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ΤΜΗΜΑ ΕΝΕΡΓΕΙΑΚΗΣ ΤΕΧΝΟΛΟΓΙΑΣ

ΕΡΓΑΣΤΗΡΙΟ ΜΕΤΑΔΟΣΗΣ ΘΕΡΜΟΤΗΤΟΣ

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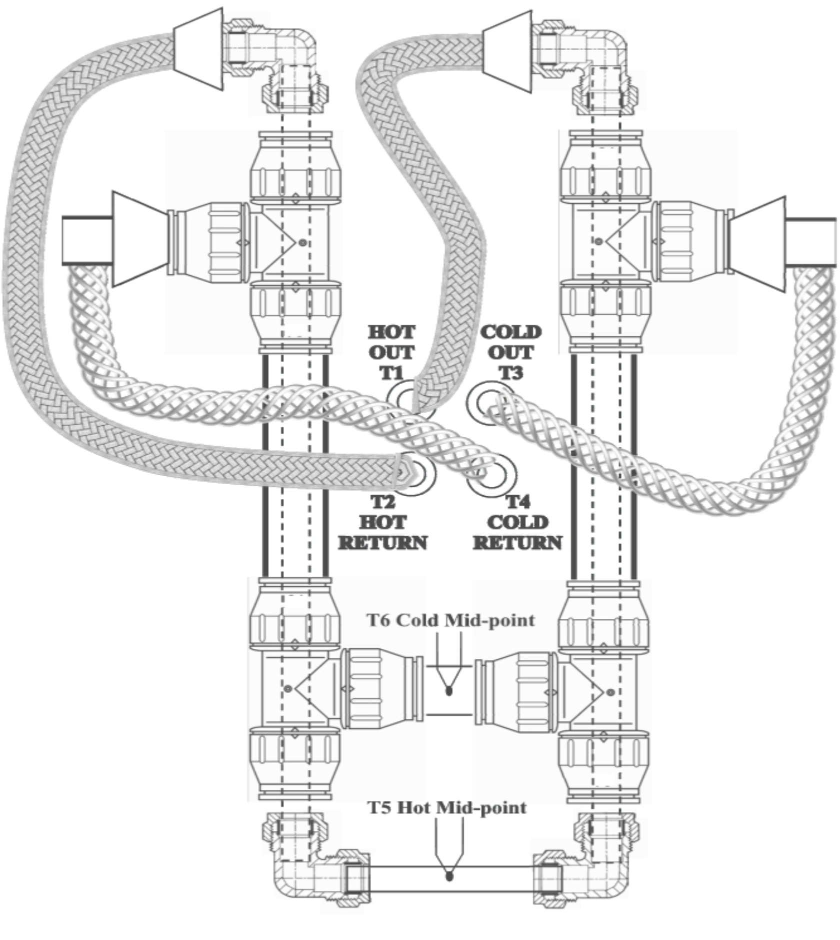
Η ΕΠΙΔΡΑΣΗ ΠΑΡΟΧΗΣ ΟΓΚΟΥ ΣΤΗΝ ΔΙΑΜΟΡΦΩΣΗ ΤΗΣ ΤΙΜΗΣ ΤΗΣ ΜΕΣΗΣ ΛΟΓΑΡΙΘΜΙΚΗΣ ΘΕΡΜΟΚΡΑΣΙΑΚΗΣ ΔΙΑΦΟΡΑΣ ΤΩΝ ΡΕΥΜΑΤΩΝ ΕΝΑΛΛΑΚΤΗ ΘΕΡΜΟΤΗΤΑΣ

Σκοπός : Η εργαστηριακή άσκηση έχει σαν σκοπό την διεξαγωγή μετρήσεων για την διερεύνηση της επίδρασης της παροχής όγκου των ρευμάτων ενός εναλλακτη θερμότητας στην τιμή της μέσης λογαριθμικής θερμοκρασιακής διαφοράς. Η άσκηση είναι δυνατόν να αναπτυχθεί για κάθε τύπο εναλλάκτη θερμότητας και διάταξη ρευμάτων (ομορροή - αντιρροή).

H101A Concentric Tube Heat Exchanger (Co-Current Flow)



T_{hi}=T1 **Θερμοκρασία εισόδου ζεστού νερού στον εναλλακτη**

T_{ho}=T2 **Θερμοκρασία εξόδου ζεστού νερού από τον εναλλακτη**

T_{ci}=T3 **Θερμοκρασία εισόδου ψυχρού νερού στον εναλλακτη**

T_{co}=T4 **Θερμοκρασία εξόδου ψυχρού νερού απο τον εναλλακτη**

T_{hm}=T5 **Μέση θερμοκρασία ζεστού νερού**

T_{cm}=T6 **Μέση θερμοκρασία ψυχρού νερού**

Δυνατότητες της εργαστηριακής διάταξης

1) Demonstration Of Indirect Heating Or Cooling By Transfer Of Heat From One Fluid Stream To Another When Separated By A Solid Wall (Fluid To Fluid Heat Transfer).

2) To perform an energy balance across a concentric tube heat exchanger and calculate the overall efficiency at different fluid flow rates

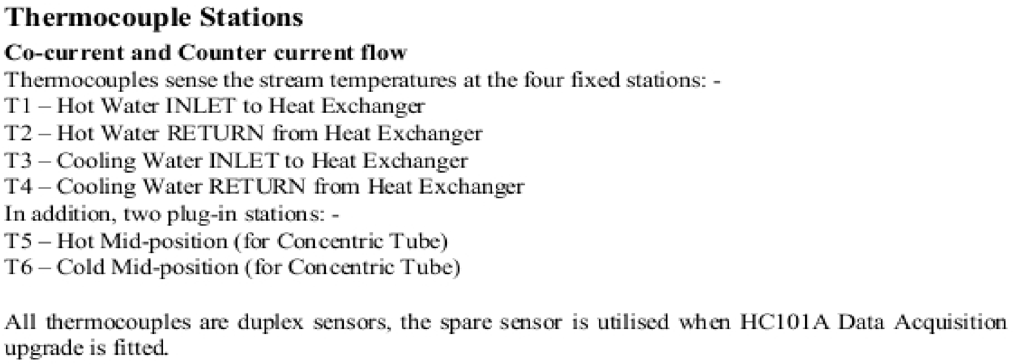
3) To demonstrate the differences between counter-current flow (flows in opposing directions) and co-current flows (flows in the same direction) and the effect on heat transferred, temperature efficiencies and temperature profiles through a concentric tube heat exchanger

4) To determine the overall heat transfer coefficient for a concentric tube heat exchanger using the logarithmic mean temperature difference to perform the calculations (for counter-current and co-current flows).

5) To investigate the effect of changes in hot fluid and cold fluid flow rate on the temperature efficiencies and overall heat transfer coefficient.

6) To investigate the effect of driving force (difference between hot stream and cold stream temperature) with counter-current and co-current flow.

Παραδείγματα θερμοκρασιακής κατανομής σε **ομορροή – αντιρροή**

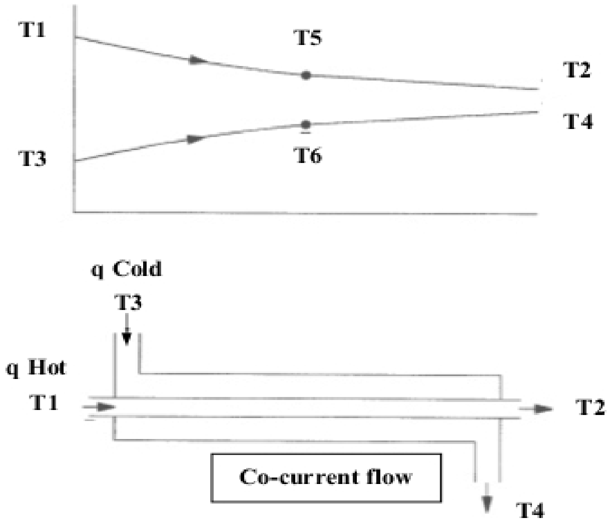


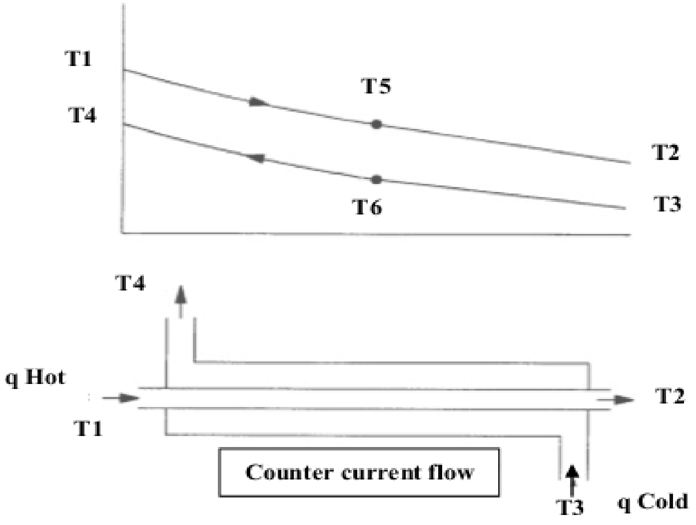
Thermocouple Stations

Co-current and Counter current flow

Thermocouples sense the stream temperatures at the four fixed stations: -
T1 – Hot Water INLET to Heat Exchanger
T2 – Hot Water RETURN from Heat Exchanger
T3 – Cooling Water INLET to Heat Exchanger
T4 – Cooling Water RETURN from Heat Exchanger
In addition, two plug-in stations: -
T5 – Hot Mid-position (for Concentric Tube)
T6 – Cold Mid-position (for Concentric Tube)

All thermocouples are duplex sensors, the spare sensor is utilised when HC101A Data Acquisition upgrade is fitted.

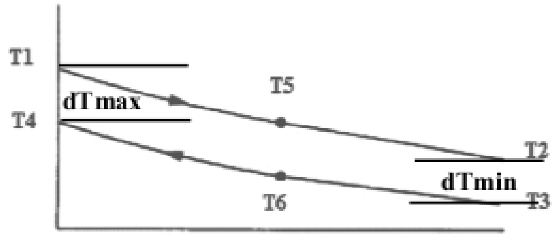




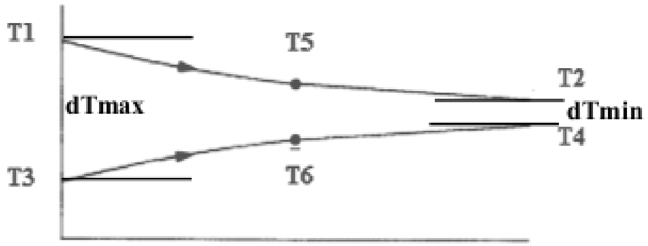
Καθώς οι θερμοκρασιακές διαφορές μεταξύ του ζεστού και ψυχρού ρεύματος μεταβάλονται κατά μήκος του εναλλάκτη θερμότητας, είναι αναγκαίο να ορισθεί μια μέση θερμοκρασιακή διαφορά ωστε να χρησιμοποιηθεί στον ενεργειακούς υπολογισμούς.

Λογαριθμική μέση θερμοκρασιακή διαφοράς

$$ΛΜΘΔ = \overline{ΔT} = \frac{ΔT_1 - ΔT_2}{\ln\frac{ΔT_1}{ΔT_2}} = \frac{dT_{max} - dT_{min}}{\ln\frac{dT_{max}}{dT_{min}}}$$



Counter current flow

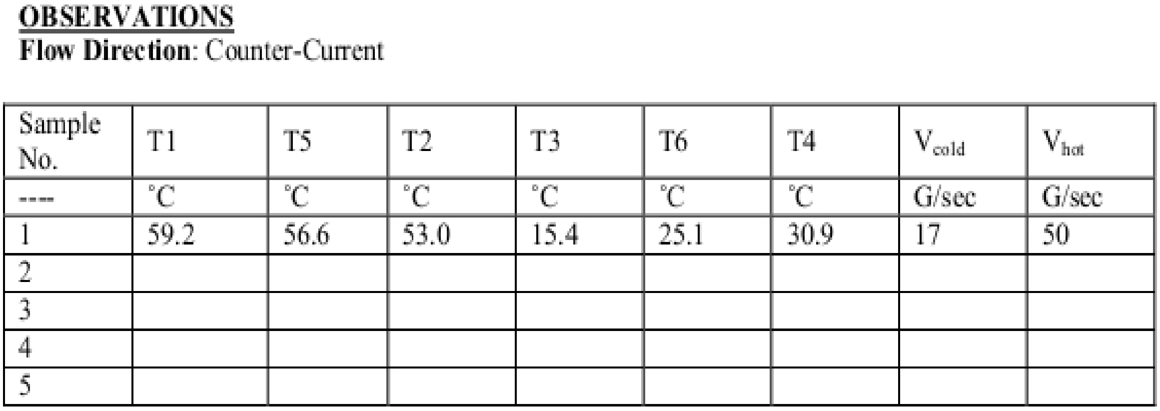


Co-current flow

Για την περίπτωση **αντιρροής**: $ΔT_1 = T_{hi} - T_{co}$ $ΔT_2 = T_{ho} - T_{ci}$

Για την περίπτωση **ομορροής**: $ΔT_1 = T_{hi} - T_{ci}$ $ΔT_2 = T_{ho} - T_{co}$

Παράδειγμα 1:



OBSERVATIONS

Flow Direction: Counter-Current

Sample No.	T1	T5	T2	T3	T6	T4	V_{cold}	V_{hot}
----	°C	°C	°C	°C	°C	°C	G/sec	G/sec
1	59.2	56.6	53.0	15.4	25.1	30.9	17	50
2								
3								
4								
5								

Calculated Data

Sample No.	Δt_{hot}	Δt_{cold}	$\dot{Q}$ e	$\dot{Q}$ a	$\eta_{Thermal}$
---	K	K	W	W	%
	6.2	15.5	1277	1099	86.1

CALCULATIONS

For the example the calculations are as follows.

It is necessary to correct mass flow rates using the conversion factors in tables 1 and 2 on pages A7 and A8. The water density ρ (kg $litre^{-1}$) and specific heat capacity Cp (kJ kg^{-1} K^{-1}) is dependant upon the temperature and the mid point temperature T5 and T6 is a good approximation of the mean temperature for the hot and cold streams.

For the Hot stream:

From table 1 and 2 at T5 = 56.6 ˚C

ρ_{hot} = 0.9852 kg $litre^{-1}$

Cp_{Hot} = 4.183 kJ kg^{-1} k^{-1}

Hence the power emitted from the hot stream $\dot{Q}$ e

$$\begin{aligned}\dot{Q}e &= V_{hot}\,\rho_{hot}\,Cp_{Hot}\,(T1 - T3) \quad \text{Watts}\\ &= 50\times 0.9852\times 4.183\times(59.2-53.0)\\ &=1277 \quad \text{Watts}\end{aligned}$$

For the cold stream:

From table 1 and 2 at T6 = 25.1 ˚C

ρ_{Cold} = 0.9970 kg $litre^{-1}$

Cp_{Cold} = 4.185 kJ kg^{-1} k^{-1}

The power absorbed by the cold stream $\dot{Q}$ a

$$\begin{aligned}\dot{Q}a &= V_{cold}\,\rho_{cold}\,Cp_{Cold}\,(T4 - T3) \quad \text{Watts}\\ &= 17\times 0.997\times 4.186\times(30.9-15.4)\\ &= 1099 \text{ Watts}\end{aligned}$$

The overall thermal efficiency

$$\eta_{\text{Thermal}} = \frac{\dot{Q}a}{\dot{Q}e}\times 100(\%)$$

Hence

$$\begin{aligned}\eta_{\text{Thermal}} &= \frac{1099}{1277}\times\ 100(\%)\\ &= 86.1\%\end{aligned}$$

Table 1 Specific Heat capacity Cp of Water in kJ kg $^{-1}$ K^{-1}

°C	0	1	2	3	4	5	6	7	8	9
0	4.1274	4.2138	4.2104	4.2074	4.2054	4.2019	4.1996	4.1974	4.1954	4.1936
10	4.1919	4.1904	4.189	4.1877	4.1866	4.1855	4.1864	4.1837	4.1829	4.1822
20	4.1816	4.181	4.1805	4.1801	4.1797	4.1793	4.1790	4.1787	4.1785	4.1783
30	4.1782	4.1781	4.1780	4.1780	4.1779	4.1779	4.1780	4.1780	4.1781	4.1782
40	4.1783	4.1784	4.1786	4.1788	4.1789	**4.1792**	4.1794	4.1796	4.1799	4.180
50	4.1804	4.1807	4.1811	4.1814	4.1817	4.1821	4.1825	4.1829	4.1833	4.1837
60	4.1841	4.1846	4.1850	4.1855	4.1860	4.1865	4.1871	4.1876	4.1882	4.1887
70	4.1893	4.1899	4.1905	4.1912	4.1918	4.1925	4.1932	4.1939	4.1964	4.1954

To use the table the vertical columns denote whole degrees and the Horizontal rows denote tens of degrees. For example the bold value 4.1792 kJ kg-1 is at 40 + 5 = 45 °C.

Alternatively the equation $\mathbf{Cp = 6x10^{-9}\ t^{4} - 1.0x10^{-6}\ t^{3} + 7.0487x10^{-5}\ t^{2} - 2.4403x10^{-3}\ t + 4.2113}$
may be used if the data is to be calculated using a spreadsheet.

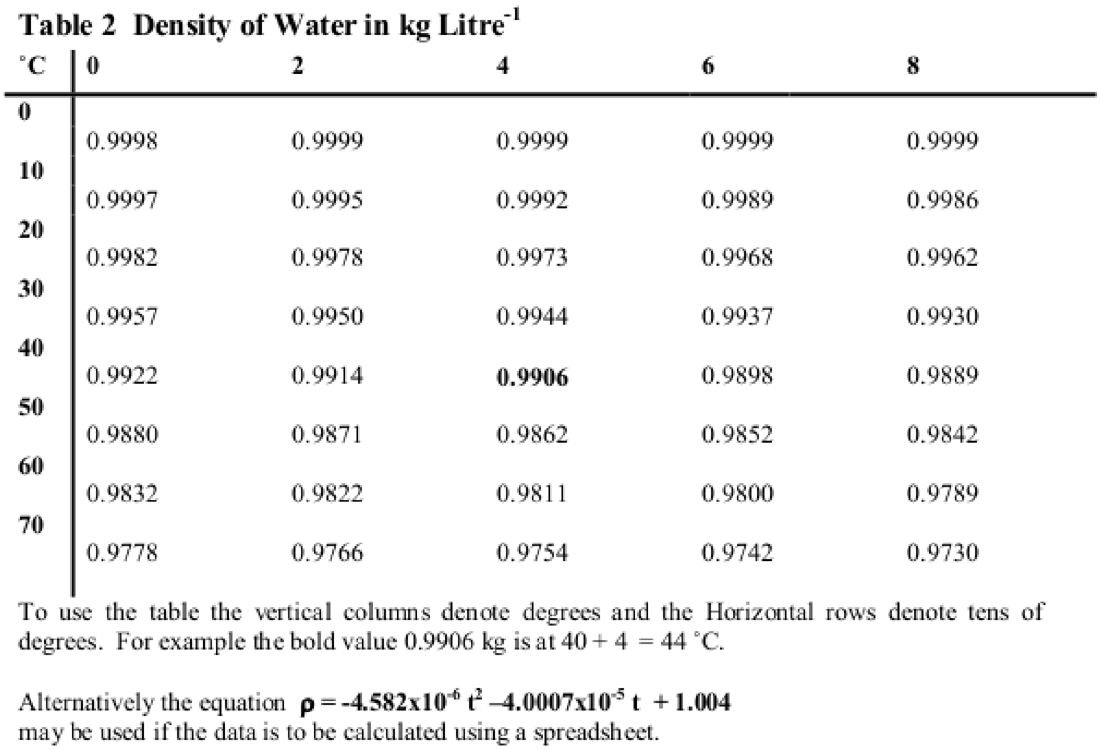


Table 2 Density of Water in kg Litre^{-1}

°C	0	2	4	6	8
0	0.9998	0.9999	0.9999	0.9999	0.9999
10	0.9997	0.9995	0.9992	0.9989	0.9986
20	0.9982	0.9978	0.9973	0.9968	0.9962
30	0.9957	0.9950	0.9944	0.9937	0.9930
40	0.9922	0.9914	**0.9906**	0.9898	0.9889
50	0.9880	0.9871	0.9862	0.9852	0.9842
60	0.9832	0.9822	0.9811	0.9800	0.9789
70	0.9778	0.9766	0.9754	0.9742	0.9730

To use the table the vertical columns denote degrees and the Horizontal rows denote tens of degrees. For example the bold value 0.9906 kg is at 40 + 4 = 44 °C.

Alternatively the equation $\boldsymbol{\rho = -4.582\text{x}10^{-6}\, t^2 - 4.0007\text{x}10^{-5}\, t + 1.004}$ may be used if the data is to be calculated using a spreadsheet.

Ορισμός και αναλυτική εξαγωγή της Λογαραθμικής Μέσης Θερμοκρασιακής Διαφοράς (LMTD)

The **logarithmic mean temperature difference** (also known as **log mean temperature difference** or simply by its initialism **LMTD**) is used to determine the temperature driving force for heat transfer in flow systems, most notably in heat exchangers. The LMTD is a logarithmic average of the temperature difference between the hot and cold feeds at each end of the double pipe exchanger (A,B). **The larger the LMTD, the more heat is transferred**. The use of the LMTD arises straightforwardly from the analysis of a heat exchanger with constant flow rate and fluid thermal properties..

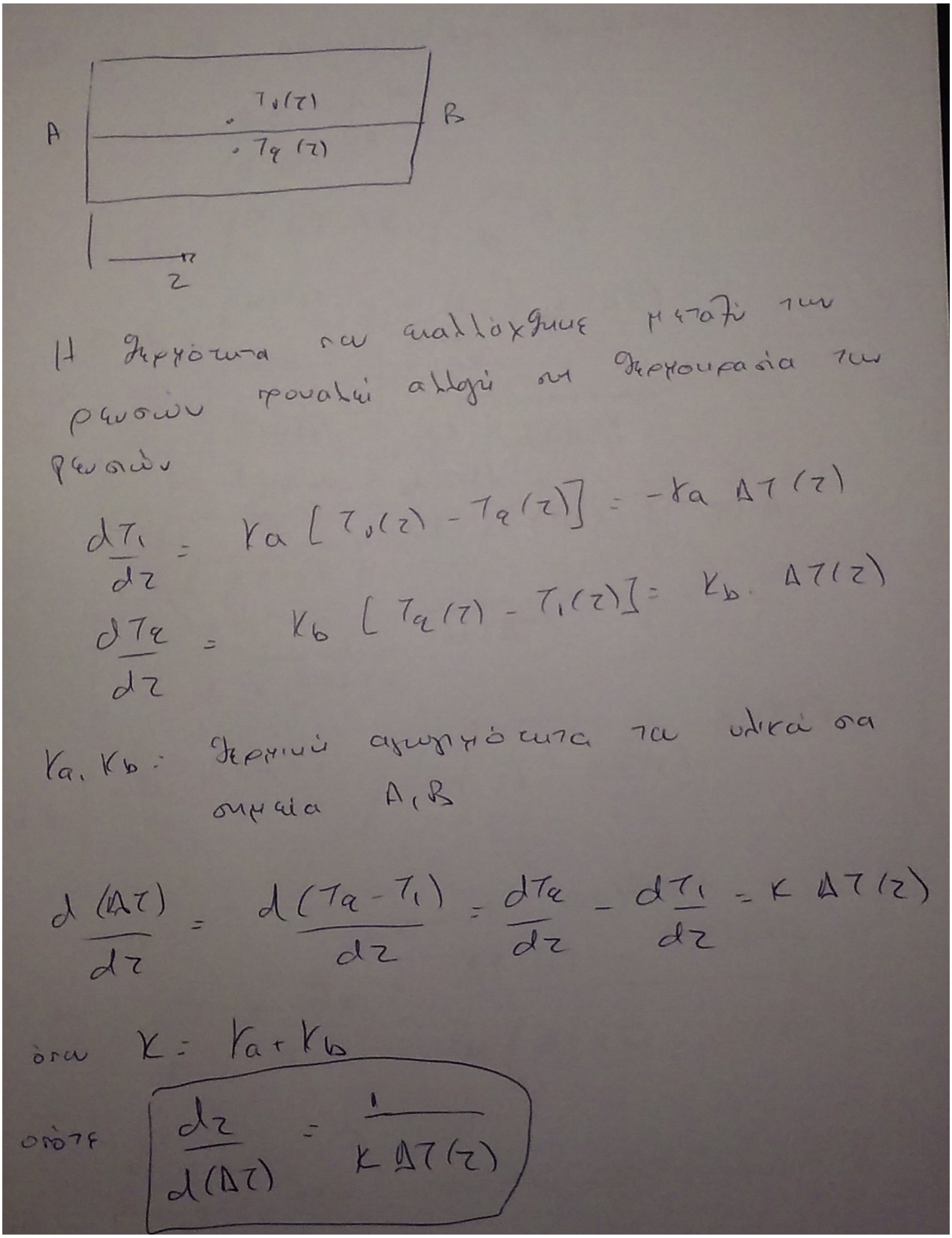
ΔT_A = Θερμοκρασιακή διαφορά των δύο ρευμάτων στο άκρο Α
ΔT_B = Θερμοκρασιακή διαφορά των δύο ρευμάτων στο άκρο Β

$$LMTD = \frac{\Delta T_A - \Delta T_B}{\ln\left(\frac{\Delta T_A}{\Delta T_B}\right)} = \frac{\Delta T_A - \Delta T_B}{\ln \Delta T_A - \ln \Delta T_B} \qquad \textbf{(1)}$$

$$Q = U \times Ar \times LMTD \qquad \textbf{(2)}$$

Where Q is the exchanged heat duty (in watts), U is the heat transfer coefficient (in watts per kelvin per square meter) and Ar is the exchange area (eq.2)

Αναλυτική εξαγωγή της μεταφερόμενης θερμότητας μεταξύ δυο ρευματων σε ομοαξονικό εναλλακτη θερμότητας, οπου εμφανίζεται ο συντελεστής LMTD.



Η θερμότητα που ανταλλάσσεται μεταξύ των ρευστών προκαλεί αλλαγή στη θερμοκρασία των ρευστών

$$\frac{dT_1}{dz} = \kappa_a \left[T_1(z) - T_2(z) \right] = -\kappa_a \Delta T(z)$$

$$\frac{dT_2}{dz} = \kappa_b \left[T_2(z) - T_1(z) \right] = \kappa_b \cdot \Delta T(z)$$

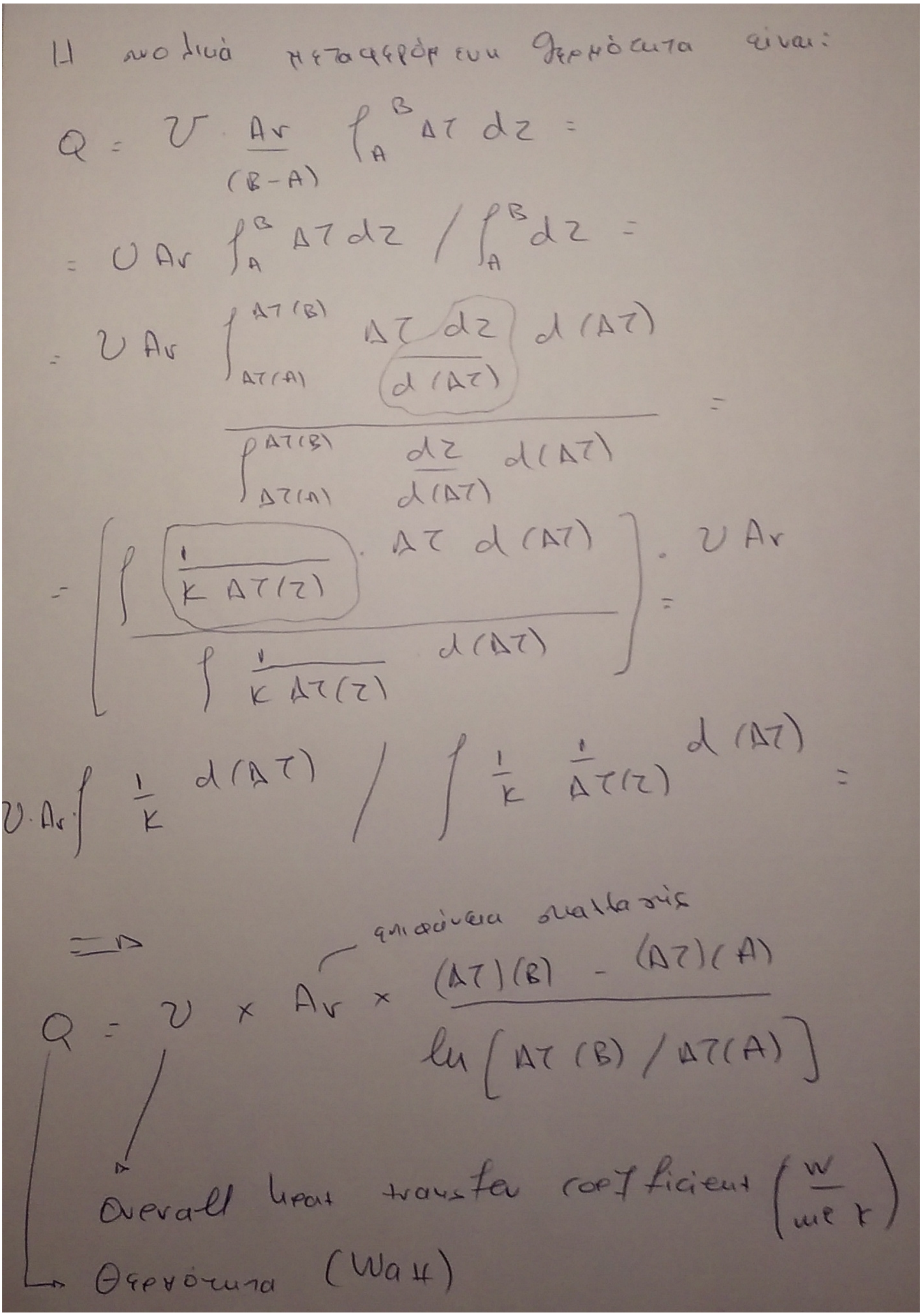
κ_a, κ_b: θερμική αγωγιμότητα τα υλικά στα σημεία A, B

$$\frac{d(\Delta T)}{dz} = \frac{d(T_2 - T_1)}{dz} = \frac{dT_2}{dz} - \frac{dT_1}{dz} = \kappa \Delta T(z)$$

όπου $\kappa = \kappa_a + \kappa_b$

οπότε

$$\boxed{\frac{dz}{d(\Delta T)} = \frac{1}{\kappa \Delta T(z)}}$$



Η συνολική μεταφερόμενη θερμότητα είναι:

$$Q = U \cdot \frac{A_r}{(B-A)} \int_A^B \Delta T \, dz =$$

$$= U A_r \int_A^B \Delta T \, dz \Big/ \int_A^B dz =$$

$$= U A_r \frac{\int_{\Delta T(A)}^{\Delta T(B)} \Delta T \boxed{\frac{dz}{d(\Delta T)}} \, d(\Delta T)}{\int_{\Delta T(A)}^{\Delta T(B)} \frac{dz}{d(\Delta T)} \, d(\Delta T)} =$$

$$= \left[\frac{\int \boxed{\frac{1}{K \, \Delta T(z)}} \cdot \Delta T \, d(\Delta T)}{\int \frac{1}{K \, \Delta T(z)} \, d(\Delta T)} \right] \cdot U A_r =$$

$$U \cdot A_r \cdot \int \frac{1}{K} \, d(\Delta T) \Big/ \int \frac{1}{K} \frac{1}{\Delta T(z)} \, d(\Delta T) =$$

$$\Longrightarrow$$

$$Q = U \times \overset{\text{επιφάνεια εναλλαγής}}{A_r} \times \frac{(\Delta T)(B) - (\Delta T)(A)}{\ln\left[\Delta T(B) / \Delta T(A)\right]}$$

U → Overall heat transfer coefficient $\left(\frac{W}{m^2 K}\right)$

Q → Θερμότητα (Watt)