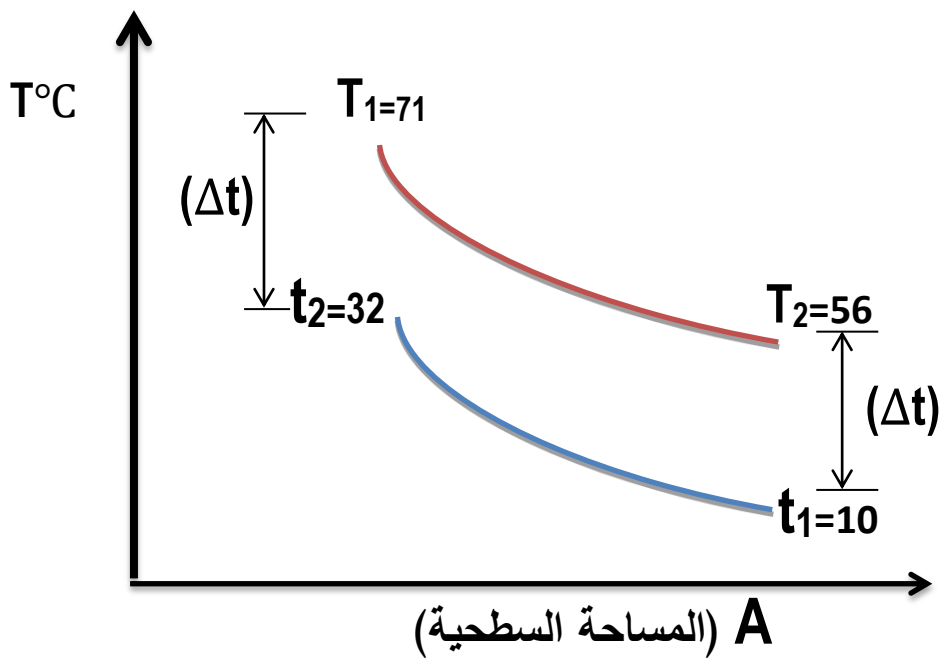


Δt_{max}=T_1-t_1=71−10=61°C

Δt_{min}=T_2-t_2=56−32=24°C

$(\Delta t)_{ln}=\frac{(\Delta t)max-(\Delta t)min}{ln\frac{(\Delta t)max}{(\Delta t)min}}=\frac{61-24}{ln\frac{61}{24}}$=(39.66)°C

2- for counter-flow heat exchanger للمتعاكس



$(\Delta t)min = T_1 - t_2 = 71 - 32 = 39^oc$

$(\Delta t)max = T_2 - t_1 = 56 - 10 = 46^0c$

$(\Delta t)_{ln} = \frac{(\Delta t)max - (\Delta t)min}{\ln\frac{(\Delta t)max}{(\Delta t)min}} = \frac{46-39}{\ln\frac{46}{39}} = (42.40)°C$

Counter flow heat exchanger is the more sufficient

المبادل المتعاكس هو الأكفأ لأنه يعطي متوسط لوغاريتمي اكبر

Q7-water with flowrate of 90800 kg/hr inter aparallel –flow heat exchanger and heated from 110°C to 175°C .the heated gases inter at 370°C and leave at 205°C.calculate the overall coefficient of heat transfer if the overall surface area is 1858m^2.

Solution

---------- :

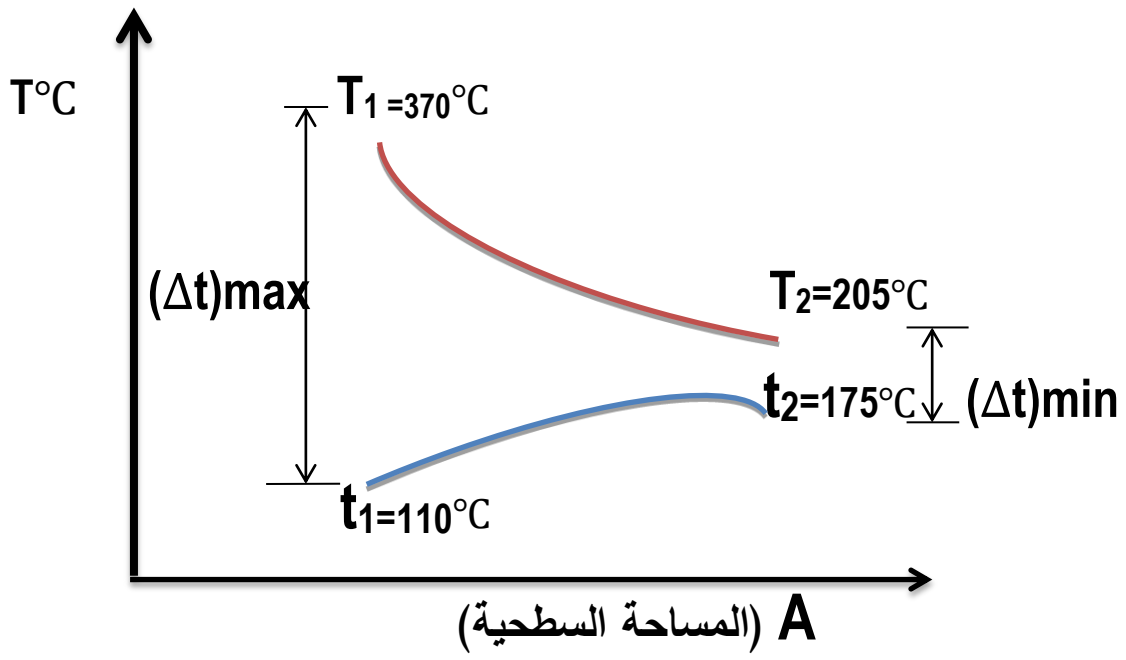
$\dot{m}_w = 90800$ kg/hr $= \frac{90800}{3600} = 25.22$ kg/sec

$q_{received} = q_{rejected} = q_{exchanged}$

$q_{received} = q_{exchanged}$

$\dot{m}_{w*}\ c_{w*}\ \Delta t_w = U*A*(\Delta t)_{ln}$

for parallel-flow heat exchanger للمتوازي



$(\Delta t)_{max} = 370 - 110 = 260°C$

$(\Delta t)_{min} = 205 - 175 = 30°C$

$$(\Delta t)_{ln} = \frac{\Delta t_{max} - \Delta t_{min}}{ln\frac{\Delta t_{max}}{\Delta t_{min}}} = \frac{260-30}{ln\frac{260}{30}} = 106.5\ °C$$

25.22*4190*(175-110)=U*1858*106.5

$U = 34.71\ w/m^2.^0k$

Q8-condenser with two paths of tubes consist of 32 copper tube with inside diameter of 0.3cm and outside diameter of 0.5cm ,the length of each pipe is 5m.steam at atmospheric pressure condensed on outside tube surface ,if 11800 kg/hr of water flowing in pipes inter at 7°C and leave at 79°C .calculate :-

1-the log-mean temperature difference

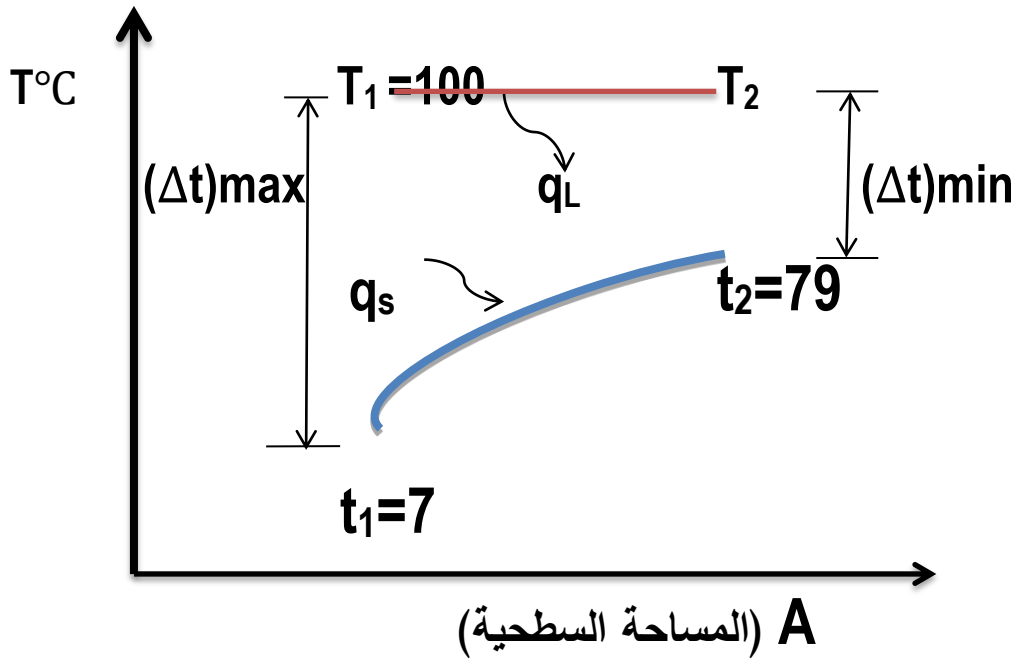
2-the overall heat transfer coefficient based on outside surface area of tubes

3-the coefficient of heat transfer beside water.

Solution

---------- :

A) At p=1atm , T=100°C



$$(\Delta t)_{ln}=\frac{\Delta t_{max}-\Delta t_{min}}{ln\frac{\Delta t_{max}}{\Delta t_{min}}}$$

$(\Delta t)_{max}$ =100−7 =93°C

$(\Delta t)_{min}$ =100−79=21°C

$$(\Delta t)_{ln}=\frac{\Delta t_{max}-\Delta t_{min}}{ln\frac{\Delta t_{max}}{\Delta t_{min}}}=\frac{93-21}{ln\frac{93}{21}}=48.38\ °C$$

q received= q rejected =q exchanged

q exchanged = q received

$U*A*(\Delta t)_{ln}= \dot{m}_w * c_w * \Delta t_w$

$$U_O=\frac{1}{\frac{r_o}{r_i h_i}+\frac{r_o ln\frac{r_o}{r_i}}{k_w}+\frac{1}{h_o}}$$

$\dot{m}_w$= 11800 kg/hr $=\frac{11800}{3600}$= 3.27kg/sec

C_C=4190 J/kg.°k

Δt_C=79-7=72°C

$U_o*(2*\pi*D_o*L)*32*48.38 =3.27*4190*72$

U_0=4056.21 w/m^2.^{0}k

To find h_i لحساب

$$t_m=\frac{t_i+t_o}{2}=\frac{7+79}{2}=43°C$$

from tables of water and at 43°C

ν =0.00604*10^{-4} m^2/sec , ρ=991 kg/m^3

N_{pr}=3.94 , K=0.634 w/m.^{0}k

$\dot{m}=\rho*u*A$

$$u=\frac{\dot{m}}{\rho*A}=\frac{3.27}{980.5*0.186}=466.81 \text{ m/sec}$$

$$(N_{Re})=\frac{u*d}{\nu}=\frac{466.81*0.003}{0.00604*10^{-4}}=231.86*10^4$$

$$N_{Nu}=0.023(N_{Re})^{0.8}(N_{pr})^{0.4}=4921.60$$

$$N_{Nu}=\frac{h*d}{k}$$

$$h_i=\frac{NNu*k}{d}=\frac{4921.6*0.634}{0.003}=1040*10^3 \text{ w/m}^2.^ok$$

Q9- saturated vapor at pressure of 7bar flowing in a steel pipe of outside diameter of 20cm and inside diameter of 18cm covered with 5cm thick of insulation with mean thermal conductivity of 0.07 w/m.^{0}k .assuming the coefficients of heat transfer beside steam and air are 5676,284 w/m^2.^{0}k .calculate the overall heat transfer coefficient and the heat transfer loss from 16m length of tube,the mean thermal conductivity of tube material is 42 w/m.^{0}k air temperature is 27°C (saturated steam temperature at 7bar is 165°C .

Solution

---------- :

$$U_O=\frac{1}{\frac{r_3}{r_1h_i}+\frac{r_3 ln\frac{r_2}{r_1}}{k_1}+\frac{r_3 ln\frac{r_3}{r_2}}{k_2}+\frac{1}{h_o}}$$

D_1=18cm , r_1=9cm=0.09m

D_2=20cm , r_2=10cm=0.1m

r_3=15cm=0.15m

$$U_O=\frac{1}{\frac{0.15}{0.09*5676}+\frac{0.15ln\frac{0.1}{0.09}}{42}+\frac{0.15ln\frac{0.15}{0.1}}{0.07}+\frac{1}{284}}=1.146\ w/m^2.^0k$$

$q=U_o*A_0*\Delta t=1.146*2*0.15*\pi*16*(165-27)=2386.01$ w

Q10-heat exchanger used to heat 6800 kg/hr of water from 21°C to 93°C .water passes through 90 copper tube with outside diameter of 1cm and 1mm wall thickness.saturated vapor at 100°C condensed on outside tubes surface and used for heating ,the latent heat for condensing vapor is 2256.7 kJ/kg.^{0}k.the tubes used of 7m long and the thermal conductivity is 109 w/m.^{0}k ,assuming the coefficient of heat transfer inside tubes is 4150 w/m^2.^{0}k .calculate the outside coefficient of heat transfer and the mass of vapor per second.

Solution

---------- :

D_0=1cm=0.01m r_o=0.005m

Δr=1mm=0.001m

r_i =0.004m

T_i=100 h_{fg}=2256.7 kJ/kg

K_w=109 , h_i=4150

h_o ? $\dot{m}_{vapor}$?

$q_{vapor}=q_{water}$

$\dot{m}_h*h_{fg}=\dot{m}_c*c_c*(\Delta t)_c$

$\dot{m}_h*2256.7*10^3=1.88*4.19*10^3*(93-21)$

$\dot{m}_h$=0.252 kg/sec

$q_{rec}=q_{exch}$

$U_O*A_O*(\Delta t)_{ln}=\dot{m}_c*c_c*(\Delta t)_c$

$$U_O*90*2*ro*\pi*7*\frac{(100-21)-(100-93)}{ln\frac{79}{7}}=\frac{6800}{3600}*4190*72$$

U_o=807.83 w/m^2.^{0}k

$$Uo=\frac{1}{\frac{0.005}{0.004*4150}+\frac{0.005*ln\frac{0.005}{0.004}}{109}+\frac{1}{h_0}}$$

h_o=1079.39 w/m^2.^{0}k

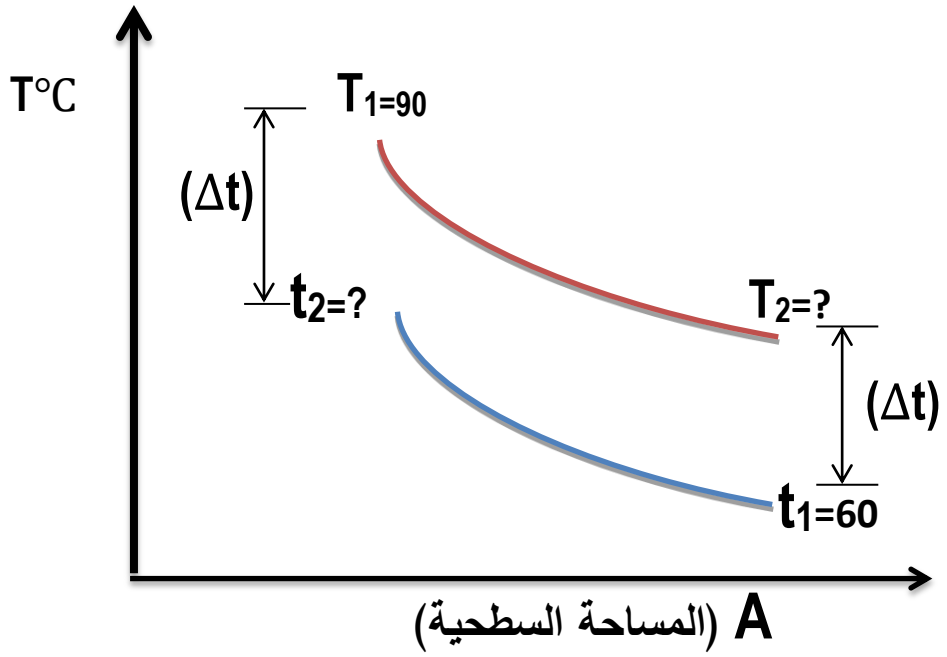
Q11- counter flow-heat exchanger used to cool oil designed on overall coefficient of heat transfer of 256 $w/m^2.^0k$,the surface area of tubes is $1.1m^2$.the flowrate of water is 850 kg/hr and the intering temperature of water is 60°C ,the heat exchanger used for cooling 370kg/hr of oil which inter at 90°C ,the specific heat of oil is 2.1 $kJ/kg.^0$ k. what are the temperatures of oil and water.

Solution

---------- :

T_2 ? t_2?

for counter-flow heat exchanger للمتعاكس



$\dot{m}_h * c_h = \frac{370}{3600} * 2.1 * 10^3 = 215.83 = C_{min}$

$\dot{m}_c * c_c = \frac{850}{3600} * 4.19 * 10^3 = 989.30 = C_{max}$

$\frac{C_{min}}{C_{max}} = \frac{215.83}{989.30} = 0.218$

$\frac{U*A}{C_{min}} = \frac{256*1.1}{215.83} = 1.30$

$\in = 0.7$

$\in = \frac{T_1 - T_2}{T_1 - t_1}$

$0.7 = \frac{90 - T_2}{90 - 60}$

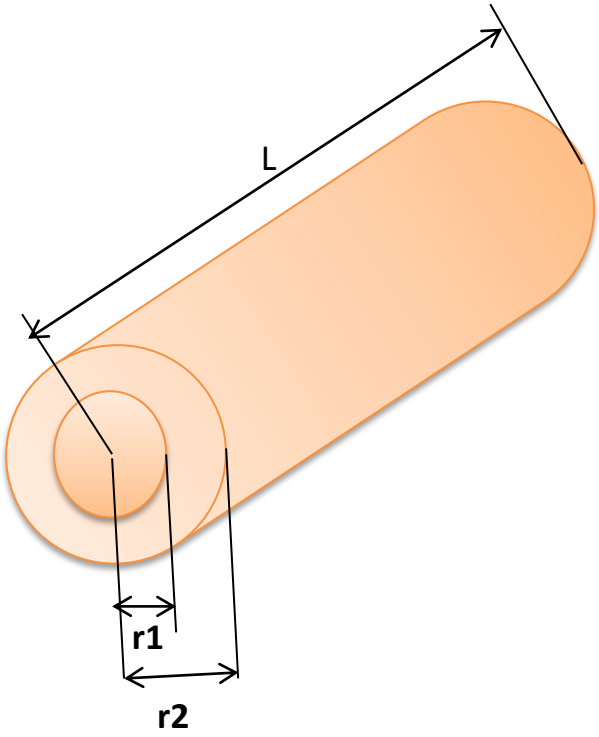
$T_2 = 69$°C

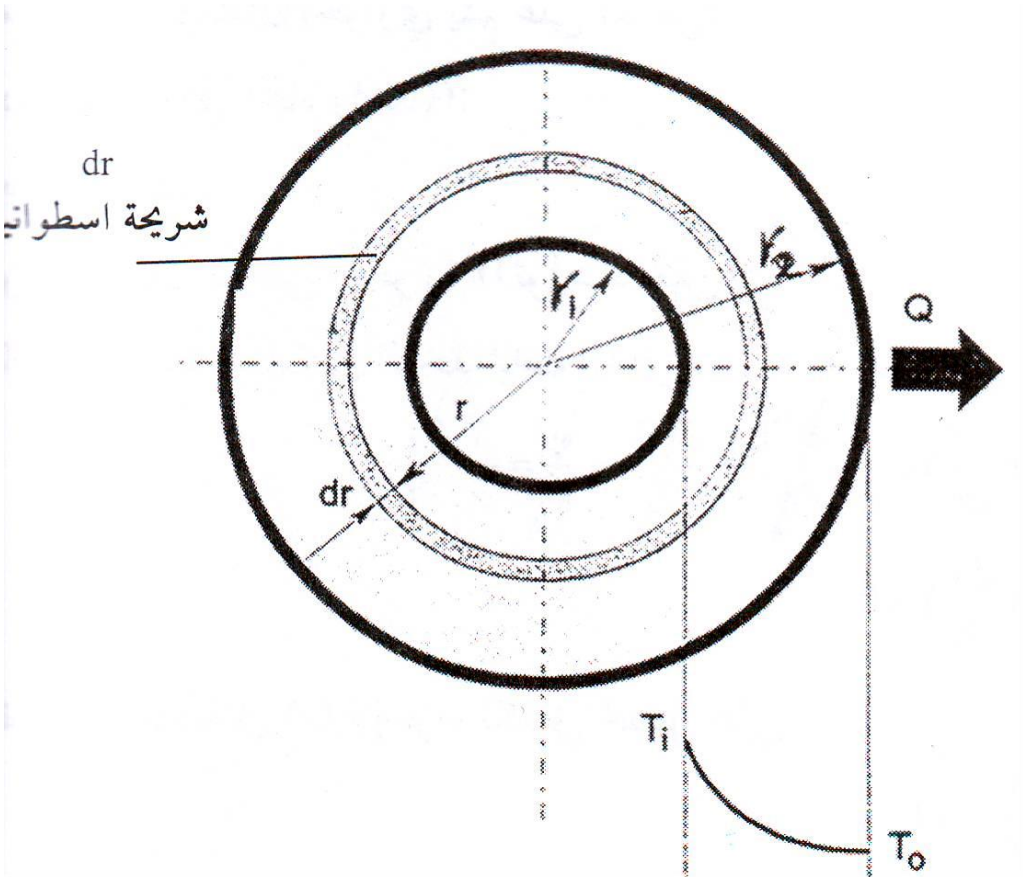
$\dot{m}_h * c_h * (\Delta t)_h = \dot{m}_c * c_c * (\Delta t)_c$

$215.83 * (90 - 60) = 989.30 * (t_2 - 60)$, $t_2 = 64.5$°C

CONDUCTION HEAT TRANSFER THROUGH a homogenous ACYLINDRICAL WALL

التوصيل الحراري خلال جدار اسطواني متجانس





$q = -K * A * \frac{dt}{dr}$

$A = 2 * r * \pi * L =$ المساحة السطحية للجدار الاسطواني

$q = -K * 2 * r * \pi * L * \frac{dt}{dr}$

By dividing on L

$\frac{q}{L} = q' = -K \times 2 \times r \times \pi \times \frac{dt}{dr}$

Where q' =heat loss per unit length= التوصيل الحراري لوحدة الطول

$\int q' \times \frac{dr}{r} = -K \times 2 \times r \times \pi \times \int dt$ بالقسمة على r

Assuming steady state where q=c بافتراض حالة مستقرة

$q' [lnr] + C = -K \times 2 \times \pi \times [t]$

$q' [lnr2] + C = -K \times 2 \times \pi \times t2$ ---------- 1

$q' [lnr1] + C = -K \times 2 \times \pi \times t1$ ----------2

بالطرح

$q'[lnr2 - lnr1] = 2 \times \pi \times K \times (t_1 - t_2)$

$q' \times ln\frac{r2}{r1} = 2 \times \pi \times K \times (t_1 - t_2)$

$q = q' \times L$

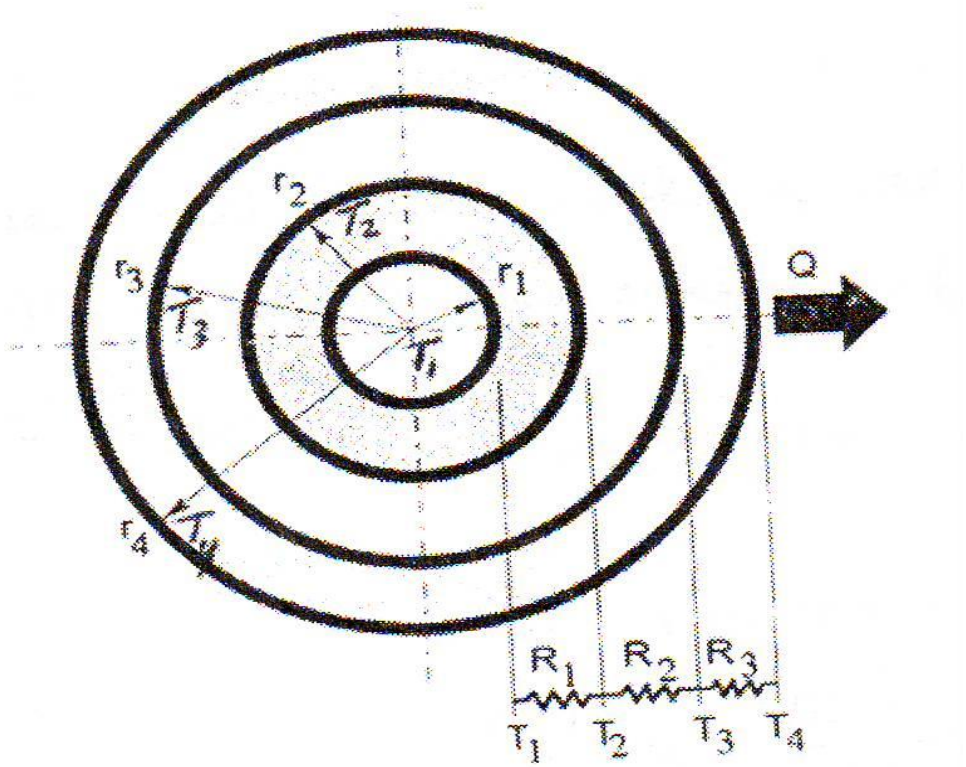
$q = \frac{(t1 - t2)}{\frac{\ln\frac{r2}{r1}}{2 * \pi * k * L}} = \frac{\Delta T}{R}$ قانون التوصيل الحراري خلال جدار اسطواني متجانس

$R = \frac{\ln\frac{r2}{r1}}{2 * \pi * k * L}$ الممانعة الحرارية لجدار اسطواني

heat resistance for cylindrical wall in $\frac{^\circ k}{w}$ = الممانعة الحرارية للجدار

CONDUCTION THROUGH ACOMPOSITE CYLINDRICAL WALL

التوصيل الحراري خلال جدار اسطواني مركب



$$q_1=\frac{2*\pi*K1*(t1-t2)}{ln\frac{r2}{r1}} \qquad (t_1-t_2)=\frac{q_1*2*\pi*K1*L}{ln\frac{r2}{r1}} \qquad \text{---------- (1)}$$

$$q_2=\frac{2*\pi*K2*(t2-t3)}{ln\frac{r3}{r2}} \qquad (t_2-t_3)=\frac{q_2*2*\pi*K2*L}{ln\frac{r3}{r2}} \qquad \text{---------- (2)}$$

$$q_3=\frac{2*\pi*K3*(t3-t4)}{ln\frac{r4}{r3}} \qquad (t_3-t_4)=\frac{q_3*2*\pi*K3*L}{ln\frac{r4}{r3}} \qquad \text{---------- (3)}$$

By adding three equations and assuming steady- state

وبجمع المعادلات الثلاث وبفرض حالة مستقرة نحصل على:

$$(t_1-t_4)= q*\left\{\frac{ln\frac{r2}{r1}}{2\pi k_1 L}+\frac{ln\frac{r3}{r2}}{2\pi k_2 L}+\frac{ln\frac{r4}{r3}}{2\pi k_3 L}\right\}$$

$$q=\frac{(t_1-t_4)}{\frac{ln\frac{r2}{r1}}{2\pi k_1 L}+\frac{ln\frac{r3}{r2}}{2\pi k_2 L}+\frac{ln\frac{r4}{r3}}{2\pi k_3 L}}$$

قانون التوصيل الحراري خلال جدار اسطواني مركب

$$q=\frac{(t_1-t_4)}{R_1+R_2+R_3}=\frac{\sum \Delta T}{R_1+R_2+R_3}=\frac{\sum \Delta T}{\sum R}$$

EFFECT OF VARIABLE THERMAL CONDUCTIVITY

تاثير معامل التوصيل الحراري المتغير

$$K_m=k_0*\{1+\beta*t\}$$

$$K_m=k_0*\{1+\beta*\frac{t_1+t_2}{2}\}$$

k_0: معامل التوصيل الحراري عند الدرجة الحرارية الاولى

β :مقدار ثابت

Where k_m :mean thermal conductivity متوسط معامل التوصيل الحراري

$$q = K_m*A*\frac{\Delta T}{\Delta X}$$

$q''=\frac{q}{A}$ =heat loss per unit area in w/m^2 الفقد الحراري لوحدة المساحة

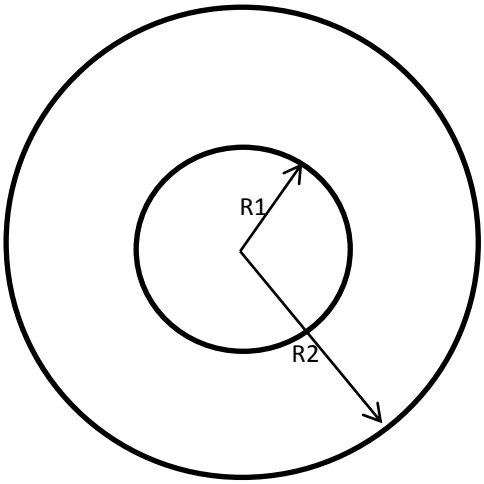
q= heat loss in W الفقد الحراري بوحدة

q'= heat loss per unit length in W/m الفقد الحراري لوحدة الطول بوحدة

$q''=\frac{q}{A}$ =heat loss per unit area in W/m^2 الفقد الحراري لوحدة المساحة بوحدة

Example(1):-calculate the heat loss from a tube of 9m long and 6cm outside diameter covered with 2.5cm thick of insulation with k=0.065 w/m.°k ,if the inside and outside temperatures of insulation are 195℃ ,27℃ respectively.

Solution:-



r1=3cm=0.03m

r2=3cm+2.5cm=5.5cm=0.055m

$$q=\frac{\Delta T}{R}=\frac{(t1-t2)}{\frac{\ln\frac{r2}{r1}}{2*\pi*k*L}}$$

$$q=\frac{(195-27)}{\frac{\ln\frac{0.055}{0.03}}{2*\pi*0.065*9}}=1019w.$$

HEAT EXCHANGERS المبادلات الحرارية

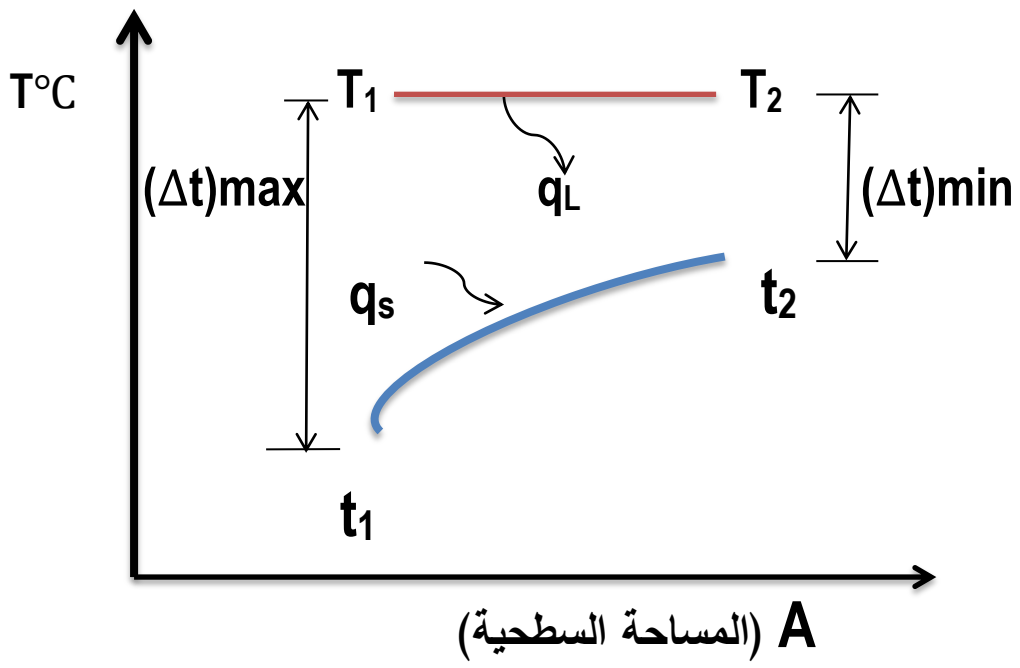
Heat exchanger:-it is a device جهاز هو contain two fluids يحتوي مائعين to the cold fluid الى المائع reject heat يفقد حرارة المائع الساخن the hot fluid, received heat from hot fluid يستقبل حرارة من والمائع البارد and the cold fluid البارد المائع الساخن .

Types of heat exchangers:-heat exchangers can be classified تصنف according:-

1- according to the work of heat exchanger بالاعتماد على وظيفة او عمل المبادل:-

A)condenser المكثف B)Boiler المرجل

A)condenserالمكثف



heat distribution for condenser

رسم التوزيع الحراري للمكثف

q_L:- Latent heat (حرارة كامنة)

q_S:-Sensible heat (حرارة محسوسة)

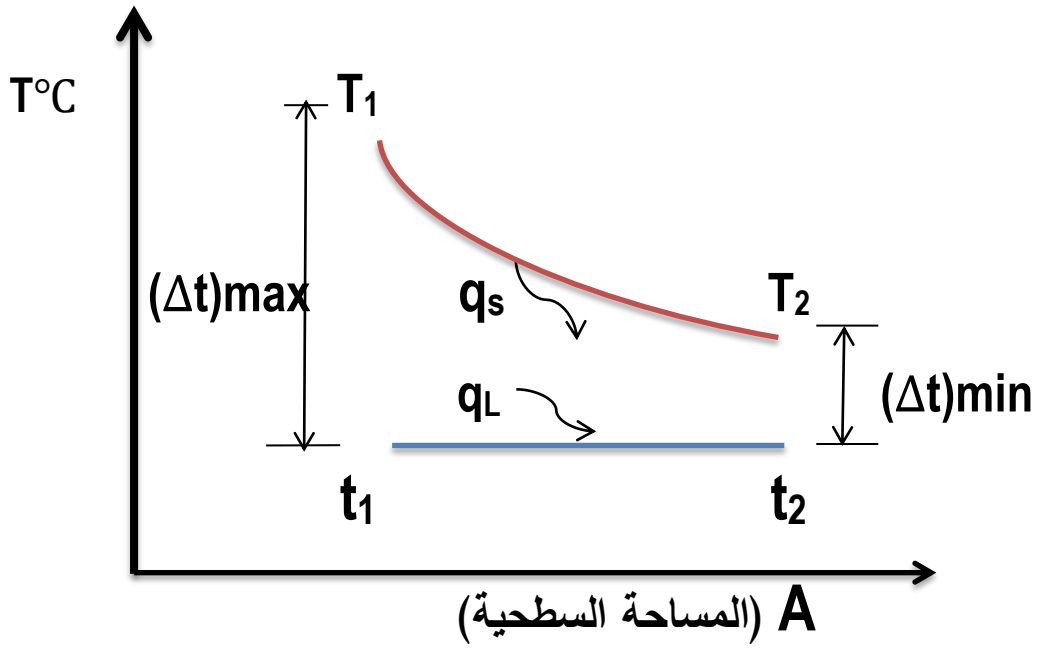
T_1:-inlet temperature of hot fluid درجة دخول المائع الساخن

T_2:-outlet temperate of hot fluid درجة خروج المائع الساخن

t_1: inlet temperature of cold fluid درجة دخول المائع البارد

t_2 : outlet temperature of cold fluid درجة خروج المائع البارد

B)Boiler المرجل

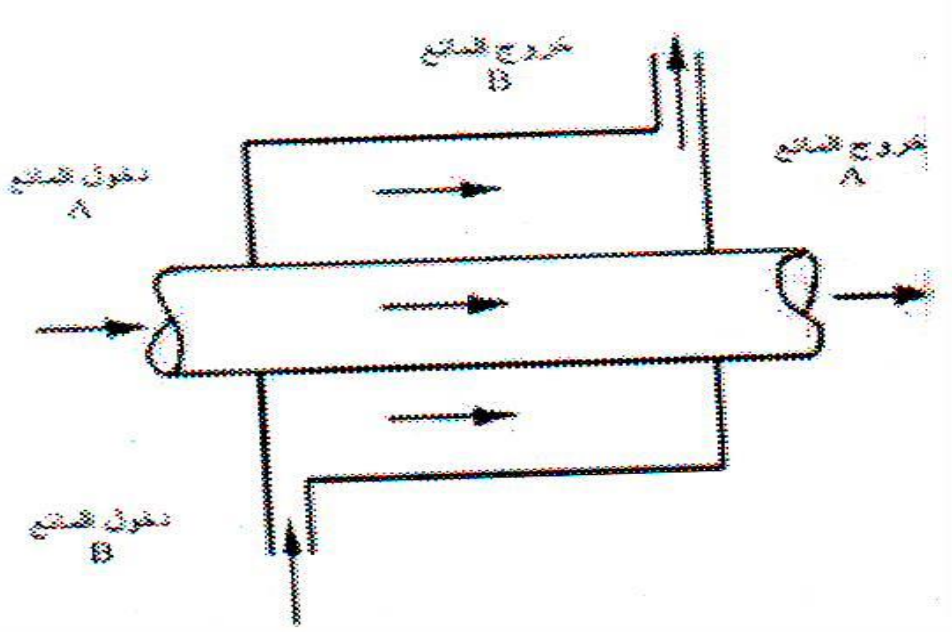


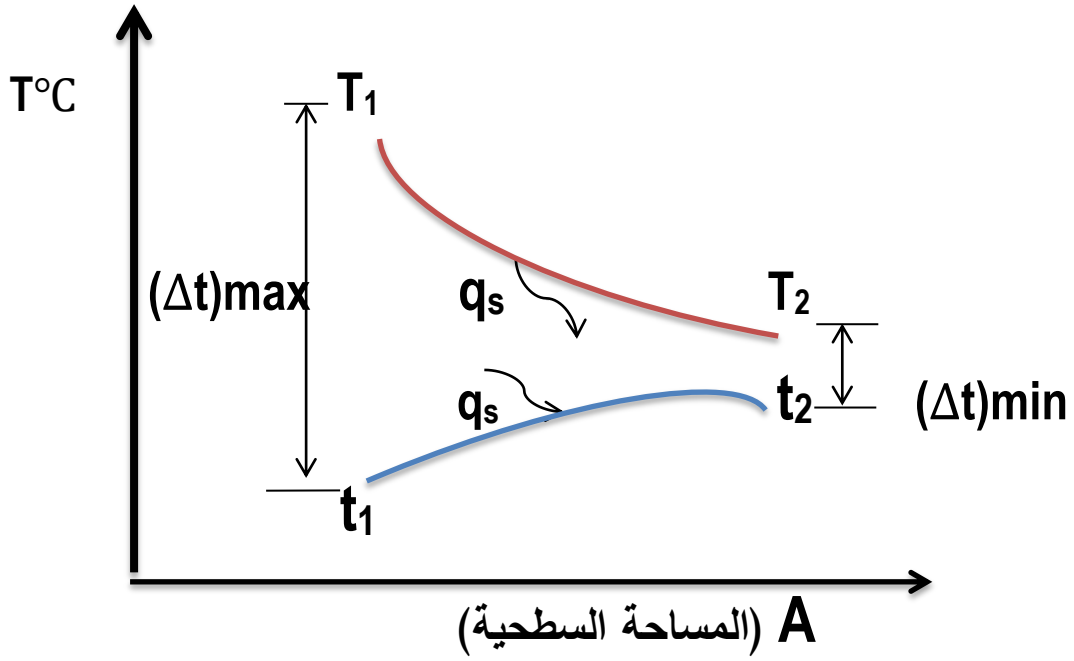
heat distribution for boiler

رسم التوزيع الحراري للمرجل

2-according to type of flow بالاعتماد على نوع الجريان

A)parallel flow heat exchangerالمبادل الحراري ذو الانسياب المتوازي

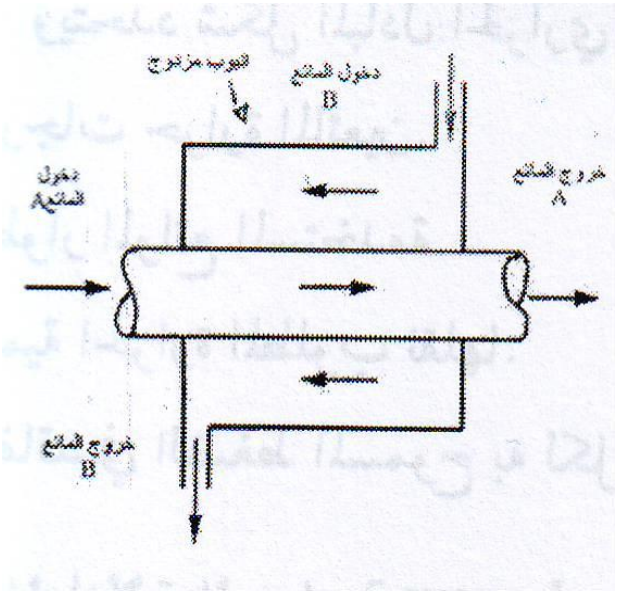


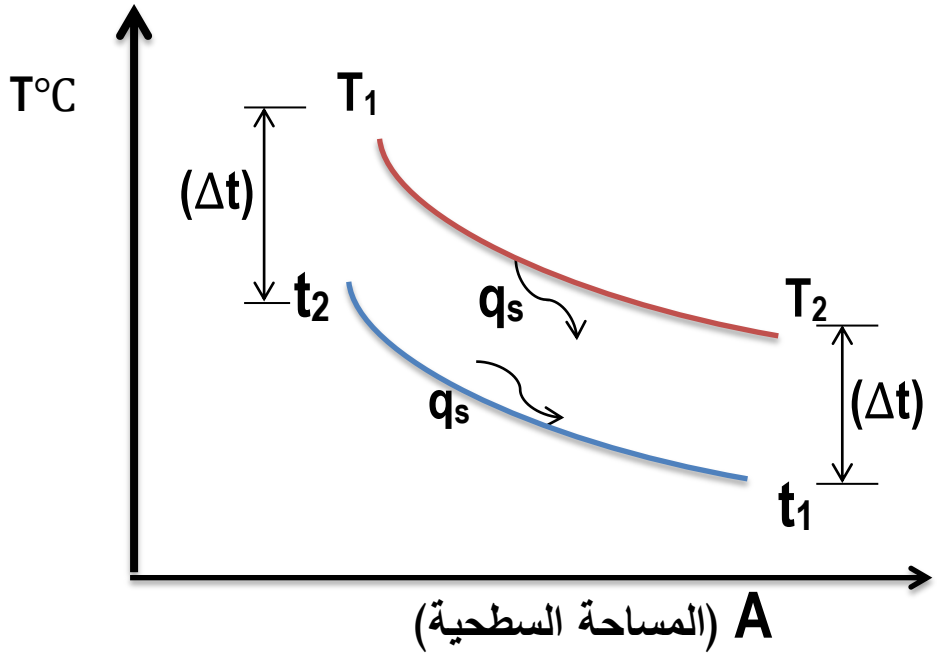


heat distribution for parallel flow

رسم التوزيع الحراري للمبادل المتوازي

B) counter flow heat exchanger المبادل الحراري ذو الانسياب المتعاكس

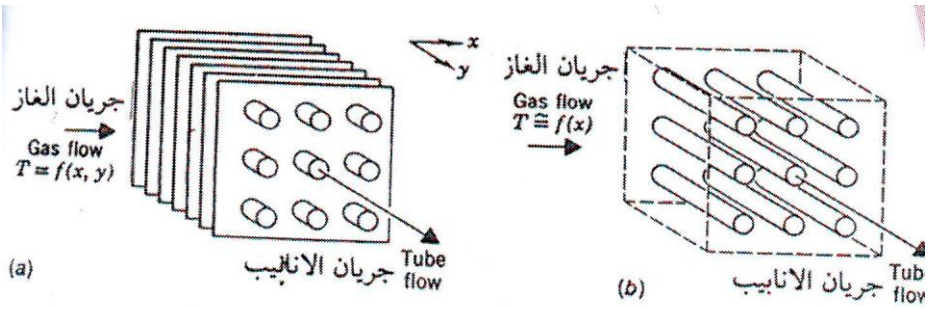




heat distribution for counter flow

رسم التوزيع الحراري للمبادل المتعاكس

المبادل الحراري ذو الانسياب المتعامد او المتقاطع C)-CROSS FLOW HEAT EXCHANGER

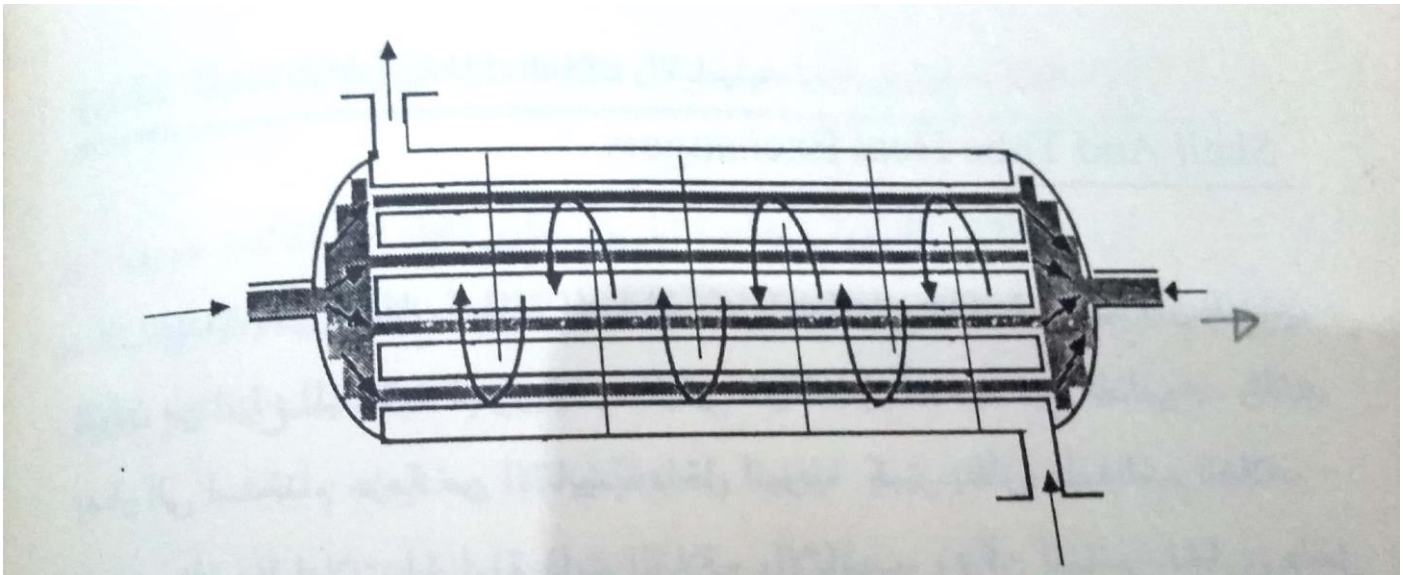


الشكل (8-3)

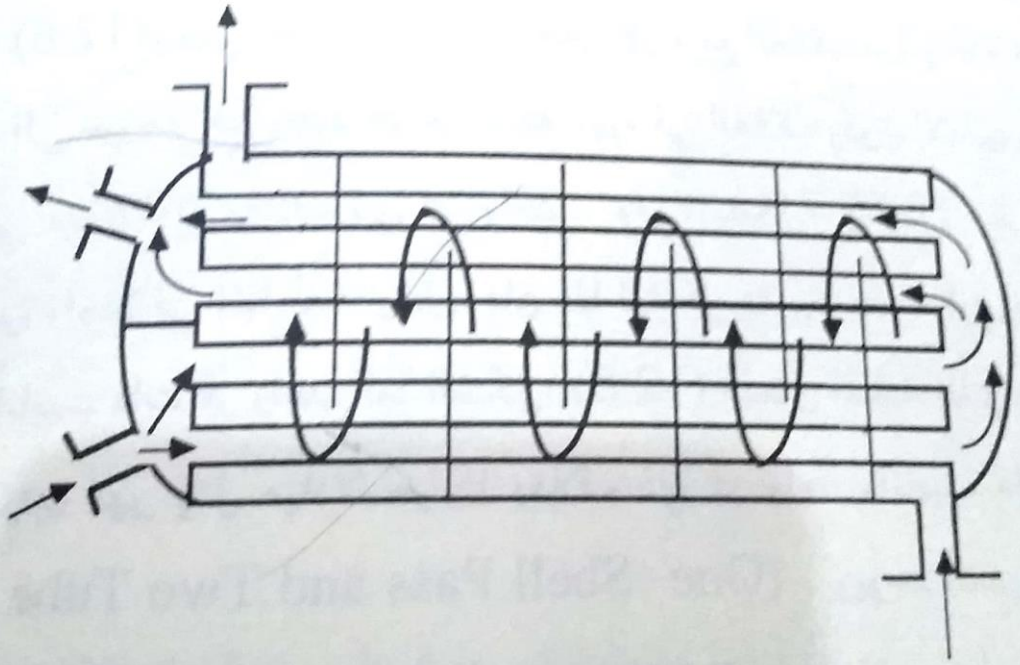
مبادلات حرارية متقاطعة الجريان (a) كلا المائعين غير مختلطين (b) مائع مختلط والاخر غير مختلط.

D) SHELL AND TUBE HEAT EXCHANGER

المبادل من نوع الاسطوانة والانبوب او الغلاف والانبوب



الشكل (12.5) مبادل حراري بغلاف ذي ممر واحد وانابيب ذات ممر واحد.



الشكل (12.6) مبادل حراري بغلاف ذي ممر واحد وانابيب ذات ممرين.

HEAT EXCHANGED BY RADIATION BETWEEN NON BLACK BODIES

التبادل الحراري بالاشعاع بين الاسطح الغير سوداء (الرمادية)

for non-black bodies configuration factor (F) will be :-

للاسطح الغير سوداء(الرمادية) وباستخدام حواجز الاشعاع يكون معامل الشكل

$$(F1\ R\ 2)gr = \frac{1}{\frac{1}{F1R2} + \left(\frac{1}{\epsilon 1} - 1\right) + \frac{A1}{A2}\left(\frac{1}{\in 2} - 1\right)}$$

$\in_1$:emissivity for first body معامل الانبعاث للسطح الاول

$\in_2$: emissivity for second bodyمعامل الانبعاث للسطح الثاني

$F_{1\ R\ 2}$: configuration factor for black body

$q_{1\to 2} = б * A_1 * (F_{1\ R\ 2})gr\ (T_1^4 - T_2^4)$

$q_{2\to 1} = б * A_2 * (F_{2\ R\ 1})gr\ (T_2^4 - T_1^4)$

$F_{1\ R\ 2}$: configuration factor for black body

معامل الشكل يؤخذ من جدول معامل الشكل وتحت حقل مستويات متصلة ببعضها عن طريق حوائط غير موصلة للحرارة

معامل الشكل للمربعات
والاقراص المتوازية والمتقابلة

نسبة الضلع او القطر الى المسافة بين المستويين	مستويات غير متصلة بحوائط		مستويات متصلة ببعضها عن طريق حوائط غير موصلة للحرارة ولكنها تشعها مرة أخرى .	
	مربعات	اقراص	مربعات	اقراص
0	0	0	0	0
0.2	0.018	0.010	0.200	0.186
0.4	0.045	0.038	0.325	0.309
0.6	0.091	0.075	0.415	0.394
0.8	0.142	0.125	0.480	0.461
1.0	0.194	0.175	0.534	0.512
1.2	0.242	0.226	0.575	0.552
1.4	0.288	0.269	0.610	0.590
1.6	0.332	0.308	0.641	0.620
1.8	0.372	0.345	0.669	0.646
2.0	0.408	0.380	0.692	0.669
2.2	0.440	0.411	0.712	0.689
2.4	0.469	0.440	0.730	0.708
2.6	0.495	0.467	0.746	0.724
2.8	0.519	0.492	0.760	0.739
3.0	0.542	0.515	0.772	0.753
3.2	0.562	0.536	0.782	0.766
3.4	0.581	0.556	0.791	0.778
3.6	0.599	0.575	0.799	0.788
3.8	0.616	0.593	0.807	0.797
4.0	0.632	0.609	0.814	0.804
4.2	0.647	0.624	0.821	0.813
4.4	0.661	0.638	0.827	0.820
4.6	0.673	0.651	0.833	0.826
4.8	0.684	0.662	0.839	0.831
5.0	0.693	0.672	0.844	0.836
5.2	0.701	0.681	0.849	0.841
5.4	0.709	0.689	0.853	0.845
5.5	0.716	0.697	0.857	0.849
5.6	0.722	0.703	0.861	0.852
5.8	0.729	0.709	0.864	0.855
6.0	0.736	0.716	0.867	0.858
6.2	0.743	0.723	0.870	0.861
6.4	0.749	0.730	0.873	0.864
6.6	0.756	0.737	0.875	0.867
6.8	0.763	0.743	0.878	0.870
7.0	0.770	0.750	0.881	0.873

(5) - جدول يبين معامل الشكل للمربعات والاقراص المتوازية والمتقابلة

والمتقابلـــــه

EXAMPLE(1):- calculate the radial energy exchanged احسب الطاقة الاشعاعية المتبادلة between two bodies بين جسمين contact with reradiating bodies متصلين بحوائط, the dimension of each body is (2m×2m) at adistance of (2m).assume the temperature of first body is (610℃)and of second body is (320℃).the emissivity facto of hot body معامل الانبعاث للجسم الساخن is (0.8) and for cold body وللجسم البارد is(0.6).

Solution:-

$S=2m \quad , \quad L=2m \qquad \frac{S}{L}=\frac{2}{2}=1$

$F_{1R2}=0.534$

$T_1=610+273=883°k$

$T_2=320+273=593°k$

$\in_1=0.8 \quad , \quad \in_2=0.6$

$$(F_{1R2})_{gr}=\frac{1}{\frac{1}{F1R2}+\left(\frac{1}{\epsilon 1}-1\right)+\frac{A1}{A2}\left(\frac{1}{\in 2}-1\right)}=\frac{1}{\frac{1}{0.534}+\left(\frac{1}{0.8}-1\right)+\frac{4}{4}\left(\frac{1}{0.6}-1\right)}$$

$(F_{1R2})_{gr}=(0.359)$

$q_{1\to 2}=б*A_1*(F1\ R\ 2)gr\ (T_1^4-T_2^4)$

$=5.67\times 4\times(0.359)\times\{(8.83)^4-(5.93)^4\}=(39428.86)w.$

HEAT TRANSFER BY FORCED CONVECTION IN EXTERNAL FLOW انتقال الحرارة بحمل جبري وجريان خارجي

THE HEATING OF FLUIDS FLOWING NORMALY TO ASINGLE PIPE

تسخين الموائع المنسابة عموديا على سلك مفرد

FOR GASES للغازات

$$N_{nu}=0.3(N_{Re})^{0.57}$$

معادلة الغازات

All properties are taken at T_f

$$T_f=\frac{t_m+t_s}{2}$$

D is the external diameter of tube.

FOR LIQUIDS للسوائل

$$N_{nu}=0.6(N_{Re})^{0.5}(N_{Pr})^{0.31}$$

معادلة السوائل

All properties are taken at T_f

$$T_f=\frac{t_m+t_s}{2}$$

HEATING OF FUID FLOWING NORMAL TO TUBES BANK

تسخين الموائع المنسابة عموديا على حزمة انابيب

FOR GASES للغازات

$$N_{nu}=0.3(N_{Re})^{0.57}$$

معادلة الغازات

All properties are taken at T∞ for gas

FOR LIQUIDS للسوائل

$$N_{nu}=0.33(N_{Re})^{0.6}(N_{Pr})^{0.3}$$

معادلة السوائل

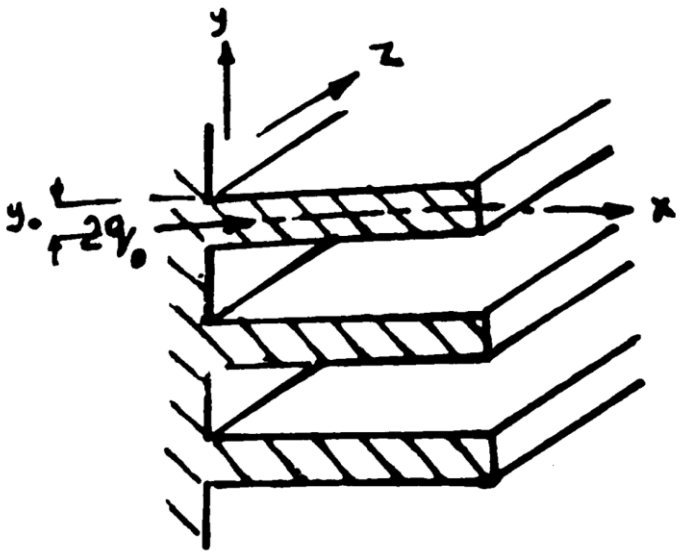
All properties are taken at T_f

HEAT TRANSFER THROUGH FINS

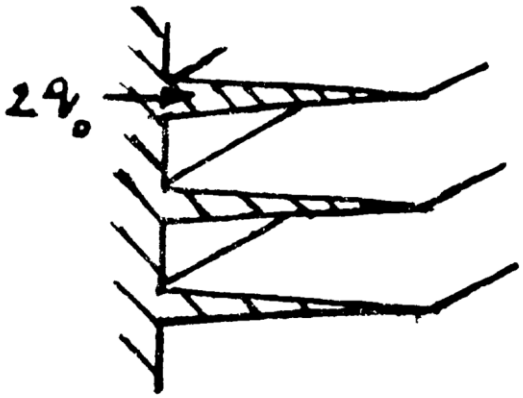
انتقال الحرارة خلال الزعانف

FINالزعنفة:- it is an extended surface هي سطح ممتد contactsيتصل with heated surface بالسطح الساخن,it is important to increaseلزيادة the heat transfer rate معدل انتقال الحرارة because وذلك لانها it increases the surface area for heat transfer تزيد المساحة السطحية لانتقال الحرارة.

****Heat transfer through fins by combined effect of conduction and convection**



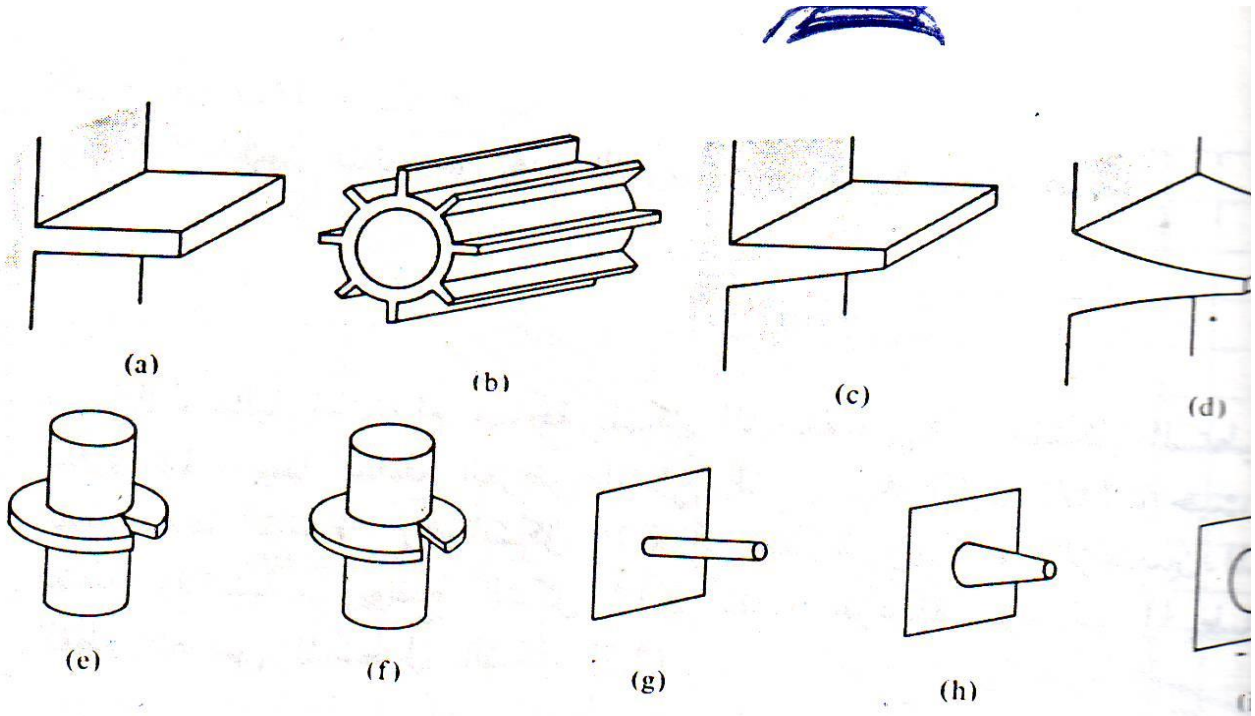
شكل (18) ـ سطح تسخين عليه زعانف ذات مقطع مستطيل



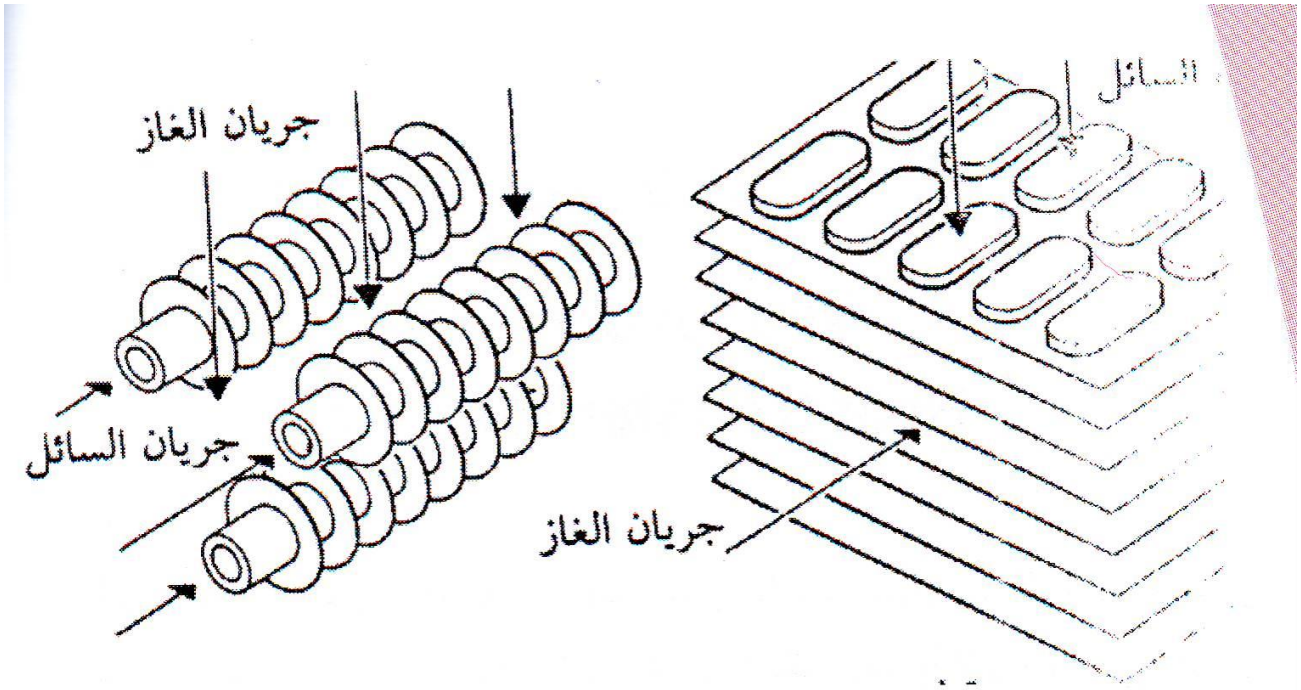
شكل (19) ـ سطح تسخين عليه زعانف ذات مقطع مثلثي الشكل

There are many types of fins:-

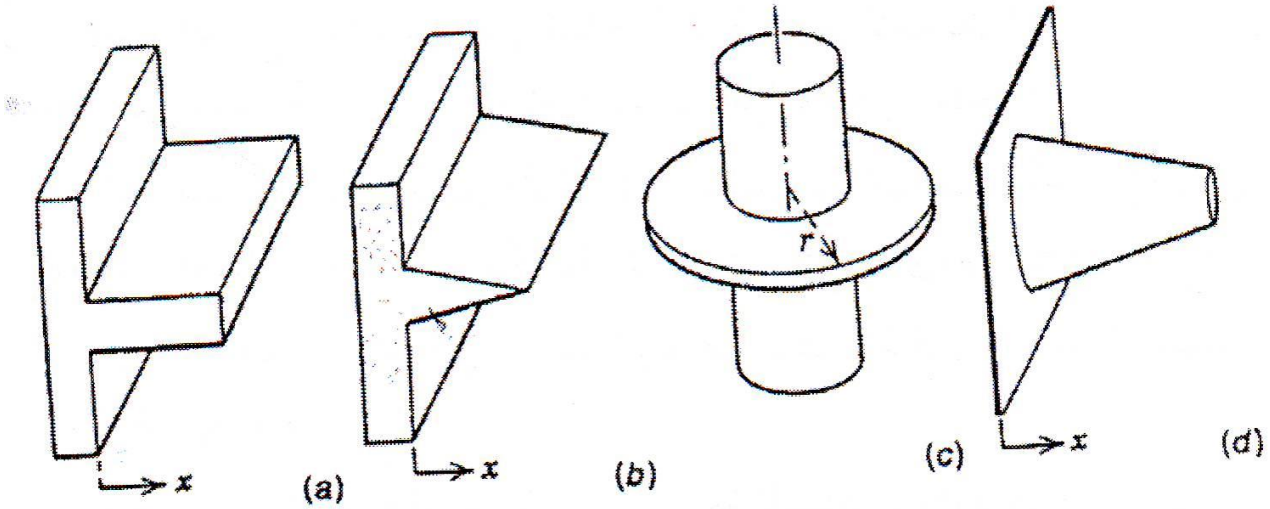
a-rectangular المستطيلة b-triangle المثلثية c-tubularالانبوبية d-pin الوتدية



2.15 اشكال تخطيطية لانواع مختلفة من الزعانف :
عنفة طولية ذات مقطع مستطيل ، (b) انبوب اسطواني بزعانف مستطيلة المقطع ، (c) زعنفة طولية
مقطع شبه منحرفي ، (d) زعنفة طولية ذات مقطع بهيئة قطع مكافيء ، (e) انبوب اسطواني بزعنفة
مستطيلة المقطع ، (p) انبوب اسطواني بزعنفة حلقية ذات مقطع هرمي مقطوع ، (g) زعنفة وتدية
انية ، (h) نتوء مخروطي مقطوع ، (i) نتوء بشكل قطع مكافيء .



الشكل (9-1) رسم تخطيطي لمبادلات حرارية ذات انابيب مزعنفة



شكل (9-2) انواع الزعانف

there are many variables effect on efficiency of fins :-

هناك عوامل تؤثر على كفاءة الزعنفة هي

1-shape of fin شكل الزعنفة

2-dimension of fin ابعاد الزعنفة

3-thermal conductivity of material of fin الموصلية الحرارية لمادة الزعنفة

4- temperature of fin درجة حرارة سطح الزعنفة

5-temperature of fluid contact درجة حرارة سطح المائع الملامس للزعنفة

6-convection heat transfer coefficient between fluid and fin معامل المواصلة السطحية بالحمل.

الفصل الثاني

التوصيل الحراري في الحالة المستقرة

التوصيل الحراري خلال جدار مستوي متجانس

التوصيل الحراري خلال جدار مستوي مركب

التوصيل الحراري خلال جدار اسطواني متجانس

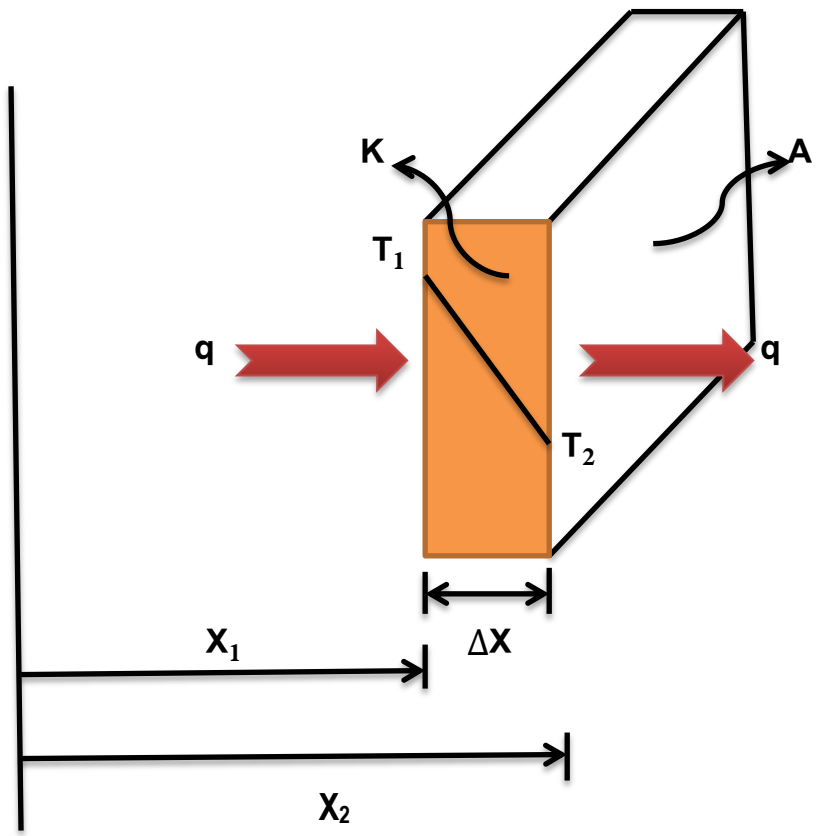
التوصيل الحراري خلال جدار اسطواني متجانس

Conduction heat transfer in steady – state التوصيل الحراري في الحالة المستقرة

Steady–state الحالة المستقرة:- it is the state at which the temperature and heat transfer remain constant with time هي الحالة التي تبقى عندها درجة الحرارة ومعدل انتقال الحرارة ثابتتين خلال زمن معين.

CONDUCTION THROUGH AHOMOGENOUS PLANE WALL:–

التوصيل الحراري خلال جدار مستوي متجانس



$$q = -k \times A \times \frac{dt}{dx}$$

$$dx \times q = -K \times A \times dT$$

$$\frac{dx \times q}{q} = \frac{-K \times A \times dT}{q}$$

by integration and assuming steady–state where q=constant we get:–

$$\int dx = \frac{-k \times A}{q} \int dt$$

$$[X] = \frac{-k \times A}{q} [T]$$

$$X_2 = \frac{-k \times A}{q} \times T_2 + C \quad \text{----------(1)}$$

$$X_1 = \frac{-k \times A}{q} \times T_1 + C \quad \text{----------(2)}$$

وبطرح المعادلتين وبفرض حالة مستقرة ---------- q=constant

$$(X_2 - X_1) = \frac{k \times A}{q} (T_1 - T_2)$$

$$\Delta X = \frac{k \times A}{q} \times \Delta T$$

$$q = K \times A \times \frac{\Delta T}{\Delta X}$$

$$q = K \times A \times \frac{\Delta T}{\Delta X}$$ ⇨ conduction heat transfer through plane wall

$$q = \frac{\Delta T}{\frac{\Delta X}{K.A}} = \frac{\Delta T}{R}$$

$R = HEAT\ RESISTANCE$ =الممانعة الحرارية

$q = \frac{\Delta T}{R}$ قانون فورير للتوصيل

$i = \frac{V}{R}$ قانون اوم

Fourier law is similar to ohm's law قانون فورير في انتقال الحرارة مشابه لقانون اوم.

HEAT RESISTANCE الممانعة الحرارية:- it is the ratio النسبة هي between بين the heat flow path (Δx) مسار الفيض الحراري to the product الى حاصل ضرب of the thermal conductivity (k) and area (A) الموصلية الحرارية للمادة والمساحة.

$$R = \frac{\Delta x}{K * A}$$ ⇨ $\frac{°k}{w}$

الممانعة الحرارية لجدار مستوي

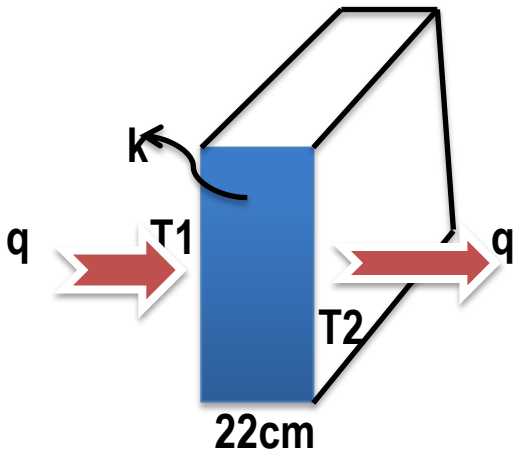
جدول يوضح الموصلية الحرارية لبعض المواد

الموصلية الحرارية بوحدة w/m.⁰k عند 27℃	المادة
399	النحاس
237	الالمنيوم
43	الفولاذ الكاربوني
0.81	الزجاج
0.2-0.3	البلاستك
0.6	الماء
0.26	اثيلين كلايكول
0.15	زيت المكائن
0.07	الفريون (سائل)
0.18	الهيدروجين
0.026	الهواء

EXAMPLE(1):-a wall of furnace of 22cm thickness with thermal conductivity k=0.312 w/m.°k .calculate the heat loss from 1m² if the outside and inside temperatures of wall are 205℃ ,816℃ respectively.

Solution

----------:



ΔX=22cm=0.22m

T2=205℃ ,T1=816℃

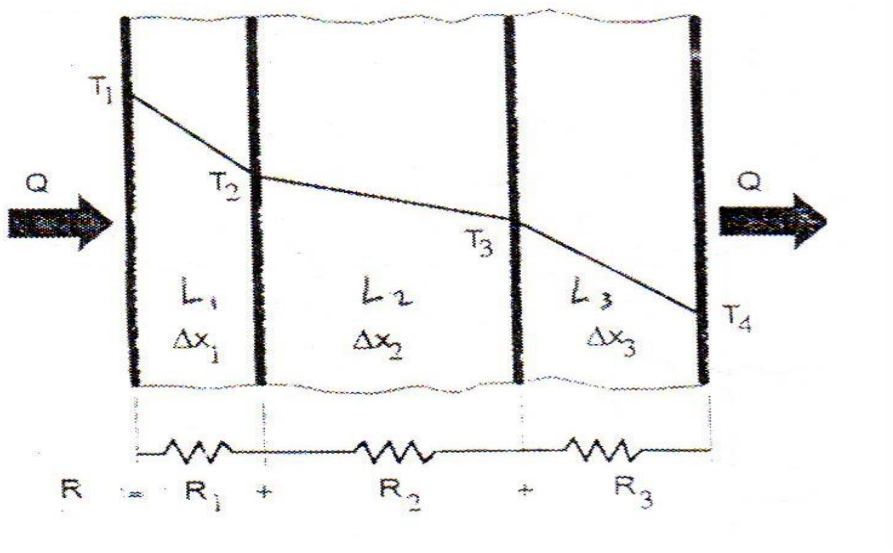
K=0.312 w/m.°k

$$q = \frac{\Delta T}{R} = \frac{\Delta T}{\frac{\Delta X}{K*A}}$$

$$q = \frac{\Delta T}{\frac{\Delta X}{K*A}} = \frac{816-205}{\frac{0.22}{0.312*1}} = 866.5 \ w$$

CONDUCTION HEAT TRANSFER THROUGH COMPOSITE PLANE WALL

التوصيل الحراري خلال جدار مستوي مركب



$q_1 = K_1 \times A \times \frac{T_1 - T_2}{\Delta X_1} \Longrightarrow T_1 - T_2 = \frac{q_1 \times \Delta x_1}{k_1 \times A}$ ---------- (1)

$q_2 = K_2 \times A \times \frac{T_2 - T_3}{\Delta X_2} \Longrightarrow T_2 - T_3 = \frac{q_2 \times \Delta x_2}{k_2 \times A}$ ---------- (2)

$q_3 = K_3 \times A \times \frac{T_3 - T_4}{\Delta X_3} \Longrightarrow T_3 - T_4 = \frac{q_3 \times \Delta x_3}{k_3 \times A}$ ---------- (3)

---

by adding three equations and assuming steady state $q_1=q_2=q_3=q$:-

وبجمع المعادلات الثلاث وبفرض حالة مستقرة نحصل على المعادلة التالية

$$T_1 - T_4 = \frac{q}{A}\left[\frac{\Delta X_1}{K_1} + \frac{\Delta X_2}{K_2} + \frac{\Delta X_3}{K_3}\right]$$

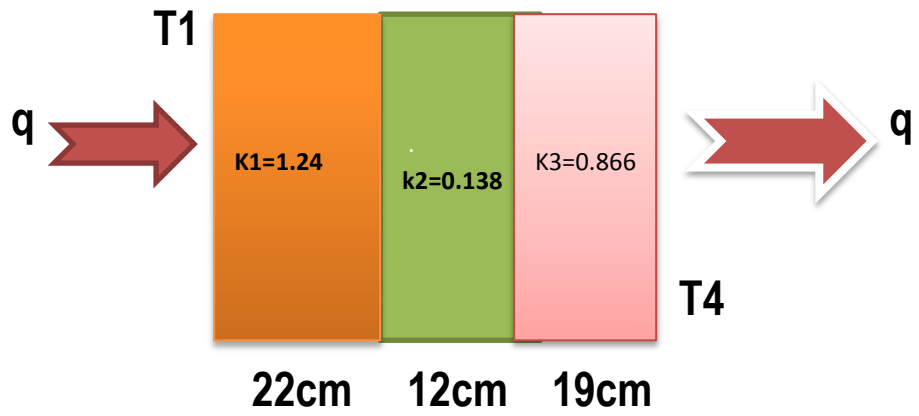
$$q = \frac{A(T1 - T4)}{\left[\frac{\Delta X_1}{K_1} + \frac{\Delta X_2}{K_2} + \frac{\Delta X_3}{K_3}\right]}$$

$$q = \frac{(T1 - T4)}{\left[\frac{\Delta X_1}{K_{1\times A}} + \frac{\Delta X_2}{K_{2\times A}} + \frac{\Delta X_3}{K_{3\times A}}\right]} = \frac{\sum \Delta T}{\sum R}$$

قانون التوصيل الحراري خلال جدار مستوي مركب

EXAMPLE(1):-a wall of furnace consist of 22cm thick of thermal brick with thermal conductivity k=1.24 w/m.°k and 12cm thick of insulation brick with thermal conductivity k=0.138 w/m.°k and 19cm thick of red brick with thermal conductivity k=0.866 w/m.°k. calculate the heat loss from 1m² if the outside and inside temperatures of wall are 70℃ ,205℃.

----------:



ΔX1=22cm=0.22m , k1=1.24 w/m.°k

ΔX2=12cm=0.12m , k2=0.138 w/m.°k

ΔX3=19cm=0.19m , k3=0.866 w/m.°k

T1=205℃ ,T4=70℃

$$q = \frac{\sum \Delta T}{\sum R} = \frac{T1-T4}{R1+R2+R3} = \frac{(T1-T4)}{\left[\frac{\Delta X_1}{K_{1A}}+\frac{\Delta X_2}{K_{2A}}+\frac{\Delta X_3}{K_{3A}}\right]}$$

$$R1=\frac{\Delta X_1}{K_{1A}}=\frac{0.22}{1.24*1}=0.177$$

$$R2=\frac{\Delta X_2}{K_{2A}}=\frac{0.12}{0.138*1}=0.869$$

$$R3=\frac{\Delta X_3}{K_{3A}}=\frac{0.19}{0.866*1}=0.219$$

$$q = \frac{T1-T4}{R1+R2+R3}=\frac{205-70}{1.265}=106.71 \ \ w$$

HEAT TRANSFER BY FORCED CONVECTION

انتقال الحرارة بالحمل الجبري

For forced convection we have flow rate of fluid $(\dot{m})$ or velocity u_∞ by using pumps or compressors or fans so we have:

$\dot{m} = \rho * u * A$ ⟹ kg/sec

For forced convection :

$q = h * A * \Delta t$

$h = \frac{Nnu * k}{d}$

N_{Nu} in forced convection depend on يعتمد على (N_{Re}, N_{pr}) numbers

For forced convection the basic equation is

$$N_{nu} = C(N_{Re})^m (N_{pr})^n$$

⟹ المعادلة العامة للحمل الجبري

FORCED CONVECTION

- **INTERNAL FLOW** — الجريان الداخلي
- **EXTERNAL FLOW** — الجريان الخارجي

HEAT TRANSFER BY FORCED CONVECTION IN INTERNAL FLOW انتقال الحرارة بالحمل الجبري لجريان داخلي

For internal flow forced convection all physical properties are taken at (mixing cup temperature) (Tm) درجة حرارة الخليط which is the average of inlet and outlet fluid temperatures

$$Tm=\frac{t_i+t_o}{2}$$

درجة حرارة الخليط

$q = h * A * (t_w - t_m)$

during the flow of fluids in tubes we use N_{Re} to determine the type of flow

if $N_{Re} < 2300$ the flow is laminar

if $N_{Re} > 2300$ the flow is turbulent

FOR TURBULENT FLOW

$$N_{Nu}=0.023(N_{Re})^{0.8}(Npr)^{n}$$

Where $n=0.4$ for heating

$n=0.3$ for cooling

for high viscosity fluids like oils

$$N_{Nu}=0.027(N_{Re})^{0.8}(Npr)^{0.3}\left(\frac{\mu}{\mu s}\right)^{0.14}$$

NOTE:- μ at t_m and μ_s at t_w

LAMINAR FLOW

$$N_{Nu}=1.86\left(N_{Re}*N_{pr}*\frac{D}{L}\right)^{0.3}\left(\frac{\mu}{\mu s}\right)^{0.14}$$

This equation used for L=1 to 3.6m long and for D=1 to 4cm.

For internal flow We use d_i in N_{Re} and N_{Nu} numbers.

EXAMPLE:- calculate the heat transfer coefficient by forced convection beside water in vapor condenser of single path if the inside diameter of tube is(2.3cm) and the cooling water inter at (17.7℃)and leave at (22.3℃),the mean velocity of water is (2.13m/s).

Solution:-

$$Tm=\frac{ti+to}{2}=\frac{17.7+22.3}{2}20^0c$$

From water tables and at 20^0c we find:-

ν =0.01006$*10^{-4}$ m^2/sec

K=0.598 w/m.^{0}k

Npr=7.03

$$(N_{Re})=\frac{u*d}{\nu}=\frac{2.13*0.023}{0.01006*10^{-4}}=48700$$

The flow is turbulent

$$N_{Nu}=0,023(N_{Re})^{0.8}(Npr)^{0.4}=0.023(48700)^{0.8}(7.03)^{0.4}=282.2$$

$$N_{Nu}=\frac{h*d}{k}$$

$$282.2=\frac{h*0.023}{0.598}$$

$$h = 7337\ w/m^2.^0k$$

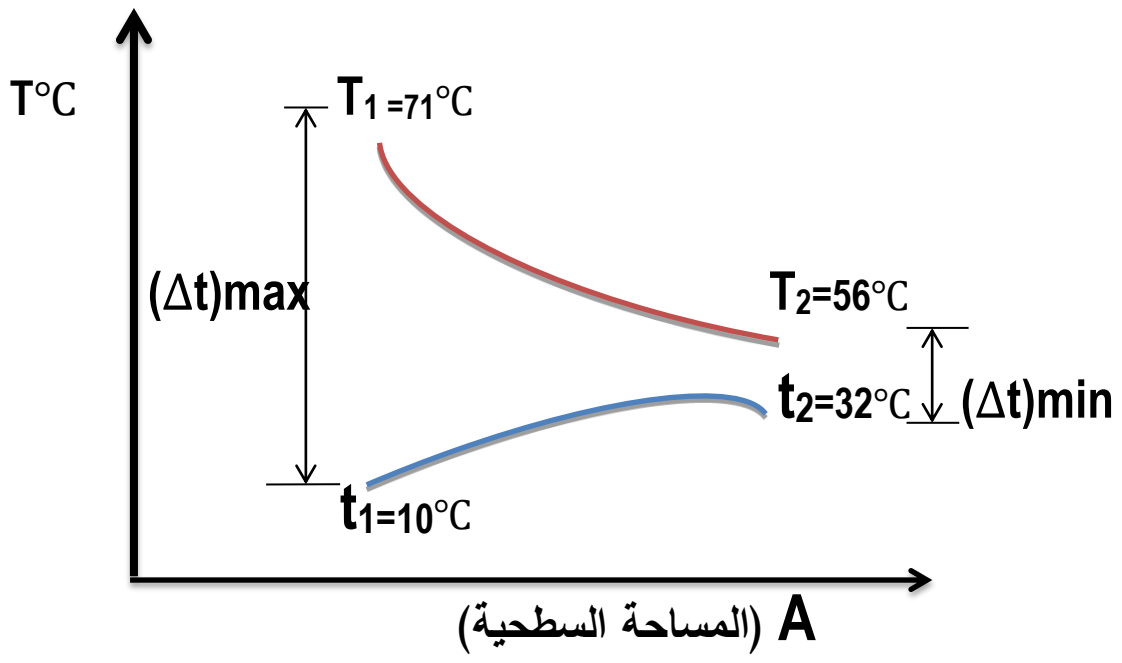
EXAMPLE(1):- air inter هواء يدخل to heat exchanger الى مبادل حراري at (71°C) and leave ويخرج at (56°C),another fluid ومائع اخر inter يدخل at (10°C) and leave ويخرج at (32°C).calculate the log- mean temperature difference احسب المتوسط اللوغاريتمي لفرق درجات الحرارة.in case of في الحالة :-

1-parallel flow heat exchanger لمبادل ذو انسياب متوازي

2-counter flow heat exchanger لمبادل ذو انسياب متعاكس

Solution:-

1-for parallel-flow heat exchanger للمتوازي

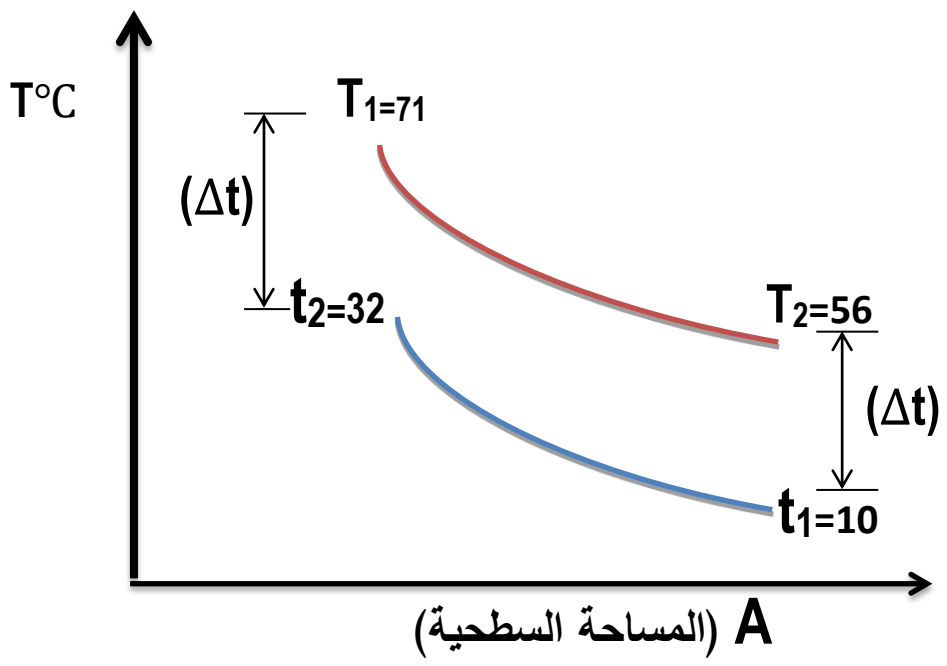


Δt_{max}=T_1-t_1=71−10=61°C

Δt_{min}=T_2-t_2=56−32=24°C

$(\Delta t)_{ln}=\frac{(\Delta t)max-(\Delta t)min}{ln\frac{(\Delta t)max}{(\Delta t)min}}=\frac{61-24}{ln\frac{61}{24}}$=(39.66)°C

2- for counter-flow heat exchanger للمتعاكس



$(\Delta t)min = T_1 - t_2 = 71 - 32 = 39^{o}c$

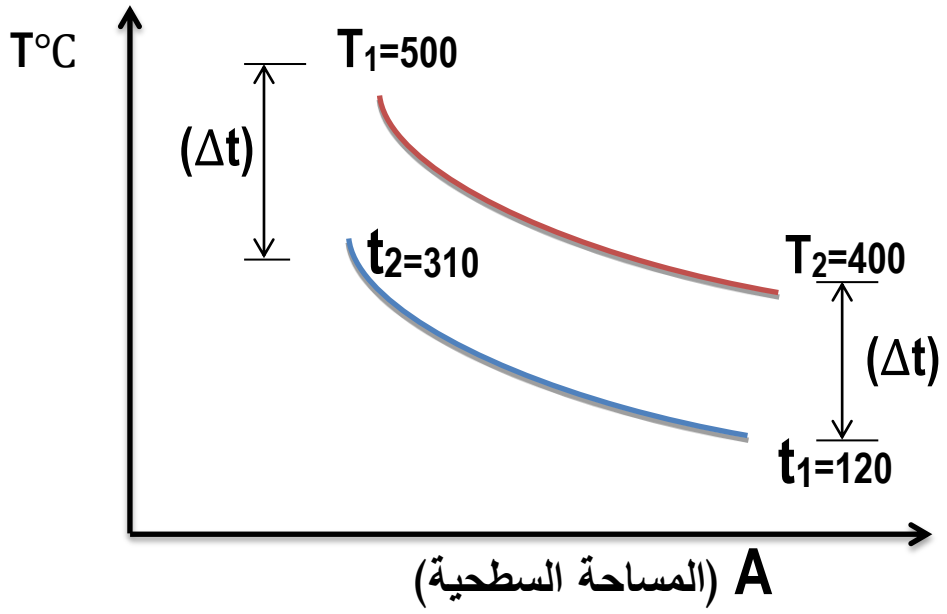
$(\Delta t)max = T_2 - t_1 = 56 - 10 = 46^{0}c$

$(\Delta t)_{ln} = \frac{(\Delta t)max - (\Delta t)min}{\ln\frac{(\Delta t)max}{(\Delta t)min}} = \frac{46-39}{\ln\frac{46}{39}} = (42.40)°C$

Counter flow heat exchanger is the more sufficient

المبادل المتعاكس هو الأكفأ لأنه يعطي متوسط لوغاريتمي اكبر

EXAMPLE(2):-Calculate احسب the log –mean temperature difference المتوسط اللوغاريتمي لفرق درجات الحرارة for counter-flow heat exchanger لمبادل ذو انسياب متعاكس consist of مكون من two shells غلافين and four paths of tubes اربع مسارات من الانابيب if the entering and leaving temperatures of shell are 500°C ,400°C respectively اذا كانت درجتي دخول وخروج مائع الغلاف هما على الترتيب and for tubes are 120°C ,310°C respectively ودرجتي دخول وخروج مائع الانابيب هما .



Solution:-

For multi-tube and shell heat exchanger we have correction factor for the log –mean temperature difference (F)

$(\Delta t)min = T_1 - t_2 = 500 - 310 = 190^0 c$

$(\Delta t)max = T_2 - t_1 = 400 - 120 = 280^o c$

$$(\Delta t)_{ln1} = \frac{(\Delta t)max - (\Delta t)min}{ln\frac{(\Delta t)max}{(\Delta t)min}} = \frac{280-190}{ln\frac{280}{190}} = \frac{90}{0.387} = (232)°C$$

$(\Delta t)ln_2 = F * (\Delta t)ln_1$

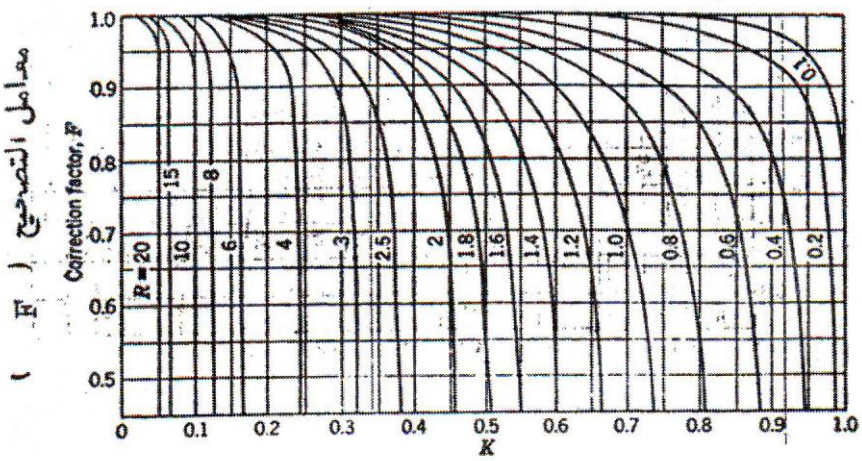
$$R = \frac{T1-T2}{t2-t1} = 0.52$$

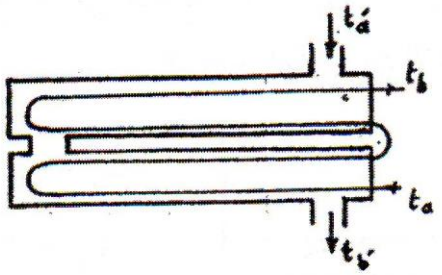
$$K = \frac{t2-t1}{T1-t1} = 0.5$$

ومن خارطة معامل التصحيح لمبادل ذو غلافين واربع مسارات نجد قيمة

$F = 0.99$

$(\Delta t)ln_2 = F * (\Delta t)ln_1 = 0.99 * 232 = 230°C$





HEAT EXCHANGER EFFICTIVENESS RATIO فاعلية المبادل الحراري

It is the ratio هي النسبة between بين actual heat transfer الحرارة الحقيقية to maximum heat transfer الى اقصى حرارة منتقلة and its symbol is(Є).

$$\epsilon = \frac{q_{actual}}{q_{max}}$$

فاعلية المبادل الحراري

$$q_{actual} = \dot{m}_h * c_h * (T_1 - T_2) = \dot{m}_c * c_c * (t_2 - t_1)$$

$$q_{maximum} = (\dot{m} * c)_{min} * (T_1 - t_1)$$

$$\epsilon = \frac{T_1 - T_2}{T_1 - t_1}$$ **if** $\dot{m}_h * c_h < \dot{m}_c * c_c$ لكل انواع المبادلات عدا المكثف

Or

$\epsilon = \frac{t_2 - t_1}{T_1 - t_1}$ if $\dot{m}c * cc < \dot{m}_h * c_h$ لكل انواع المبادلات عدا المرجل

$$\epsilon = \frac{1 - e^{\left(-U * \frac{A}{Cmin}\right)\left(1 + \frac{Cmin}{Cmax}\right)}}{1 + \frac{Cmin}{Cmax}}$$ للمتوازي

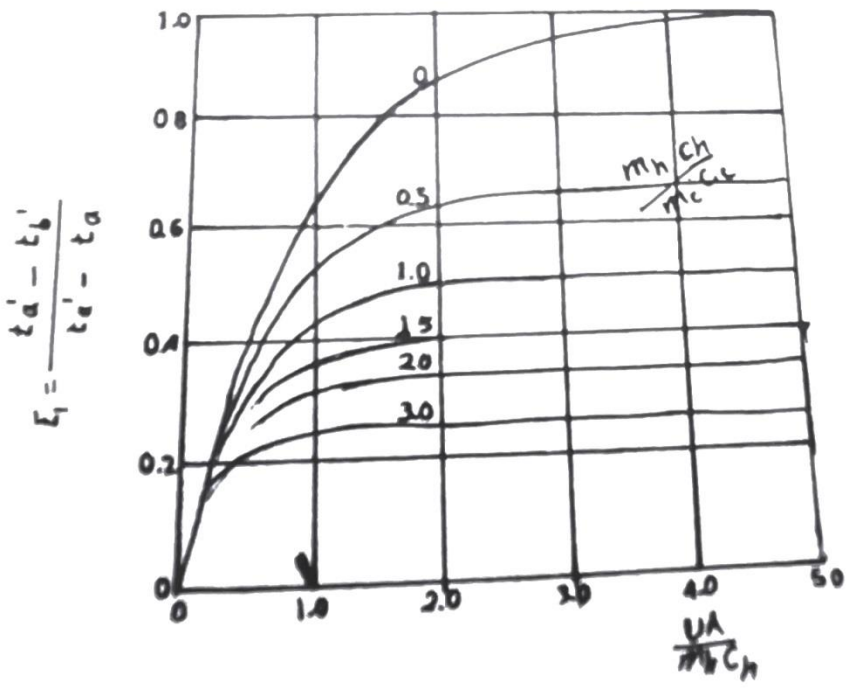
$$\epsilon = \frac{1 - e^{\left(-U * \frac{A}{Cmin}\right)\left(1 - \frac{Cmin}{Cmax}\right)}}{1 - \frac{Cmin}{Cmax} * e^{\left(-U * \frac{A}{Cmin}\right)\left(1 - \frac{Cmin}{Cmax}\right)}}$$ للمتعاكس

C_{min} or C_{max} $= m_h * c_h$ or $m_c * c_c$ = THERMAL CAPACITY السعة الحرارية

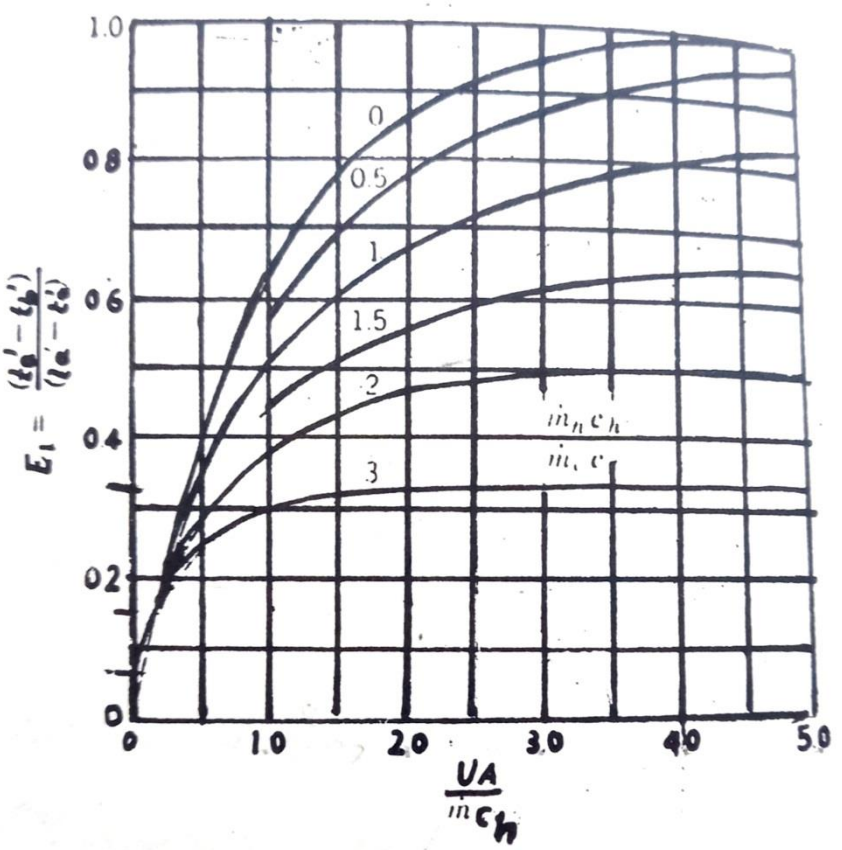
$\frac{U * A}{C_{min}}$ = NTU = NUMBER OF TRANSFER UNITS عدد وحدات الانتقال

$\frac{C_{min}}{C_{max}}$ = thermal capacity rate = معدل السعة الحرارية

Heat exchanger effectiveness ratio (ϵ) فاعلية المبادل الحراري can be found from special charts يمكن استخراجها من خرائط خاصة حسب نوع المبادل for parallel flow heat exchanger and for counter flow heat exchanger



شكل (15) ـ نسبة فاعلية المبادل الحراري ذو الانسياب المتوازي

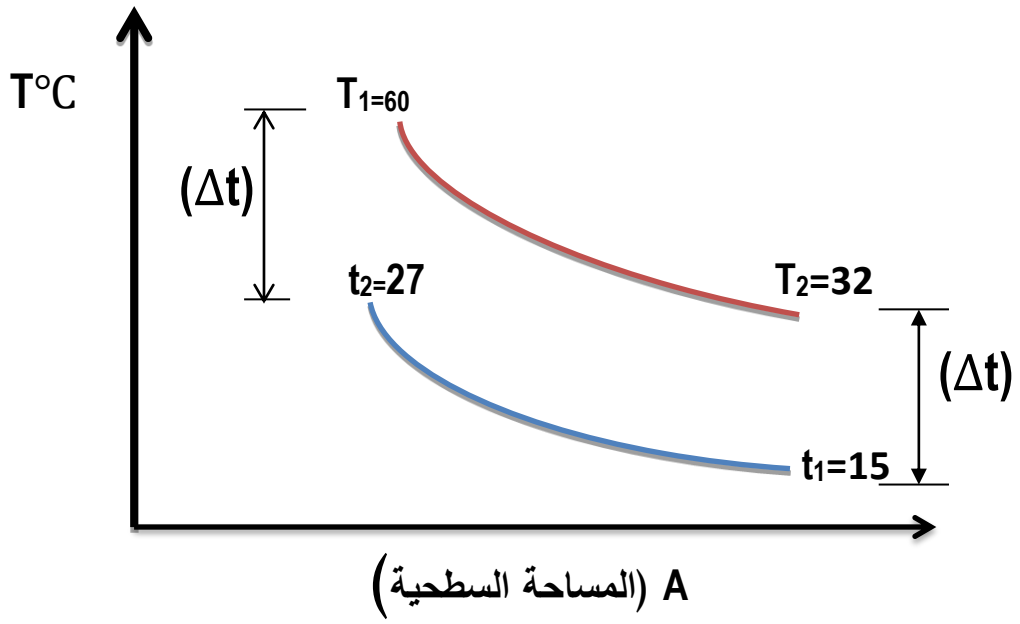


شكل (16) ـ نسبة فاعلية المبادل الحراري ذو الانسياب المتعاكس

EXAMPLE(1):- counter-flow heat exchanger is designed to cool 900 kg/hr of oil from 60℃ to 32℃,by using cooling water inter at 15℃,the specific heat of oil is 2.1kJ/kg.°k and the leaving temperature of water is 27℃. calculate the product حاصل ضرب of the overall coefficient of heat transfer U and the area A.

Solution:-

for counter-flow heat exchanger للمتعاكس



الطريقة الاولى للحل

$(\Delta t)_{max} = T_1 - t_2 = 60 - 27 = 33^{o}c$

$(\Delta t)_{min} = T_2 - t_1 = 32 - 15 = 17^{0}c$

$$(\Delta t)_{ln} = \frac{(\Delta t)max - (\Delta t)min}{\ln\frac{(\Delta t)max}{(\Delta t)min}} = \frac{33-17}{\ln\frac{33}{17}} = (24.13)°C$$

$q_{rejected} = q_{exchanged}$

$\dot{m}_h * c_h * (T_1 - T_2) = U * A * (\Delta t)_{ln}$

$\frac{900}{3600} * 2.1 * 1000 * (60 - 32) = U * A * 24.13$

$U * A = 609 w/°k.$

الطريقة الثانية للحل

$q_{rejected}=q_{recived}$

$\dot{m}_h * c_h * (T_1 - T_2) = \dot{m}_c * c_c * (t_2 - t_1)$

$900 * 2.1 * 1000 * (60-32) = \dot{m}c * 4.19 * 1000 * (27-15)$

$\dot{m}_c = 1050$ kg/hr

$\dot{m}_h * c_h = \frac{900}{3600} * 2.1 * 1000 = 524 = C_{min}$

$\dot{m}_c * c_c = \frac{1050}{3600} * 4.19 * 1000 = 1222 = C_{max}$

$\frac{C_{min}}{C_{max}} = \frac{525}{1222} = 0.43$

$\epsilon = \frac{T_1 - T_2}{T_1 - t_1}$ if $\dot{m}_h * c_h < \dot{m}_c * c_c$

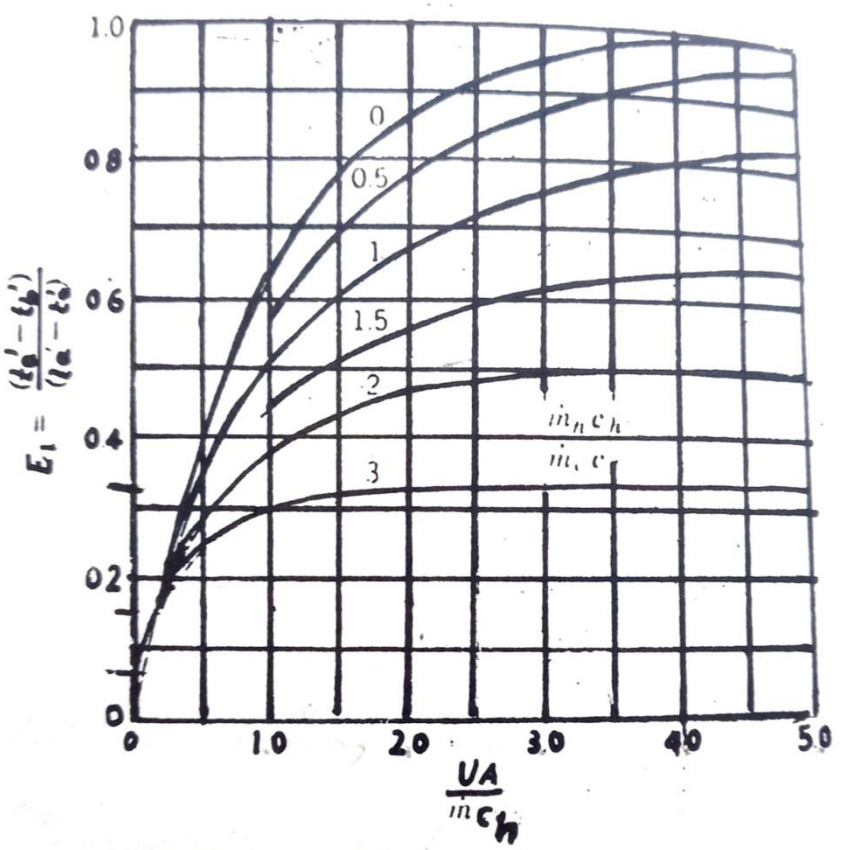
$\epsilon = \frac{60-32}{60-15} = 0.62$

ومن خارطة الفاعلية لمبادل ذو انسياب متعاكس نجد

$\frac{U * A}{C_{min}} = 1.16$

$U * A = 1.16 * C_{min} = 1.16 * \frac{900}{3600}$

$U * A = 609 w/^{\circ}k$



شكل (16) ـ نسبة فاعلية المبادل الحراري ذو الانسياب المتعاكس

HEAT TRANSFER BY THE COMBINED EFFECT OF CONDUCTION AND CONVECTION

انتقال الحرارة بتاثير متحد للتوصيل والحمل معا

There are two statesهناك حالتان for Heat transfer لانتقال الحرارة by combined effect متحد بتاثيرof conduction and convection للتوصيل والحمل معا whichوالتي are occurتحدث at walls of buildingsعند جدران الابنية and heat exchangers والمبادلات الحرارية

For combined effect the heat transfer rate q

قانون معدل انتقال الحرارة بتاثير متحد للتوصيل والحمل معا

$$q=U*A*\Delta t$$

q:heat transfer rate by combined effect of conduction and convection in w

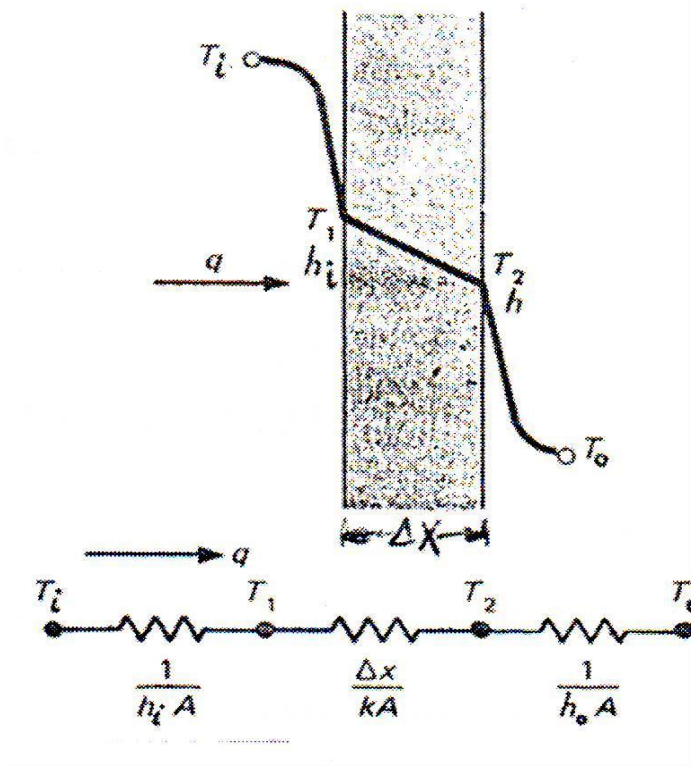
A: area in m^2

Δt: temperature difference between two fluids =ti– to

U=overall coefficientالاجمالي المعامل of heat transfer in $w/m^2.k$

HEAT TRANSMISSION BETWEEN TWO FLUIDS THROUGH APLANE WALL

انتقال الحرارة بين مائعين يفصل بينهما جدار مستوي



$q = h_i * A * \Delta t = h_i * A * (t_i - t_1)$ ---------$(ti-t1) = \frac{q}{hi * A}$ -------1

$q = kw * A * \frac{\Delta t}{\Delta X} = kw * A * \frac{(t1 - t2)}{\Delta X}$ ------$(t1-t2) = \frac{q * \Delta x}{kw * A}$ ---------2

$q = h_o * A * \Delta t = h_o * A * (t_2 - t_o)$ ---------$(t2-to) = \frac{q}{h0 * A}$ -------3

by adding three equation we have:-ويجمع المعادلات الثلاث نحصل

$$(ti-to) = \frac{q}{A}\left[\frac{1}{h_i} + \frac{\Delta X}{kw} + \frac{1}{h_o}\right]$$

$$q = \frac{A \times \Delta T}{\frac{1}{hi} + \frac{\Delta x}{k_w} + \frac{1}{ho}}$$

$$q = U * A * \Delta t$$

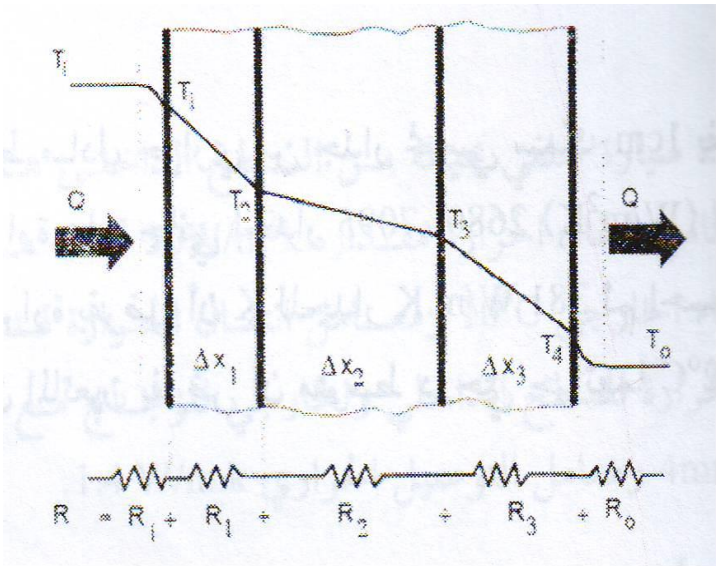
$$U = \frac{1}{\frac{1}{hi} + \frac{\Delta x}{k_w} + \frac{1}{ho}}$$

in $W/m^2.^0k$

المعامل الاجمالي لانتقال الحرارة بين مائعين يفصل بينهما جدار مستوي

thermal conduction through composite plane wall with thermal convection boundaries

واذا كان الجدار الفاصل بين المائعين متعدد الطبقات



$$U = \frac{1}{\frac{1}{hi} + \frac{\Delta x1}{kw1} + \frac{\Delta x2}{kw2} + \frac{\Delta x3}{kw3} + \frac{1}{ho}}$$

المعامل الاجمالي لانتقال الحرارة بين مائعين يفصل بينهما جدار مستوي مركب

EXAMPLE(1) :- the wall of heat exchanger is made of مصنوع copperمن النحاس with(1cm) thickسمكه, Assumeافترض the coefficient of heat transfer معاملات انتقال الحرارة at wall sides على جانبي الجدار are (7095,2680) $w/m^2.^0k$ respectivelyعلى الترتيب.

Calculate:-

1- the overall coefficient of heat transfer U if k_w=381w/m.^{0}k

2-the heat transfer rate per unit area معدل انتقال الحرارة لوحدة المساحة (q'') if the temperatures are(82℃),(53℃).

Solution:-

$$1\text{-}U=\frac{1}{\frac{1}{hi}+\frac{\Delta x}{kw}+\frac{1}{ho}}=\frac{1}{\frac{1}{7095}+\frac{0.01}{381}+\frac{1}{2680}}$$

$$U=1851\ w/m^2.^ok$$

2- $q''= U*\Delta t=1851*(82-53)=53679\ w/m^2$

HEAT TRANSFER BY RADIATION

انتقال الحرارة بالاشعاع

Heat transfer by radiation تنتقل الحرارة بالاشعاع as an electromagnetic waves بشكل موجات كهرومغناطيسية in vacuum في الفراغ,it needs no medium ولاتحتاج الى وسيط.it transferred at velocity of light وتنتقل بسرعة الضوء.

$u_L = 3 * 10^8$ m/sec= سرعة الضوء

$u = \lambda * H$= سرعة الفوتون

where

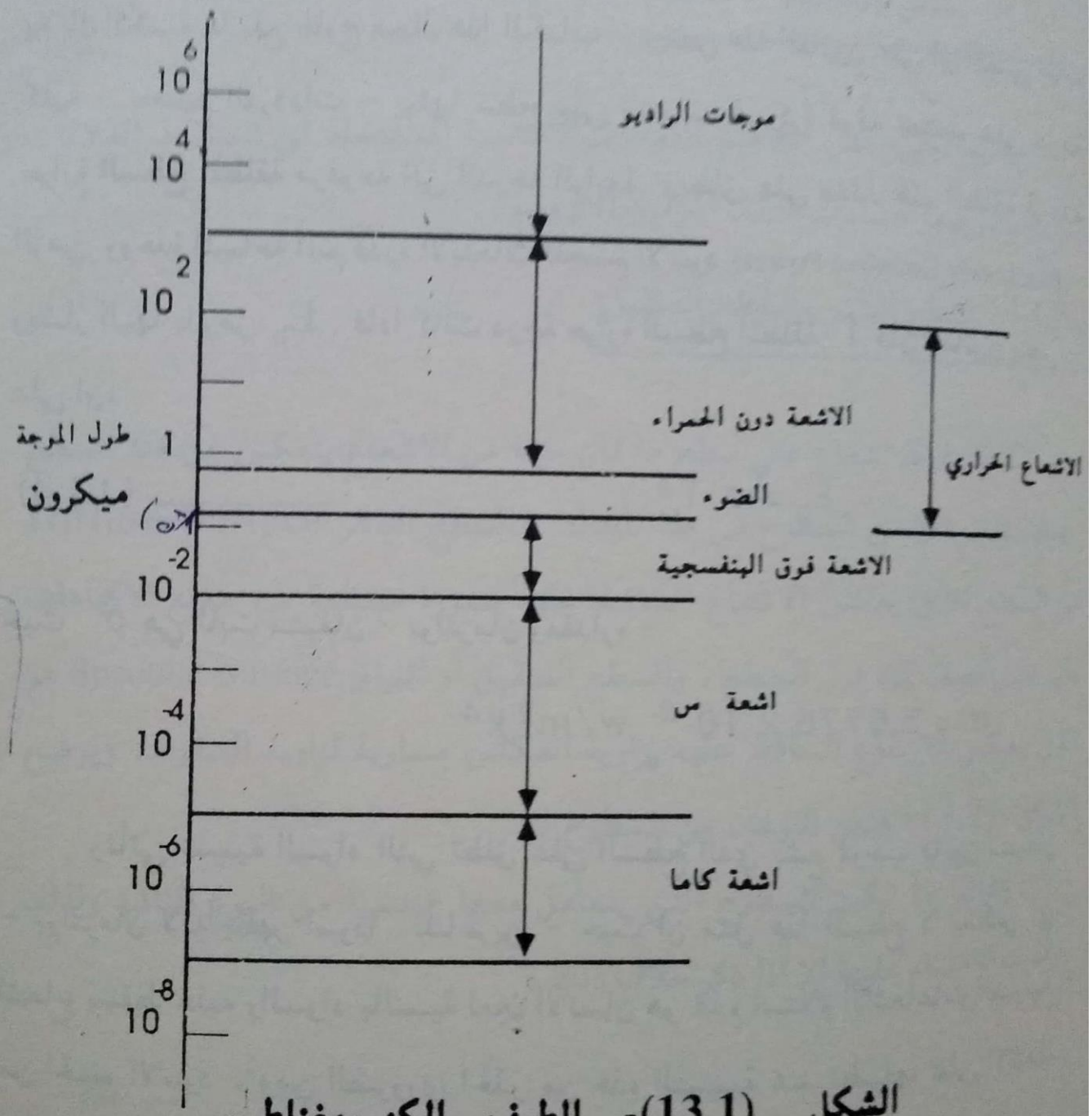
λ=wave length in (micron μ) الطول الموجي بوحدة مايكرون=10^{-6} m

H=frequency in hertz التردد=$\frac{1}{sec}$

اما سرعة انتقال الاشعاع في الاوساط المادية الاخرى التي تسمح بنفاذ الاشعة خلالها فيعتمد على معامل الانكسار n_o حيث ان سرعة الاشعاع c

$$C = \frac{\text{سرعة الضوء}}{\text{معامل الانكسار}}$$

Thermal radiation lies الاشعاع الحراري يقع عند طول موجي (0.1---100)μ as shown in figure:-

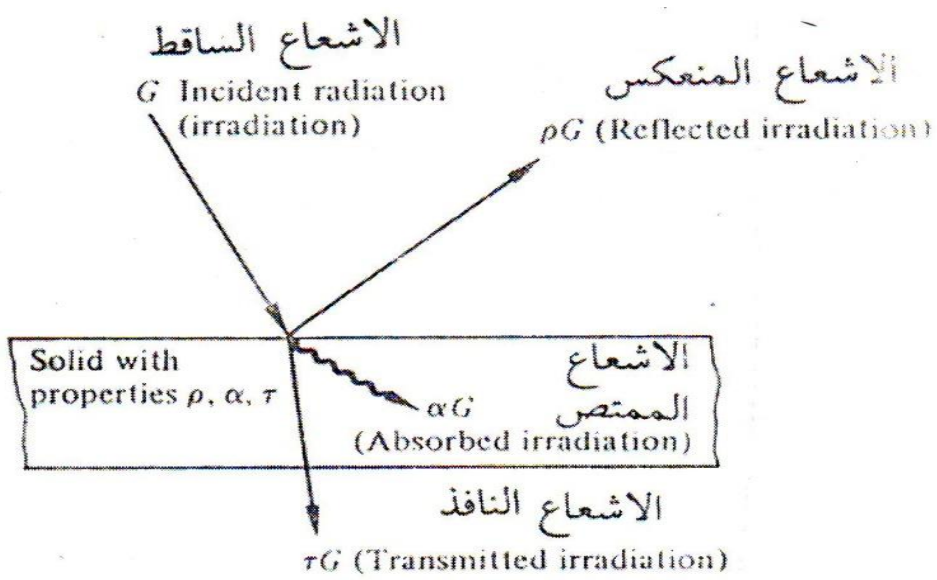


الشكل (13.1)- الطيف الكهرومغناطيسي

PROPERTIES OF RADIATION :- خواص الاشعاع

When the thermal radial lies عندما يسقط اشعاع, some of it absorb(α)جزء منه يمتص,some of it reflect (ρ) جزء ينعكسand the other trans miss (τ) والباقي ينفذ ,so that بحيث ان:-

$$\alpha+\rho+\tau=1$$



$$\alpha=\frac{\text{الطاقة الممتصة}}{\text{الطاقة الكلية الساقطة}}=\frac{\theta\alpha}{\theta}$$

α= absorbtivity factor =معامل الامتصاص

$$\rho=\frac{\text{الطاقة المنعكسة}}{\text{الطاقة الكلية الساقطة}}=\frac{\theta\rho}{\theta}$$

ρ = reflectivity factor =معامل الانعكاس

$$\tau=\frac{\text{الطاقة النافذة}}{\text{الطاقة الكلية الساقطة}}=\frac{\theta\tau}{\theta}$$

τ=transmissivity factor=معامل النفاذ

for black body $(\alpha)=1$ للجسم الاسود

for dark body $(\tau)=0$ للجسم المعتم

for glass body $(\tau)=1$ للزجاج

for mirror $(\rho)=1$ للمرايا

BLACK BODY الجسم الاسود:-the body الذي هو الجسم that absorb all energy يمتص كل الطاقة and don't reflect or trans miss any part of it ولايعكس او ينفذ اي منها.

$$\alpha+\cancel{\rho}+\cancel{\tau}=1$$

$(\alpha)_b=1$ for black body

STEFAN_BOLTZMAN LAW FOR RADIATION

قانون ستيفان - بولتزمان للاشعاع

$q_b \alpha A_* T^4$

$q_b = б * A * T^4$

قانون ستيفان– بولتزمان للجسم الاسود

q_b=time rate of radiated energy in watt معدل الطاقة الاشعاعية للجسم الاسود

A=area in m^2

б =Stefan-Boltzman constant ثابت ستيفان–بولتزمان

$=5.67_* 10^{-8} w/m^2.^0k^4$

T:absolute temperature in ^0k درجة الحرارة المطلقة للجسم

For grey body للجسم الرمادي we use emissivity factor($\in$) <1

$q_{gr} = \epsilon * A * б * T^4$

معدل الطاقة الاشعاعية للجسم الغير اسود او الرمادي

$\in$معامل الانبعاث: هو النسبة بين الطاقة التي يشعها الجسم الغير اسود الى الطاقة التي يشعها الجسم الاسود

emissivity factor $\in gr<1$ معامل الانبعاثية للجسم الرمادي

emissivity factor $\in_b = 1$ معامل الانبعاثية للجسم الاسود

HEAT TRANSFER
Problems for conduction(chapter two)

Q1-if the rate of heat loss in hour through square meter of furnace wall with 45 cm thick is 5110 kJ .calculate the outside surface temperature of wall if the inside surface temperature is 1040℃ and the mean thermal conductivity of wall is 1.04 w/m.^{o}k.

Solution

$$\frac{q}{hr} = 5110 \text{ kJ/hr}$$

$$q=\frac{\Delta T}{R}=\frac{(Ti-To)}{\frac{\Delta x}{k.A}}=\frac{(1040-To)}{\frac{0.45}{1.04*1}}$$

$$\frac{5110*1000J}{hr*3600\ sec}=\frac{(1040-To)}{\frac{0.45}{1.04*1}}$$

To=427℃

Q2- calculate the rate of heat loss per square meter of plane wall with 25 cm thick ,if the inside and outside temperatures are 450℃,50℃ respectively and the mean thermal conductivity of wall in w/m.^{o}k varies with temperature in the relation given:-
K=0.111+0.03t

Solution

$$q''=k_m*\frac{\Delta T}{\Delta X}$$

$$k_m=0.111+0.003[\frac{450+273+50+273}{2}]=1.68 \text{ w/m.}^o\text{k}$$

$$q''=1.68*\frac{450-50}{0.25}= 2688 \text{ w/m}^2$$

Q3- calculate the heat loss per square meter of composite furnace wall made of 20 cm thick of thermal brick and 15 cm thick of insulation brick and 10 cm thick of brick ,if the inside and outside temperatures of furnace are 1100℃,100℃, respectively and the mean thermal conductivity of the three layers are 1.2,0.128,1.62 w/m.^{o}k respectively.

Solution

$$q=\frac{\sum \Delta T}{\sum R}=\frac{Ti-To}{R1+R2+R3}$$

$$q''=\frac{Ti-To}{\frac{\Delta X1}{K1}+\frac{\Delta X2}{K2}+\frac{\Delta X3}{K3}}=\frac{1100-100}{\frac{0.2}{1.2}+\frac{0.15}{0.128}+\frac{0.1}{1.62}}=714.42\ w/m^2$$

Q4-- calculate the rate of heat loss from awall of furnace with 20 cm thick, the inside and outside temperatures of furnace are 980℃,200℃, respectively if the thermal conductivity of materials of wall is 1.231 w/m.^{o}k ,if we use an insulation with 0.75 cm thick and k=0.092 w/m.^{o}k ,so that the heat loss decrease to 24%. Calculate the outer temperature of insolation ,the price of insolation is 1.25ID/m.Find the time required to pay this price ,it is 24 hr in day and the thermal energy is 0.85ID/10^{6}kJ.

Solution

$$q=\frac{\Delta T}{R}=\frac{(Ti-To)}{\frac{\Delta x}{k.A}}$$

Before insulation $q_1''=\frac{(Ti-To)}{\frac{\Delta x}{k}}=\frac{(980-200)}{\frac{0.2}{1.231}}=4800.9\ w/m^2$

After insulation $q_2''=q_1''-0.24\,q_1''=0.76\,q_1''=3648.6\ w/m^2$

$$q_2''=\frac{\sum \Delta T}{\sum R}=\frac{T1-T3}{R1+R2}=\frac{T1-T3}{\frac{\Delta X1}{K1}+\frac{\Delta X2}{K2}}$$

$$3648.6==\frac{980-T3}{\frac{0.2}{1.231}+\frac{0.0075}{0.092}}\ \frac{KJ}{hr.m^2}$$

T3=89.77℃

$q_1''-q_2''=4800.9-3648.8=1152.3\ w/m^2$

The energy win $=1152.3\ \frac{J}{sec.m^2}=1.1523\ \frac{KJ}{sec.m^2}\times\frac{3600\ sec}{hr}=4147.2\ \frac{KJ}{hr.m^2}$

The energy price= 4147.2 $\frac{KJ}{hr.m^2}$ $\times$0.85 $\frac{ID}{10^6 KJ}$ =3.52*10^{-3} $\frac{ID}{hr.m^2}$

Time = $\frac{1.25\ \frac{ID}{m^2}}{3.52*10^{-3}\frac{ID}{hr.m^2}}$ =355.11 hr

1 day =24 hr

Time = $\frac{355.11\ hr}{24\frac{hr}{day}}$ = 14.79 day.

Q5- if the inside wall of furnace made of thermal brick with (10cm)thick and the outside wall of red brick with (20cm) thick ,the inside and outside temperatures are (7oo℃),(120℃)respectively.to decrease the heat loss we add an insulation with (5cm) thick and thermal conductivity of (0.063) w/m.^{o}k so that the temperatures will be (730),(670),(517).(77)℃ respectivily.calculate 1) the heat loss without insulation 2) the heat loss with insulation 3) express the heat loss in second state as aratio of heat loss in first state.

Solution

$$q = \frac{\sum \Delta T}{\sum R} = \frac{Ti - To}{R1 + R2}$$

$$q_1'' = \frac{T1 - T3}{\frac{\Delta X1}{K1} + \frac{\Delta X2}{K2}} = \frac{700 - 120}{\frac{0.1}{K1} + \frac{0.2}{K2}}$$ without insulation

$$q_2'' = \frac{517 - 77}{\frac{0.05}{0.063}} = 554.4$$ w/m^2 with insulation

for steady state $q_2'' = q_1'' = q_3''$

$$554.4 = \frac{730 - 670}{\frac{0.1}{K1}} \Longrightarrow K_1 = 0.924$$ w/m.^{o}k

$$554.4 = \frac{670 - 517}{\frac{0.2}{K2}} \Longrightarrow K_2 = 0.724$$ w/m.^{o}k

$$q_1'' = \frac{T1 - T3}{\frac{\Delta X1}{K1} + \frac{\Delta X2}{K2}} = \frac{700 - 120}{\frac{0.1}{0.924} + \frac{0.2}{0.724}} = 1510.41$$ w/m^2

$$\frac{q_2''}{q_1''} \times 100\% = \frac{554.4}{1510.4} \times 100\% = 36.7\%$$

Q6-starting from the equation for conduction heat transfer per unit length from atube .prove that heat loss per m^2 from the outside surface of tube which outside diameter is D_2 and inside diameter is $D_1$is given by :-

$$q'' = \frac{2*k(t1-t2)}{D_2 ln\frac{D2}{D1}} \quad w/m^2$$

Solution

$$q' = \frac{\Delta T}{R} = \frac{(T_1 - T_2)}{\frac{ln\frac{r_2}{r_1}}{2\pi K}}$$

$$q' = \frac{q}{L} \qquad q = q'*L$$

$$q = 2\pi kL \frac{(T_1 - T_2)}{ln\frac{\frac{D_2}{2}}{\frac{D_1}{2}}}$$

$$q = \frac{2\pi kL\,(T_1 - T_2)}{ln\frac{D_2}{D_1}}$$

$$q'' = \frac{q}{A_2}$$

$$A_2 = \pi.D_2.L$$

$$q'' = \frac{2\pi kL\,(T_1 - T_2)}{ln\frac{D_2}{D_1}(\pi.D_2.L)}$$

$$q'' = \frac{2k\,(T_1 - T_2)}{D_2 ln\frac{D_2}{D_1}}$$

Q7//-calculate the heat loss per square meter from the outside surface of tube with outside diameter of (10cm) covered with (1cm) thick of insulation of thermal conductivity of (o.o7) w/m.^{o}k ,assume the inside and outside temperatures of insulation are (274),(32)℃ respectively.

Solution

$$q = \frac{\Delta T}{R} = \frac{(T_1 - T_2)}{\frac{ln\frac{r_2}{r_1}}{2\pi KL}}$$

$$q'' = \frac{q}{A_1} \qquad A_1 = \pi.2r_1.L$$

$$q'' = \frac{q}{\pi.2r_1.L} = \frac{(T_1 - T_2)}{\frac{ln\frac{r_2}{r_1}}{2\pi KL} \times \pi.2r_1.L}$$

$$q'' = \frac{(274-32)}{\frac{ln\frac{0.06}{0.05}}{0.07} \times 0.05} = 1548.54 \ W/m^2$$

Q8// Asteam passing through atube of outside diameter of 20 cm covered with 5 cm of insulation of thermal conductivity of 0.096 w/m.^{0}k . calculate the heat loss per 100 m length of atube if the inside and outside temperatures of insulation are 451,45℃.

Solution

$$q = \frac{\Delta T}{R} = \frac{(T_1 - T_2)}{\frac{ln\frac{r_2}{r_1}}{2\pi KL}} = \frac{(451-45)}{\frac{ln\frac{15}{10}}{2\pi 0.096 * 100}} = 60398.15 \ w$$

Q9// Atube of 25cm diameter covered with 2.5cm thick of insulation with k=0.074 w/m.^{0}k and 5cm thick of another insulation with k=o.o61 w/m.^{0}k .if the inside and outside temperatures are 364℃ ,46℃ respectively. calculate the heat loss per 100m^{2} from the outside surface of tube.

Solution

$$q = \frac{\sum \Delta T}{\sum \Delta R} = \frac{(T_i - T_o)}{\frac{ln\frac{r_2}{r_1}}{2\pi k_1 L} + \frac{ln\frac{r_3}{r_2}}{2\pi k_2 L}}$$

$q'' = \frac{q}{A_3}$ $A_3=\pi.D_3.L$ $100=3.14\times0.35\times L$ $L=90.94$ m

$$q = \frac{(364-46)}{\frac{ln\frac{12.5}{10}}{2\times3.14\times0.074\times90.94}+\frac{ln\frac{17.5}{12.5}}{2\times3.14\times0.061\times90.94}} = 21299.39 \text{ w}$$

$$q'' = \frac{q}{A_3} = \frac{q}{100} = 212.99 \text{ w/m}^2$$

Q10// **Atube of 22cm outside diameter and 20cm inside diameter ,if the inside and outside temperatures of tube are 226 ,222 respectively and the thermal conductivity of tube is 43.4 w/m.^{0}k .calculate A) the heat loss per meter length .B)The reduction in heat lossif we use an insulation with 4cm thick and k=0.0658 w/m.^{0}k covered the tube ,if the inside and outside temperatures of insulation are 270 ,64 . C) The insid temperature of tube in case B.**

Solution

A) $q_1' = \frac{(T_1-T_2)}{\frac{ln\frac{r_2}{r_1}}{2\pi k_1}} = \frac{(226-222)}{\frac{ln\frac{11}{10}}{2\pi\times43.4}} = 11444.32$ w/m

B) $q_2' = \frac{(T_2-T_3)}{\frac{ln\frac{r_3}{r_2}}{2\pi k_2}} = \frac{(270-64)}{\frac{ln\frac{15}{11}}{2\pi\times0.0658}} = 274.59$ w/m

Decreasing in heat loss $q' = \frac{q1'-q2'}{q1'} = \frac{11444.32-274.59}{11444.32} = 0.97$

C) $q_2' = \frac{(t_1'-64)}{\frac{ln\frac{r_2}{r_1}}{2\pi k_1}+\frac{ln\frac{r_3}{r_2}}{2\pi k_2}}$

$$274.59 = \frac{(t_1'-64)}{\frac{ln\frac{11}{10}}{2\pi\times43.4}+\frac{ln\frac{15}{11}}{2\pi\times0.0658}}$$

$t_1' = 270.09$°C

Q11// Steam passing through atube of outside diameter of 60cm and 410m long covered with 5cm thick of insulation with k=0.0892 w/m.^{0}k and 4cm thick of another insulation with k= 0.0595 w/m.^{0}k ,if the inside and outside temperatures are 405℃ ,56℃ .respectively.calculate A) the heat loss per hr.B) the heat loss per m^2 from outside surface of insulation .C) heat loss per m^2 of tube D) temperature between two insulations.

Solution

$$q = \frac{\sum \Delta T}{\sum \Delta R} = \frac{(T_1 - T_3)}{\frac{ln\frac{r_2}{r_1}}{2\pi k_1 L} + \frac{ln\frac{r_3}{r_2}}{2\pi k_2 L}}$$

$$q = \frac{(405-56)}{\frac{ln\frac{35}{30}}{2\times3.14\times0.089\times410} + \frac{ln\frac{39}{35}}{2\times3.14\times0.059\times410}} = 252483\ W = 252.483\ KW$$

A) $q = 252.483\frac{KJ}{sec} \times 3600\frac{sec}{hr} = 908928\frac{KJ}{hr}$

B) $q'' = \frac{q}{A_3} = \frac{q}{2\pi r_3 . L} = \frac{25248\times1000}{2\pi\times0.39\times410} = 251.3\ W/m^2$

C) $q'' = \frac{q}{A_1} = \frac{q}{2\pi r_1 . L} = \frac{25248\times1000}{2\pi\times0.3\times410} = 326.69\ W/m^2$

D) q_1 after insulation = q through insulation

$$252483 = \frac{(405-t_2)}{\frac{ln\frac{35}{30}}{2\pi 0.089\ 410}} =$$

$t_2 = 235.4$℃

HEAT TRANSFER BY FREE CONVECTION

انتقال الحرارة بالحمل الحر

FOR FREE CONVECTION ALL PHYSICAL PROPERTIES كل الخواص الفيزيائية ARE TAKEN تؤخذ FROM TABLES SHOWN BELOW من الجداول ادناه AT BOUNDARY LAYER TEMPERATURE بدرجة حرارة الطبقة الحدودية (Tf) WHICH IS THE AVERAGE معدل OF WALL AND FLUID TEMPERATURES درجتي حرارة السطح والمائع.

$$T_F = \frac{T_w + T_\infty}{2}$$

درجة حرارة الطبقة الحدودية

TABLES FOR PROPERTIES OF WATER AND AIR

الخواص الحرارية التقنية للماء

T °C	ρ kg/m³	Cp kJ/kg.°k	γ cm²/sec	K w/m.°k	Npr	β 1/°k
20	998.2	4.183	0.01006	0.598	7.03	0.00020
40	992.1	4.178	0.00658	0.627	4.35	0.00038
60	983	4.191	0.00479	0.651	3.01	0.00054
80	972	4.149	0.00364	0.669	2.22	0.00065
100	958	4.216	0.00294	0.682	1.75	0.00078
150	917	4.271	0.00201	0.683	1.15	0.00113
200	865	4.501	0.00160	0.665	0.97	0.00155
250	799.2	4.860	0.00140	0.625	0.87	0.00229

الخواص الحرارية التقنية للهواء

T ℃	ρ kg/m³	Cp kJ/kg.°k	γ cm²/sec	k w/m.°k	Npr
−173	3.672	1.026	0.0190	0.0092	0.770
−73	1.803	1.005	0.0737	0.0181	0.739
27	1.200	1.055	0.154	0.0263	0.708
127	0.900	1.013	0.254	0.0336	0.689
227	0.719	1.039	0.372	0.0404	0.680
327	0.600	1.055	0.504	0.0466	0.680
427	0.513	1.076	0.650	0.0523	0.684
527	0.450	1.097	0.870	0.0578	0.689
627	0.401	1.112	0.974	0.0628	0.696
727	0.359	1.143	1.160	0.0676	0.702
927	0.301	1.176	1.540	0.0763	0.714
1127	0.257	1.214	1.970	0.0844	0.726
1327	0.225	1.248	2.420	0.0926	0.741
1527	0.201	1.285	2.900	0.0995	0.759
1727	0.179	1.340	3.450	0.1059	0.783
1927	0.163	1.419	4.010	0.1118	0.831
2127	0.149	1.574	4.620	0.1175	0.916

IMPERICAL RELATION FOR FREE CONVECTION

العلاقات التجريبية للحمل الحر

The mean convection heat transfer coefficient (h) can be expressed by N_{NU} معامل انتقال الحرارة بالحمل يعبر عنه بعدد

$$h=\frac{N_{NU}*k}{d}$$

$$N_{NU}=C(N_{Gr}*N_{Pr})^m$$

المعادلة العامة للحمل الحر

Where $m=0.25$ **for laminar flow** للجريان الطباقي

$m=0.33$ **for turbulent flow** للجريان الاضطرابي

$(N_{Gr}*N_{Pr}) = N_{Ra}$ = Rayleigh number = عدد رايليه

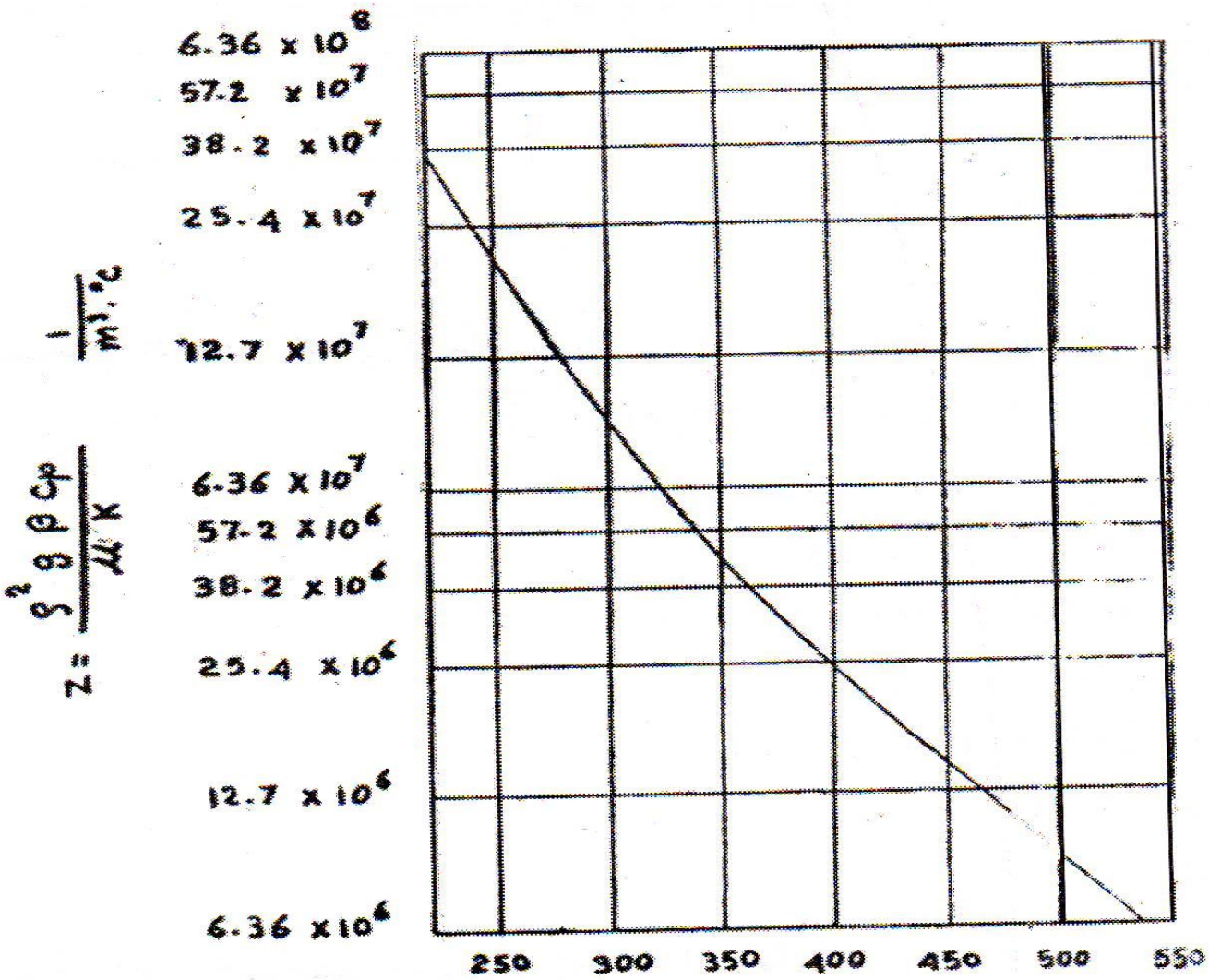
$$(N_{Gr}*N_{Pr}) = N_{Ra} = D^3 * \Delta t * \left[\frac{(g*\beta*\rho^2*cp)}{\mu*k}\right]$$

$$(N_{Gr}*N_{Pr}) = N_{Ra} = D^3 * \Delta t * Z$$

$$Z = \frac{g*\beta*\rho^2*cp}{\mu*k} \quad \text{in } \frac{1}{m^3.°k}$$

قيمةz للهواء تؤخذ من خارطة خاصة وعند درجة حرارة الطبقة الحدودية بالكلفن

The value of z for air only in chart

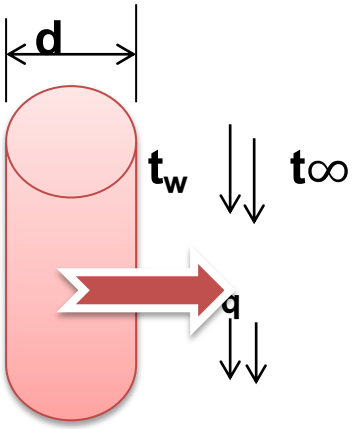


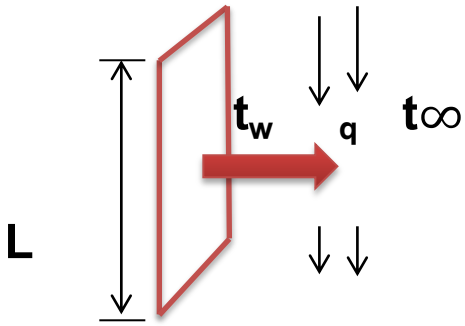
درجة حرارة الطبقة الحدية Tf (k) (عند ضغط 1 جوي)

شكل (3–6) بياني لتعيين قيم Z للهواء

HEAT TRANSFER FROM VERTICAL SURFACES الاسطح العمودية AND CYLINDERS BY FREE CONVECTION

انتقال الحرارة بالحمل الحر من الاسطح العمودية والاسطوانات العمودية





$$(N_{Nu})=C*(N_{Gr}*N_{Pr})^m$$

If $10^9 > (N_{Gr}*N_{Pr}) > 10^4$ the flow is laminar

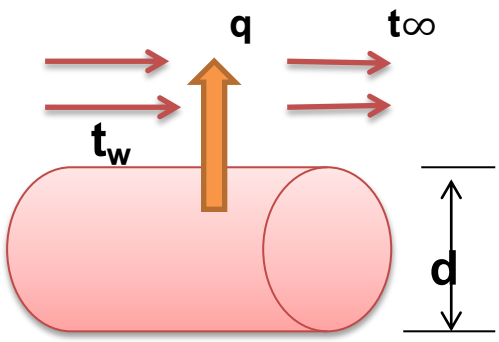
$$N_{Nu}=0.59(N_{Gr}*N_{pr})^{0.25}$$

If $10^{12} > (N_{Gr}*N_{Pr}) > 10^9$ the flow is turbulent

$$N_{Nu}=0.13(N_{Gr}*N_{pr})^{0.33}$$

HEAT TRANSFER FROM HORIZONTAL الافقية CYLINDERS BY FREE CONVECTION

انتقال الحرارة بالحمل الحر من الاسطوانات الافقية



If $10^9 > (N_{Gr*}N_{Pr}) > 10^4$ the flow is laminar

$$N_{Nu}=0.53(N_{Gr*}N_{pr})^{0.25}$$

If $10^{12} > (N_{Gr*}N_{Pr}) > 10^9$ the flow is turbulent

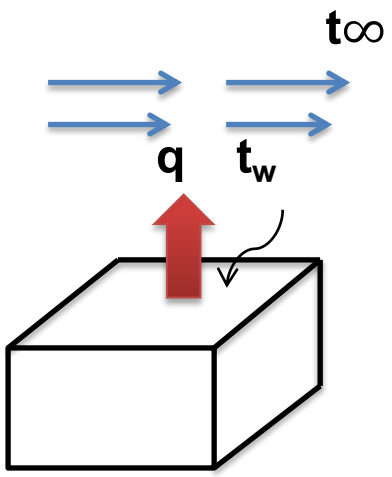
$$N_{Nu}=1.24(N_{Gr*}N_{pr})^{0.33}$$

HEAT TRANSFER BY FREE CONVECTION FROM HORIZONTAL SQUARE SURFACES

انتقال الحرارة بالحمل الحر من الاسطح الافقية المربعة

A)SQUARE SURFACE WHICH IS UP HOT OR DOWN COLD

السطح الافقي المربع ساخن من الاعلى وبارد من الاسفل



If $2*10^7 > (N_{Gr*}N_{Pr}) > 10^5$ the flow is laminar

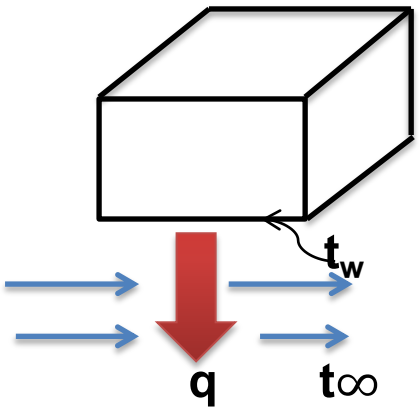
$$N_{Nu}=0.54(N_{Gr*}N_{pr})^{0.25}$$

If $3*10^{10} > (N_{Gr*}N_{Pr}) > 2*10^7$ the flow is turbulent

$$N_{Nu}=0.14(N_{Gr*}N_{pr})^{0.33}$$

B)SQUARE SURFACE WHICH IS UP COLD OR DOWN HOT

السطح الافقي المربع بارد من الاعلى وساخن من الاسفل

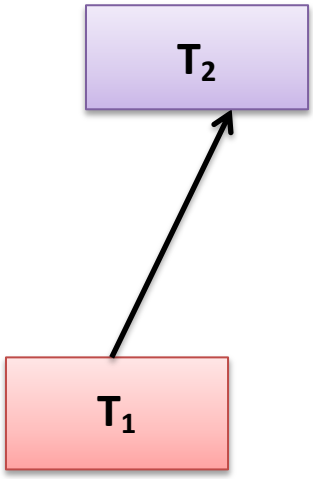


$N_{Nu}=0.27(N_{Gr*}N_{pr})^{0.25}$ for laminar flow

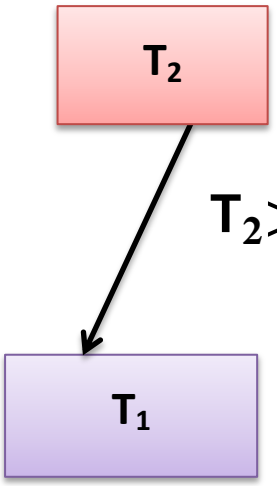
$N_{Nu}=0.14(N_{Gr*}N_{pr})^{0.33}$ for turbulent flow

HEAT EXCHANGED BY RADIATION BETWEEN BLACK BODIES

التبادل الحراري بالإشعاع بين الاسطح السوداء



$T_1 > T_2$ او $T_2 > T_1$



$q_{1\to2} = б * A_1 * F_{1\to2}(T_1^4 - T_2^4)$------ in W

$q_{2\to1} = б * A_2 * F_{2\to1}(T_2^4 - T_1^4)$------ in W

$q_{1\to3} = б * A_1 * F_{1\to3}(T_1^4 - T_3^4)$------ in W

$q_{3\to1} = б * A_3 * F_{3\to1}(T_3^4 - T_1^4)$

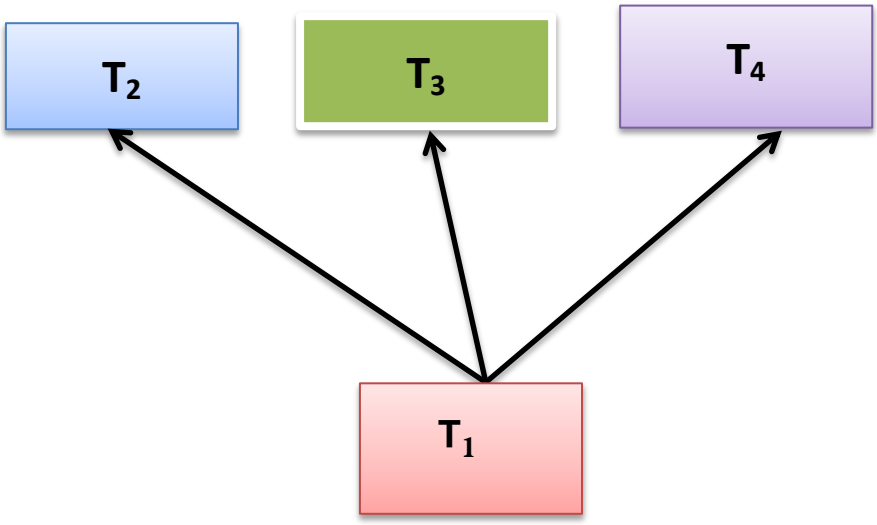
$q_{1\to2} = -q_{2\to1}$

$q_{1\to3} = -q_{3\to1}$

F=configuration factor= معامل الشكل وهو خالي من الوحدات

ومعامل الشكل يحدد كمية المساحة التي يراها احد السطحين من الاخر لذا فهو يعتمد على وضع السطحين وزاويتهما بالنسبة لبعضهما وكذلك مدى استوائية او تقعر او تحدب السطحين ويؤخذ من جداول خاصة.

For many black bodies ولعدة اسطح سوداء



$$q_{net}=\sigma * A_1 * F_{1\to2}(T_1^4-T_2^4)+\sigma * A_1 * F_{1\to3}(T_1^4-T_3^4)+\sigma * A_1 * F_{1\to4}(T_1^4-T_4^4)$$

if the two black bodies are parallel and large اذا كانت الاسطح السوداء متوازية ولا متناهية بالكبر

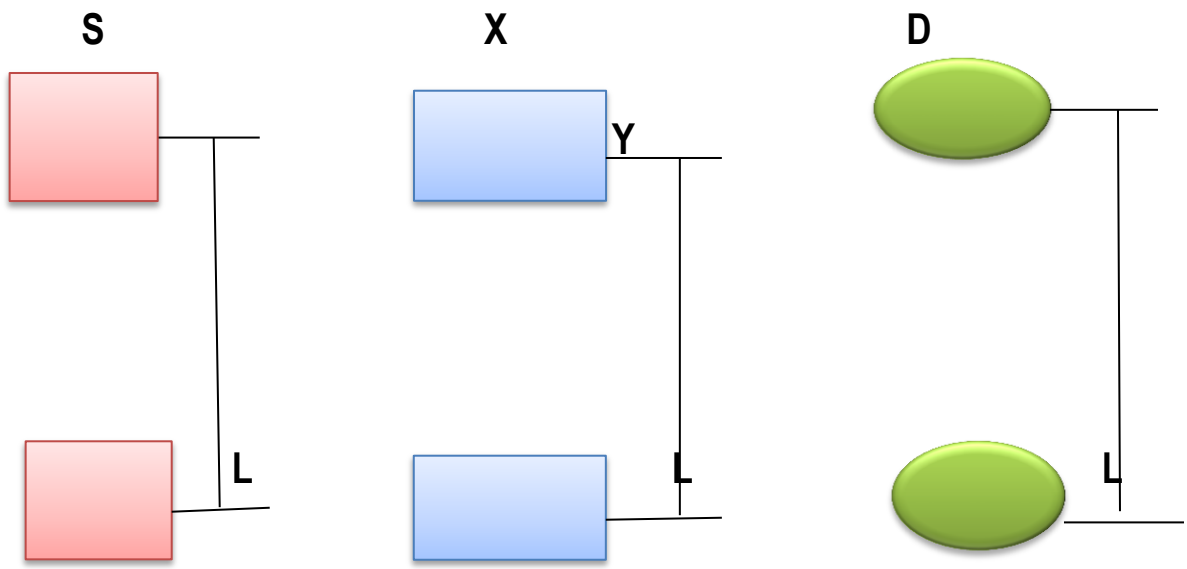
$$F_{1\to2}=F_{2\to1}=1$$

$$\therefore q_{1\to2}=\sigma * A\,(T_1^4-T_2^4)\text{-------in W}$$

$$q''_{1\to2}=\sigma\,(T_1^4-T_2^4)\text{-------in W/m}^2$$

HEAT EXCHAGED BY RADIATION BETWEEN BLACK EQUALL PARALLEL SQUARES,DISKS,RECTANGULARS

التبادل الحراري بالاشعاع بين الاسطح السوداء المتوازية على شكل مربعات او اقراص او مستطيلات



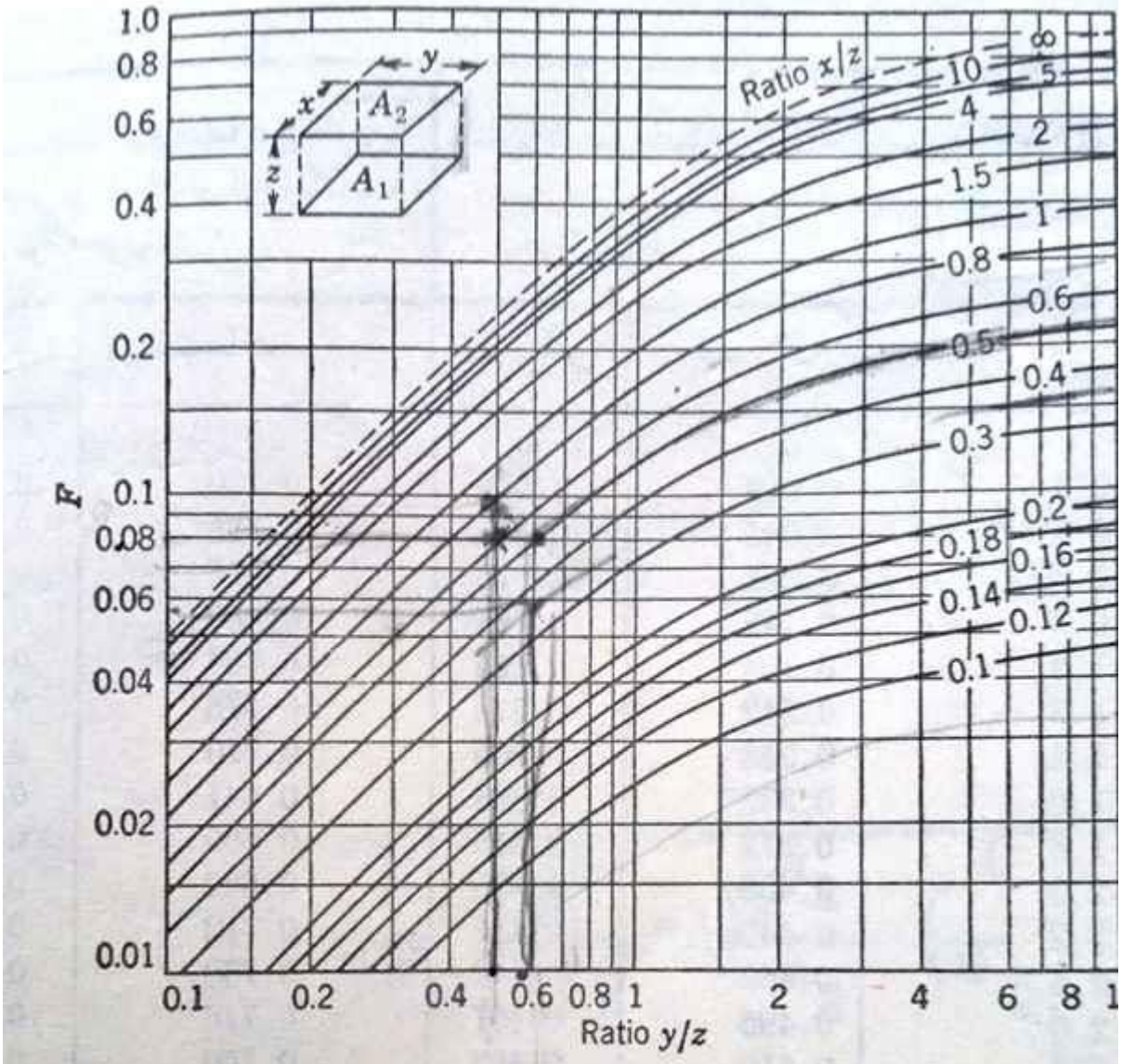
For parallel square black bodies, and for parallel disks , configuration factor (F) معامل depends on <u>square side</u> (S) طول ضلع المربع or <u>diameter of disk</u> (D) او قطر القرص to the <u>distance between them</u> (L) الى المسافة بينهما, thus it taken from tables:-

معامل الشكل للاسطح السوداء المتوازية على شكل مربعات او اقراص او اشكال متوازية يعتمد على طول ضلع المربع او قطر القرص او ابعاد المستطيل والمسافة بين هذه الاسطح ويؤخذ من جداول خاصة

نسبة طول الضلع او القطر الى المسافة بين المستويين	مستويات غير متصلة بحوائط		مستويات متصلة ببعضها بحوائط غير موصلة للحرارة	
	مربعات	اقراص	مربعات	اقراص
0	0	0	0	0
0.2	0.018	0.010	0.200	0.186
0.4	0.045	0.038	0.325	0.309
0.6	0.091	0.075	0.415	0.394
0.8	0.142	0.125	0.480	0.461
1	0.194	0.175	0.534	0.512
1.2	0.242	0.226	0.575	0.552
1.4	0.288	0.269	0.610	0.590
1.6	0.332	0.308	0.641	0.620
1.8	0.372	0.345	0.669	0.646
2	0.408	0.380	0.692	0.669
2.2	0.440	0.411	0.712	0.689
2.4	0.469	0.440	0.730	0.708
2.6	0.495	0.467	0.746	0.724
2.8	0.519	0.492	0.760	0.739
3.0	0.542	0.515	0.772	0.753
3.2	0.562	0.536	0.782	0.766
3.4	0.581	0.556	0.791	0.778
3.6	0.599	0.575	0.799	0.788
3.8	0.616	0.593	0.807	0.797
4.0	0.632	0.609	0.814	0.804
4.2	0.647	0.624	0.821	0.813
4.4	0.661	0.638	0.827	0.820
4.6	0.673	0.651	0.833	0.826
4.8	0.684	0.662	0.839	0.831
5.0	0.693	0.672	0.844	0.836
5.2	0.701	0.681	0.849	0.841
5.4	0.709	0.689	0.853	0.845
5.5	0.716	0.697	0.857	0.849
5.6	0.722	0.703	0.861	0.852
5.8	0.729	0.709	0.864	0.855
6.0	0.736	0.716	0.867	0.858
6.2	0.743	0.732	0.870	0.861
6.4	0.749	0.730	0.873	0.864
6.6	0.756	0.737	0.857	0.867
6.8	0.763	0.743	0.878	0.870
7.0	0.770	0.750	0.881	0.873

Figure (1)

واما بالنسبة للمستطيلات فيتم استخراج معامل الشكل من الخارطة التالية:-



شكل (6) ـ معامل الشكل للمستطيلات المتوازية

EXAMPLE(1):- calculate the radial energy per unit area احسب الطاقة الاشعاعية لوحدة المساحة between two infinite black bodies بين سطحين اسودين لا متناهين بالكبر if the temperatures of bodies are (500℃),(200℃) respectively على الترتيب.

Solution:-

$F_{1\to2} = F_{2\to1} = 1$ for infinite body

$T_1 = 500+273 = 773°k$

$T_2 = 200+273 = 473°k$

$q_{1\to2} = б * A * F_{1\to2}(T_1^4 - T_2^4)$

$q''_{1\to2} = б * F_{1\to2}(T_1^4 - T_2^4)$

$q''_{1\to2} = 5.67 * 1 * \left\{\left(\frac{773}{100}\right)^4 - \left(\frac{473}{100}\right)^4\right\}$, $\left(\frac{773}{100}\right)^4 = \frac{773^4}{100^4} = 773^4 * 10^{-8}$

$q''_{1\to2} = (17406.11)\ w/m^2$

EXAMPLE(2):- Two black parallel disks قرصان اسودان متوازيان have same area لهما نفس المساحة each one of (60cm)diameter قطر كل منهما , placed موضوعة بحيث ان so that the distance between them المسافة بينهما is (30cm).the temperatures of disks are (250°c),(150°c). calculate the net radial energy exchanged between the two disks per square meter احسب صافي الطاقة الاشعاعية المتبادلة بينهما لكل متر مربع.

Solution:-

$T_1 = 250+273 = 523°k$

$T_2 = 150+273 = 423°k$

$q_{1\to2} = б * A * F_{1\to2}(T_1^4 - T_2^4)$

$\frac{D}{L} = \frac{60}{30} = 2$

F for disk from chart=0.38

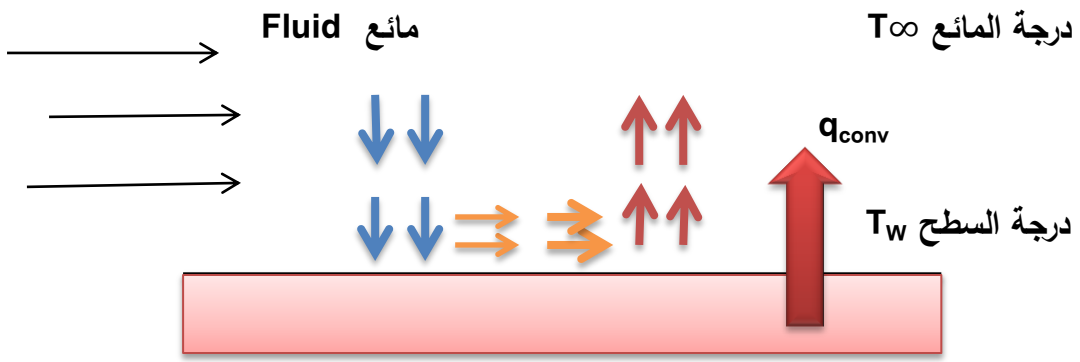
$q_{1\to2} = 5.67 \times 1 \times 0.38 \times (5.23^4 - 4.23^4) = (4711.27)$w

Chapter three

CONVECTION HEAT TRANSFER

انتقال الحرارة بالحمل

Convection heat transfer occur يحدث between بين a heated solid surfaces الاسطح الصلبة الساخنةand contact fluids والموائع الملامسة لها when there is a temperature difference between them عندما يكون هناك فرق في درجات الحرارة.



CONVECTION

- **FREE CONVECTION** — الحمل الحر
- **FORCED CONVECTION** — الحمل الجبري

For each type of convection on we use newton's law ولكلا النوعين يستخدم قانون نيوتن

$$q = h * A * \Delta t$$

قانون نيوتن للحمل

q =convection heat transfer rate in w

A=area in m^2

$\Delta t = t_w - t_\infty$

t_w=surface temperature in ^{0}k درجة حرارة السطح

$t\infty$ =fluid temperature in ^{0}k درجة حرارة المائع

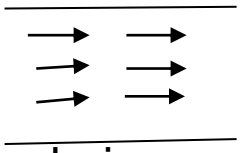
h :convection heat transfer coefficient in w/m^2.^{0}k معامل المواصلة السطحية بالحمل

** h depends يعتمد على on different variables متغيرات كثيرة such as shape كالشكل كثافة density,درجة خشونة السطح roughness of Surface, ابعاد السطح dimension,للسطح موصليته الحرارية thermal conductivity of fluid, حرارته النوعية specific heat, لزوجتهviscosity,المائع and velocityسرعته .

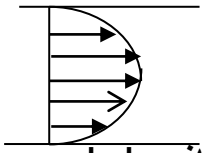
SIMILARITY OF FLOW OF FLUIDS التشابه في جريان الموائع

There are two types of flow:-

1-laminar flow الجريان الطباقي:-it is the flow at which the fluid molecules جزيئات المائع move تتحرك in parallel layers بشكل طبقات متوازية.

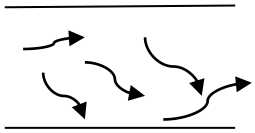


laminar

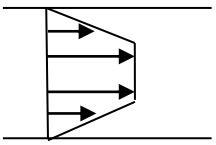


parabola قطع مكافئ

2-turbulent flow الجريان الاضطرابي:- it is the flow at which the fluid molecules جزيئات المائع have eddies تكون دوامات.



Turbulent



curve منحني منبسط

To determine the type of flow we calculate Reynol،s number (N_{Re})

ولتحديد نوع الجريان يتم حساب عدد رينولد

$$(N_{Re})=\frac{u*d}{\nu}$$

Where:-

u = velocity in $\frac{m}{sec}$ سرعة المائع بوحدة

$d = \text{diameter in m.}$ قطر الانبوب بوحدة

ν =Kinematic viscosity in m^2/sec اللزوجة الكينماتية بوحدة

$$\nu = \frac{\mu}{\rho}$$

$\mu = \text{dynamic viscosity in Pa} * \text{sec.}$ اللزوجة الدينامية بوحدة

ρ= density of fluid in kg/m^3 كثافة المائع بوحدة

For circular tubes if في الانابيب الدائرية المقطع

$N_{Re} < 2300$ the flow is laminar

$N_{Re} > 2300$ the flow is turbulent.

2300 is critical Reynol's number (N_{Re}) رقم رينولد الحرج

$N_{Re} > 3000$ the flow is fully turbulent. اضطرابي كليا

MOST DIMENSIONLESS GROUPS اهم المجاميع اللابعدية

1- Reynol's number عدد رينولد $(N_{Re}) = \frac{u*d}{\nu}$

2- Grashof number عدد كراشوف $(N_{Gr}) = \frac{g*\beta*\Delta t*\rho^2*D^3}{\mu^2}$ او

$(N_{Gr}) = \frac{g*\beta*\Delta t*D^3}{\nu^2}$

3- Prandtl number عدد براندتل $(N_{Pr}) = \frac{\mu*cp}{K}$

4-Nusselt number عدد نوسلت $(N_{Nu}) = \frac{h*d}{K}$

β is the bulk modulus of expansion in $\frac{1}{°K}$ معامل التمدد الحجمي

β للماء تاخذ من الجداول , $\beta = \frac{1}{t\infty+273}$ للغازأو الهواء

C_P is the specific heat in J/kg.^{0}k الحرارة النوعية للمائع بوحدة

EXAMPLE(1):- prove اثبت ان that N_{Re} is a dimensionless groupعدد لا بعدي

Length :L :m

Mass :M :kg

Time :t :sec

Temperature :T:℃ ,^{0}k

$u = m/sec = L*t^{-1}$

D=m=L

$\nu = m^2/sec = L^2*t^{-1}$

$$(N_{Re}) = \frac{u*d}{\nu} = \frac{L*t^{-1}*L}{L^2*t^{-1}} = \frac{L^2*t^{-1}}{L^2*t^{-1}} = 1$$

EXAMPLE(2):- prove that N_{NU} is a dimensionless group

$$(N_{Nu}) = \frac{h*D}{k}$$

$$h = \frac{w}{m^2.°k} = \frac{J}{sec*m^2.°k} = \frac{N*m}{sec*m^2.°k} = \frac{kg*m*m}{sec^3*m^2.°k} =$$

$$h = \frac{kg*m^2}{sec^3*m^2.°k} = \frac{kg}{sec^3*°k}$$

D=m=L

$$K=\frac{w}{m.^{\circ}k}=\frac{J}{sec*m.^{\circ}k}=\frac{N*m}{sec*m.^{\circ}k}=\frac{kg*m*m}{sec^{3}*m.^{\circ}k}=\frac{kg*m}{sec^{3}*^{\circ}k}$$

$$(N_{Nu})=\frac{h*D}{k}=\frac{\frac{kg}{sec^{3}*^{\circ}k}*m}{\frac{kg*m}{sec^{3}*^{\circ}k}}=1$$

<u>Home work(1):</u>-prove that N_{Gr} is a dimensionless group

<u>Home work(2):</u>- prove that N_{pr} is a dimensionless group

Q3- Calculate the heat transfer rate from a hot vertical surface of 15cm high and 23cm width at a temperature of 124 ℃to the air at 38℃ .

Solution

----------:-

$$T_f = \frac{t_w + t_\infty}{2} = \frac{124+38}{2} = 81℃+273=354°K$$

By using the chart of Z and at T_f we find Z

$$Z = 38.2*10^6 + (57.2 - 38.2)*10^6 * \frac{2}{7} = 4.36*10^7 \frac{1}{m^3.℃}$$

$$N_{Ra} = N_{Gr}.N_{Pr} = L^3*\Delta t*Z = (0.15)^3*(86)*4.36*10^7 = 1.26*10^7 \frac{1}{m^3.℃}$$

$$N_{Ra} = 1.26*10^7 \frac{1}{m^3.℃}$$

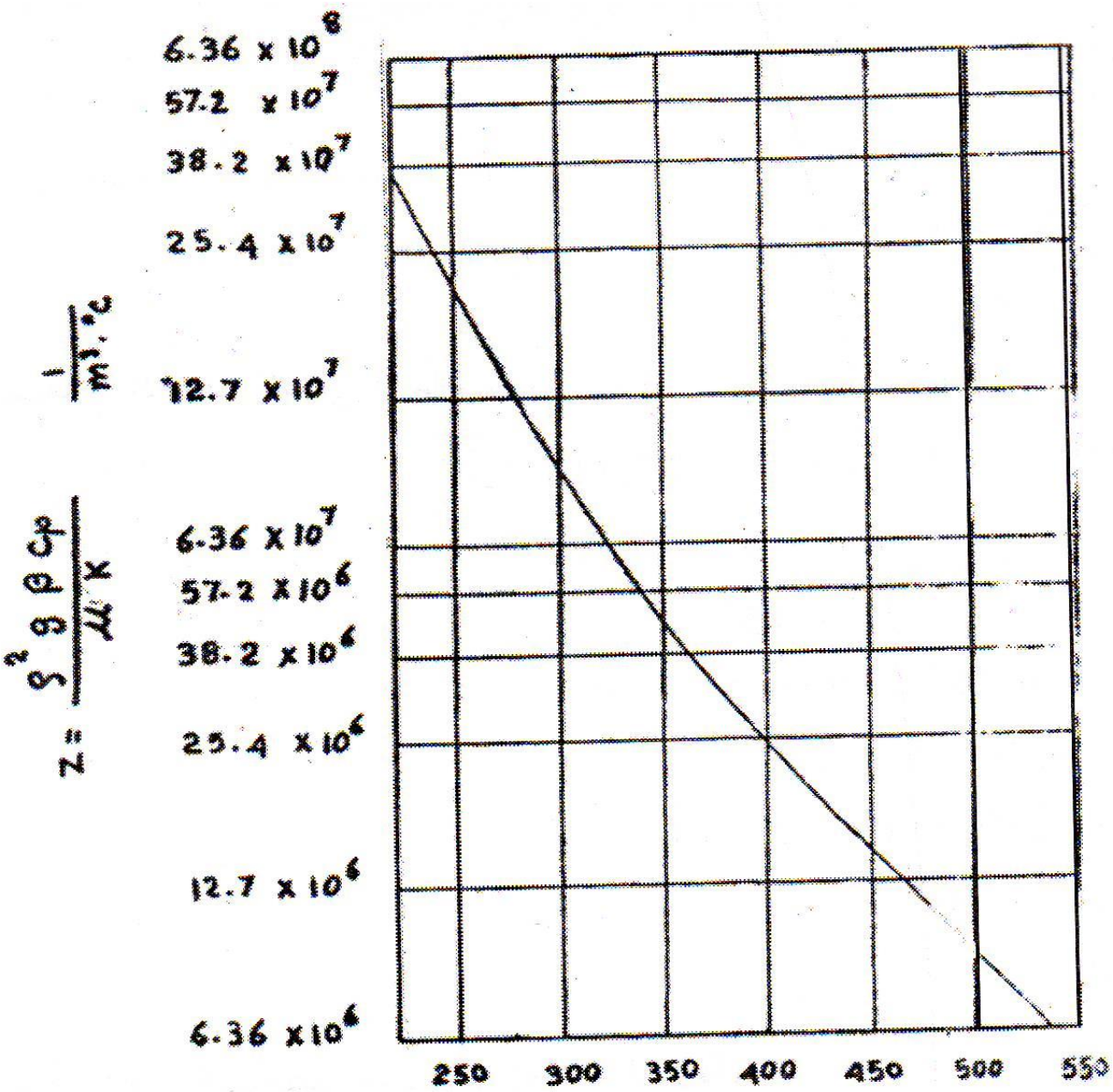
$10^9 > N_{Ra} > 10^4$ **the flow is laminar**

$$N_{nu} = 0.59(1.26*10^7)^{0.25} = 35.15$$

k for air from tables of air at t_f=81℃ is 0.0302 w/m.^{0}k

$$h = \frac{Nnu*k}{L} = \frac{35.15*0.0302}{0.15} = 6.89\ w/m^2.°k$$

$$q = h*A*\Delta t = 20.44\ W$$



درجة حرارة الطبقة الحدية **Tf (k)** (عند ضغط **1** جوي)

شكل (**3–6**) بياني لتعيين قيم **Z** للهواء

Q6-Along pipe of 8cm outside diameter passing horizontally through a room with air temperature of 22 ℃.the outside surface temperature of tube is 102℃ . Calculate the heat transfer rate by free convection from the outside surface area of tube to the air .

Q7-if the pipe of Q6 passing through water at atmospheric pressure and same air temperature. Calculate the heat transfer rate by free convection from the outside surface temperature of tube to the water.

Solution

---------- :

$$T_f = \frac{t_w + t_\infty}{2} = \frac{102+22}{2} = 62℃$$

From tables of water and at 62℃ we find:-

$\nu = 0.00467 * 10^{-4} cm^2/sec$, $Cp = 4.186 * 10^3$ J/kg.°k

$\rho = 981.9$ kg/m^3 , k=0.649 w/m.°k , $\beta = 0.000551 \frac{1}{o_k}$

$N_{pr} = 2.93$

$$N_{Ra} = N_{Gr} * N_{pr} = \frac{g * \beta * \Delta t * d^3}{\nu^2} \times N_{pr} = \frac{9.8 * 0.000551 * 80 * (0.08)^3}{(0.00467 * 10^{-4})^2} \times 2.93$$

$N_{Ra} = 2.9 * 10^9$

$10^{12} > N_{Ra} > 10^9$ the flow is turbulent

$N_{Nu} = 1.24 (N_{Ra})^{0.33} = 1.24 (2.9 * 10^9)^{0.33} = 1664.42$

k for water from tables of water at $t_f = 62℃$ is 0.649 w/m.°k

$$h = \frac{Nnu * k}{d} = \frac{1664.42 * 0.649}{0.08} = 13340.36 \text{ w/m}^2.°k$$

$q'' = h * \Delta t = 13340.36 * 80 = 1067.22$ kw/m^2

Q8// if Grashof and Prandtl numbers of fluid surrounding a horizontal cylinder with 5cm diameter are 10^4 and 10 respectively .assuming the thermal conductivity of fluid is 0.029 w/m.°k.calculate the convection heat transfer coefficient between fluid and cylinder also the heat transfer rate by free convection from 55m long of tube if the temperature of tube is 91℃ and the air temperature is 21℃.

Solution

---------- :

$N_{Gr} * N_{pr} = 10^5$

$10^9 > N_{Ra} > 10^4$ the flow is laminar

$N_{Nu}=0.53(N_{Ra})^{0.25}=0.53(10^5)^{0.25}=9.42$

$h=\frac{Nnu*k}{d}=\frac{9.42*0.029}{0.05}=5.46\ w/m^2.°k$

$h=5.46\ w/m^2.°k$

$q=h*A*\Delta t=5.46*\pi*0.05*55*70=3301.97\ W.$

Q9//An electric current passing through thermal silk of 10mm diameter and 10cm long, the silk submerged vertically in water at 40℃ under atmospheric pressure so that the water reach boiling temperature,if we assume the silk temperature is constant at 118℃ .calculate the electrical energy lost.

Solution

---------- :

$q=h*A*\Delta t$

$A=\pi*D*L=3.14*0.01*0.1=3.14*10^{-3}\ m^2$

$\Delta t=118-40=78℃$

$T_f=\frac{t_w+t_\infty}{2}=\frac{118+40}{2}=79℃\sim 80℃$

From tables of water and at 80℃ we find:-

$ע=0.00364*10^{-4}\ m^2/sec\quad,\ \beta=0.00065\ \frac{1}{o_k}$

$k=0.669\ w/m.°k\qquad,\ N_{pr}=2.22$

$N_{Ra}=N_{Gr}*N_{pr}=\frac{g*\beta*\Delta t*d^3}{ע^2}\times N_{pr}=\frac{9.8*0.00065*78*0.01^3}{(0.00364*10^{-4})^2}\times 2.22$

$N_{Ra}=8.32*10^6$

$10^9>N_{Ra}>10^4$ **the flow is laminar**

$N_{Nu}=0.59(N_{Ra})^{0.25}=0.59(8.32*10^6)^{0.25}=31.68$

$h=\frac{Nnu*k}{d}=\frac{31.68*0.669}{0.01}=2119.39\ w/m^2.°k$

$q=h*A*\Delta t=2119.39*\pi*0.01*0.1*78=519.34\ W$

$q=519.34\ W$ = **electrical energy lost**

LOG-MEAN TEMPERATURE DIFFERENCE(LMTD)

المتوسط اللوغاريتمي لفرق درجات الحرارة

لحساب معدل الحرارة المتبادلة بين المائعين في المبادل الحراري نستخدم القانون التالي

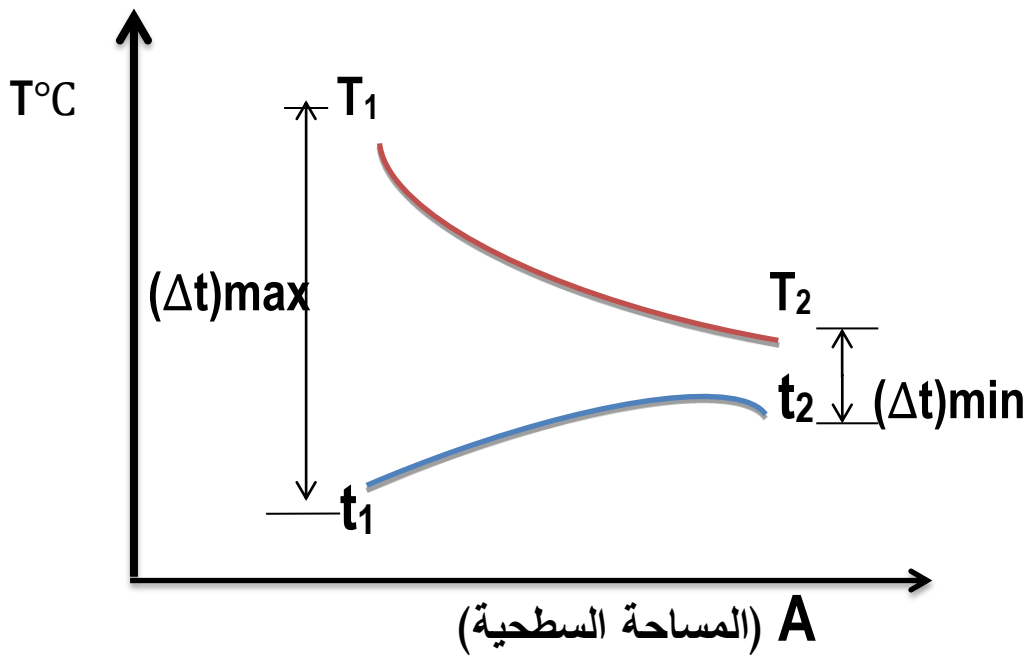
$$q = U * A * (\Delta t)_{ln}$$

Heat exchanged in heat exchanger الحرارة المتبادلة بين المائعين في المبادل الحراري

Δt_{ln} = LMTD= log-mean temperature difference المتوسط اللوغاريتمي لفرق درجات الحرارة

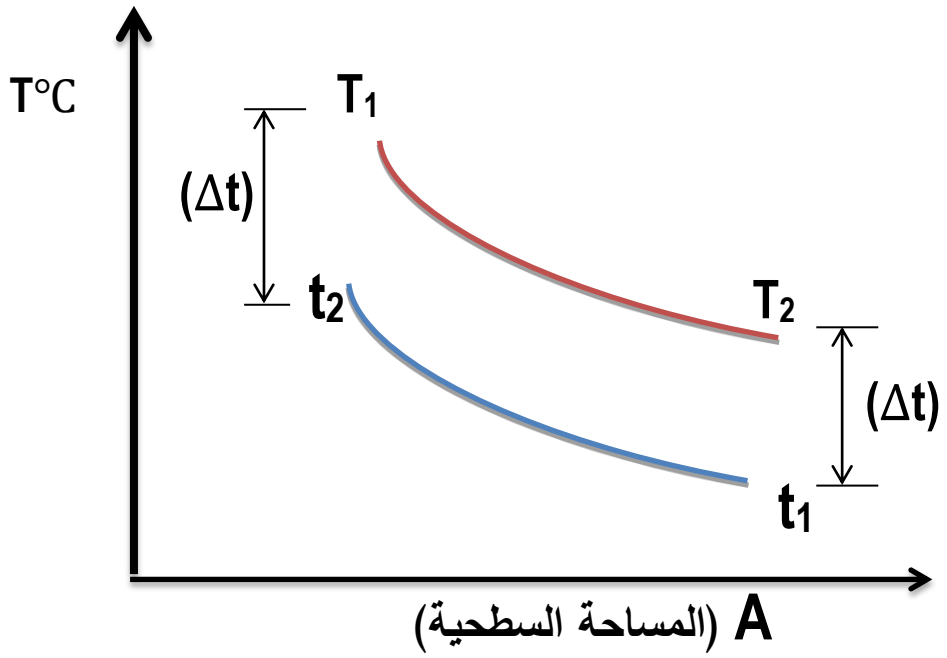
$$(\Delta t)_{ln} = \frac{(\Delta t)max - (\Delta t)min}{ln\frac{(\Delta t)max}{(\Delta t)min}}$$

المتوسط اللوغاريتمي لفرق درجات الحرارة



$\Delta t_{max} = T_1 - t_1$

$\Delta t_{min} = T_2 - t_2$ لكل انواع المبادلات ماعدا المبادل المتعاكس



للمتعاكس يكون

$\Delta t = T_1 - t_2$

$\Delta t = T_2 - t_1$

CORRECTION FACTOR FOR (LMTD):-

معامل التصحيح للمتوسط اللوغاريتمي

For heat exchanger للمبادلات الحرارية of multi tubes and shells المتعددة الاغلفة والمسارات, we must correct يجب تصحيح the log mean temperature difference بمعامل يسمى معامل التصحيح by correction factor (F) المتوسط اللوغاريتمي

$(\Delta t)_{ln2} = (F) * (\Delta t)_{ln1}$

$(\Delta t)_{ln2}$:-after correct بعد التصحيح

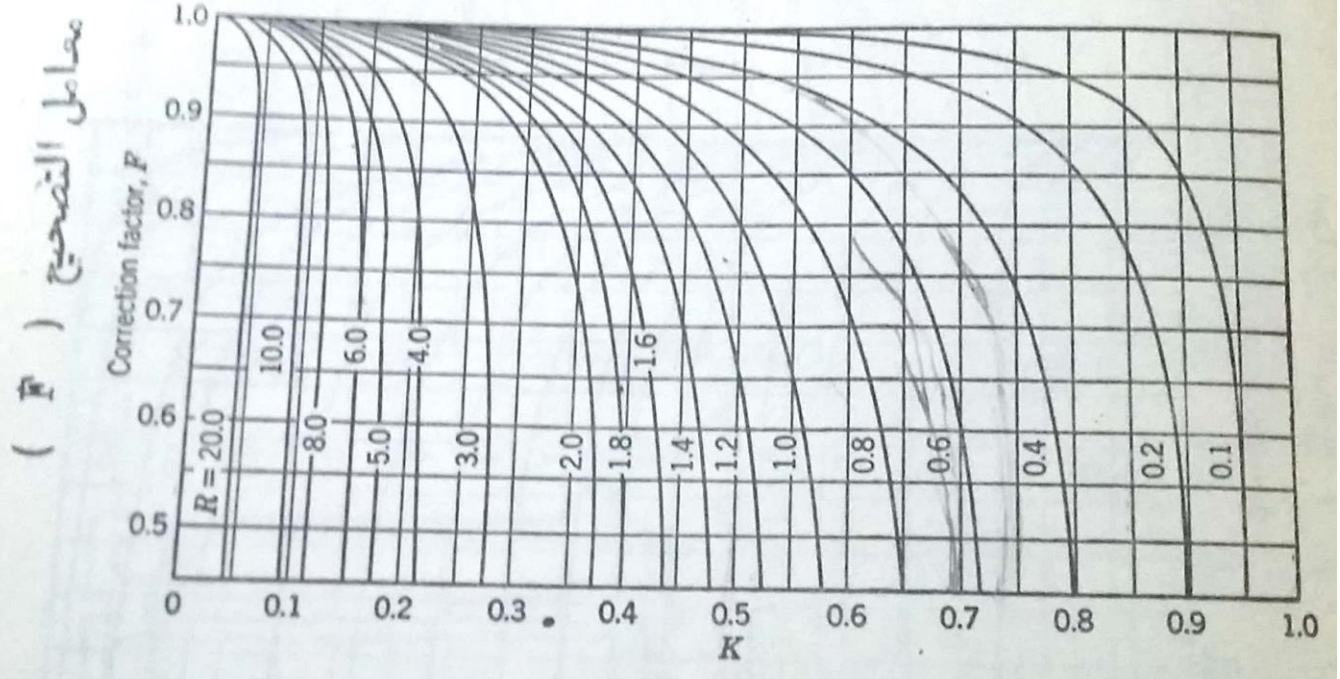
$(\Delta t)_{ln1}$:-before correct قبل التصحيح

(F) found in special charts for each heat exchanger , we use (R)and (K)

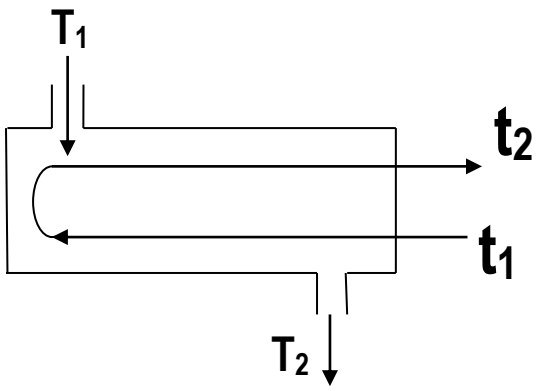
و يمكن استخراج معامل التصحيح من خارطة خاصة بالاعتماد على قيمتي

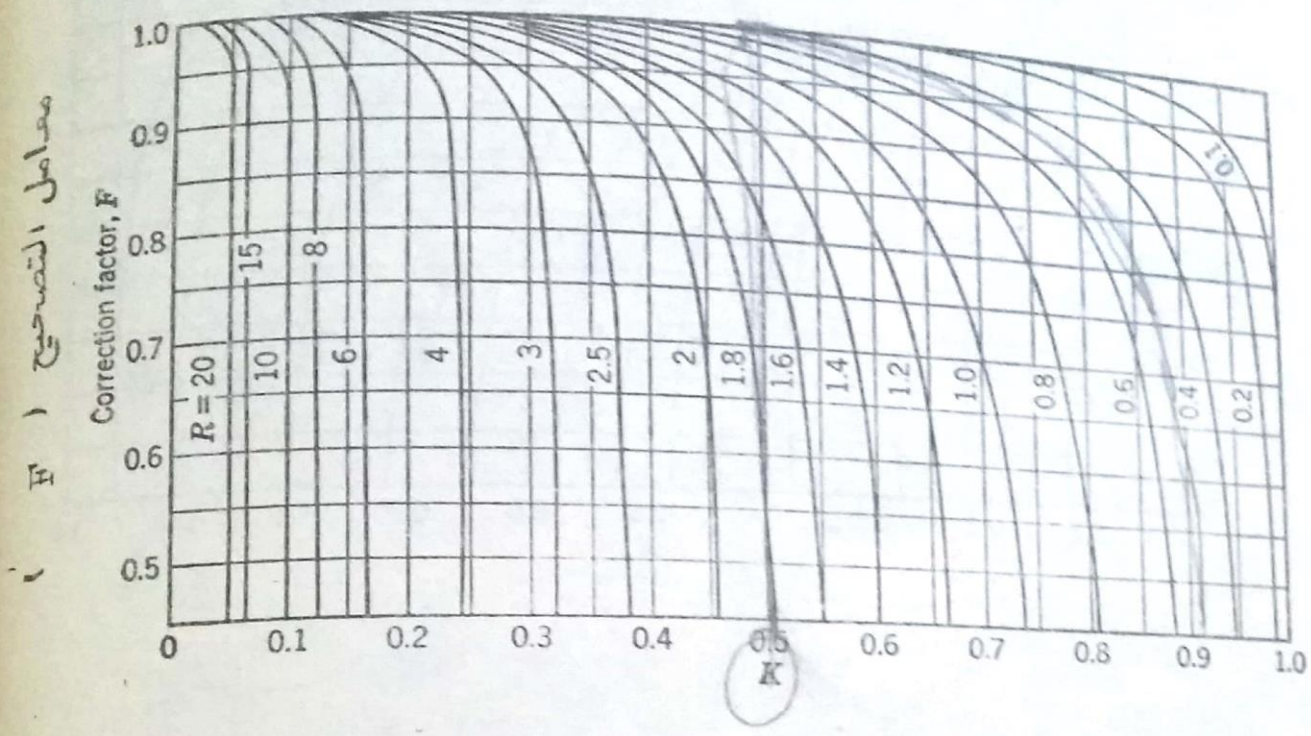
$$R=\frac{T_1 - T_2}{t_2 - t_1}$$

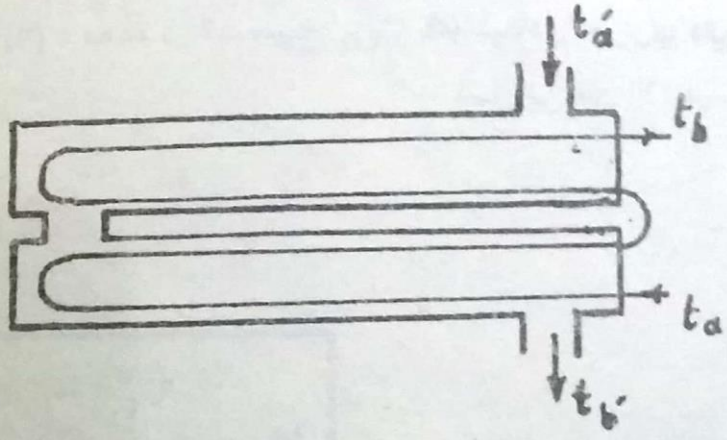
$$K=\frac{t_2 - t_1}{T_1 - t_1}$$



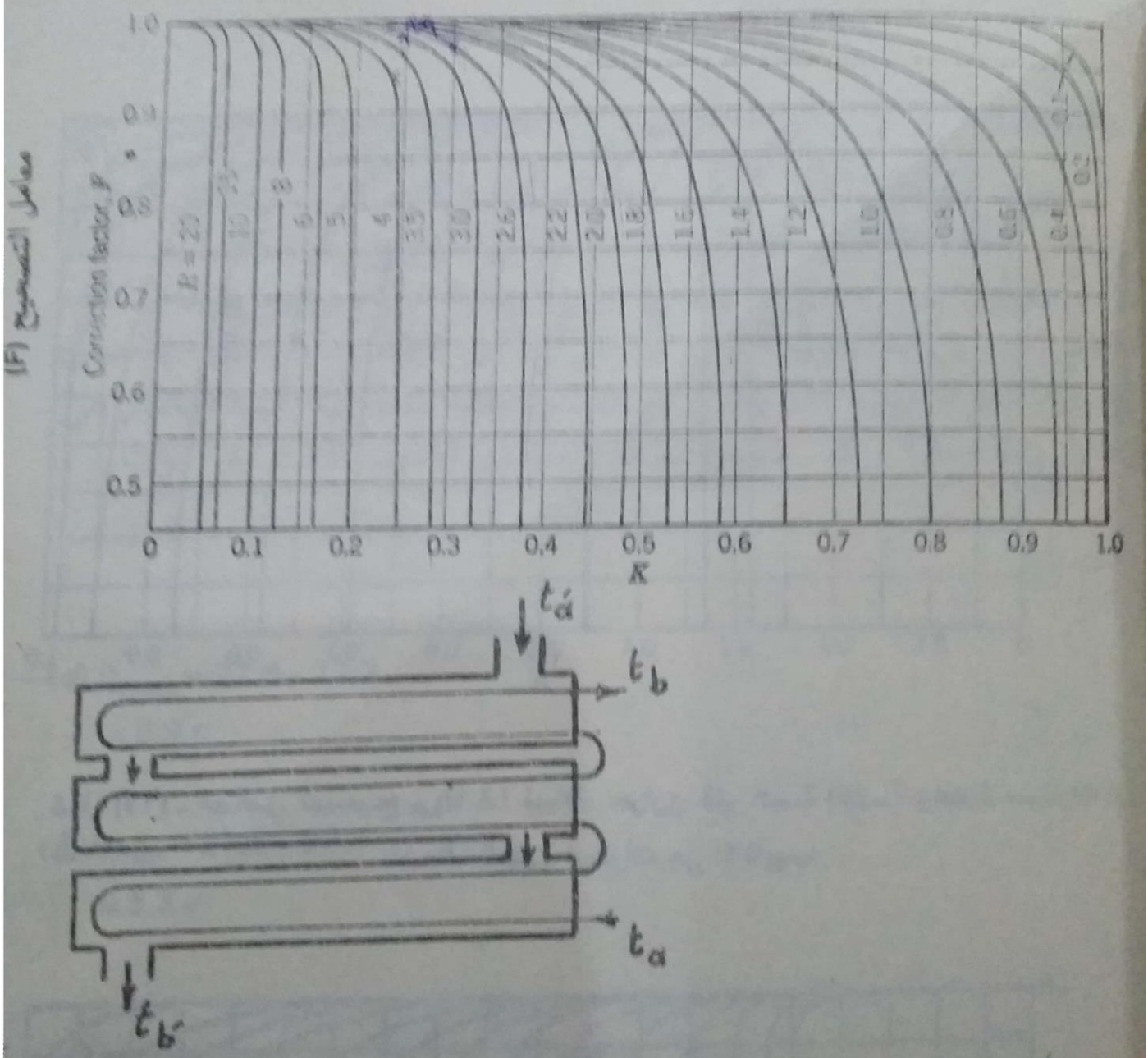
شكل (9) - معامل تصحيح $(\Delta t)_{Ln}$ لمبادل حراري ذي غلاف واحد ومسارين او اضعاف المسارين من الانابيب


T1
t2
t1
T2

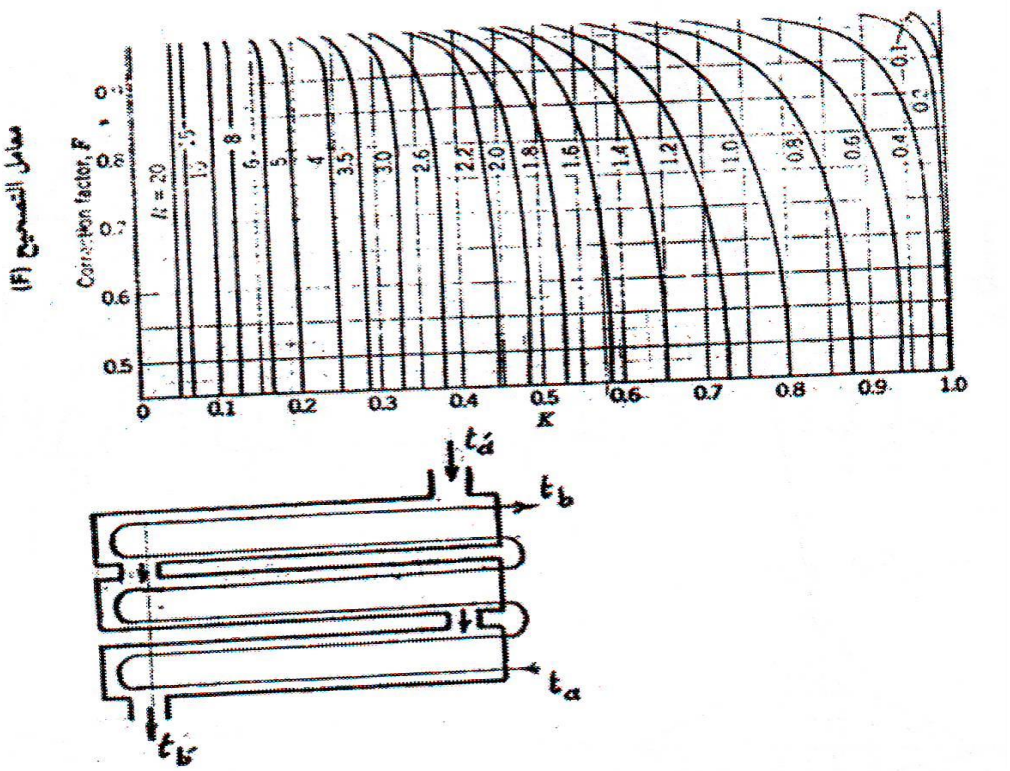




شكل (10) ـ معامل تصحيح $(\Delta t)_{Ln}$ للمبادل الحراري ذي الغلافين واربعة مسارات او اضعاف الاربعة مسارات من الانابيب



شكل (11) معامل تصحيح Δt_{Ln} لمبادل حراري ذي ثلاث الحلقة وستة مسارات او اضعاف الستة مسارات من الانابيب



Correction factor for heat exchanger with three shells and six tubes

FOR HEAT EXCHANGER

$q_{rejected} = q_{recived} = q_{exchanged}$

q rejected المفقودة $= m_h * c_h * \Delta T_h = m_h * c_h * (T_1 - T_2)$

q received المكتسبة $= m_c * c_c * t_c = m_c * c_c * (t_2 - t_1)$

q exchanged المتبادلة $= U * A * (\Delta t)_{ln}$