ANALYTICAL APPROACH FOR THE ASSESSMENT OF OPTIMUM PERFORMANCE OF PROPANE PRE-COOLING CYCLE WITH AERIAL COOLING IN LNG PLANTS

By

Ayat Shawky Mahmoud Najjaa

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
CHEMICAL ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

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Title of Thesis:

Analytical approach for the assessment of optimum performance propane pre-cooling cycle with aerial cooling in LNG plants .

Key Words:
Aerial cooler, PPMRC, Optimum performance, Aerial mass flow rate, Surrounding ambient aerial temperature.

Summary:
An analytical approach is developed to check the aerial flow rate required for aerial cooler used in a propane pre-cooling mixed refrigerant components cycle operating in a Liquefied natural gas (LNG) plant located at Damietta, Egypt. The presented analytical approach takes into concern the changes in both the ambient air inlet temperature and the aerial mass flow rate. Based on an economic objective function, namely the annual total cost of the aerial cooler, the optimum operating conditions and hence the best performance of the propane pre-cooling mixed refrigerant cycle with aerial cooling was determined for various ambient aerial surrounding temperatures. Two algorithms are presented which can be used effectively with good engineering accuracy to control the process fluid (propane) outlet temperature in the propane precooling cycle through regulation of the air flow rate. The ambient air inlet temperature is modeled analytically by simplifying periodic relations. Numerical results are obtained reflecting the performance of the air-cooled heat exchanger which cools both NG (natural gas) and MR (mixed refrigerant) in the selected LNG plant. The obtained results revealed that the periodic hourly variations of the ambient air inlet temperature in the summertime have a much impact on the required air flow rate, while its influence becomes relatively less pronounced in winter

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Nomenclature

A_f	(fin surface area/m length), m2/m
A_o	(A_{po} + A_f) =(total outside surface area/m length), m^2/m
A_{pi}	(inside surface area of bare tube/m length), m^2/m
A_{po}	(exterior area of bare tube/m length), m^2/m
A_x	extended finned tube surface heat transfer area, m^2
APM	total extended tube external area/m length, m^2/m
APSM	ratio of external tube OD bare surface area to bundle face area, m^2/m^2
AR	(A_o/A_{po}) = ratio of fin tube area to exterior area of tube, m^2/m^2
d_i	Internal tube diameter, (m)
$(C_p)_{air}$	specific heat of air,(kJ /Kg °C)
$(C_p)_{propane}$	specific heat of propane , (kJ /Kg °C)
CMTD	corrected mean temperature difference, ℃
$D_{eqv.}$	equivalent diameter, m
F_t	cross flow correction factor
FA	face area, m^2
% free area	percentage free area
G_{air}	(air mass flow rate/free area), kg/m^2 s
G''	total vapour concerned in one tube, lb./hr.
g	acceleration of gravity ,4.18$\times 10^8$ft /$(hr)^2$
h_i	inside tube film heat transfer coefficient, J/m^2 s ℃
h_o	outside tube (finned-tube) heat transfer coefficient, J/m^2 s ℃
h_{dirt}	fouling coefficient for inside of the tube, W/m^2 K
$(k)_{air}$	thermal conductivity of air, W/m K
$(k)_{aluminum}$	thermal conductivity of aluminum, W/m K
$(k)_{propane}$	thermal conductivity of propane, W/m K
L	tube length, m
Lo	(r_2- r_1), fin height, m
LNG	Liquefied Natural Gas
MTD	mean temperature difference, ℃
MW	Molecular weight of humid air
N_T	number of tubes
Nu	Nusselt number
Pr	Prandtl number
P_w^s	vapor pressure water, Kpa
PPMRC	Propane precooling mixed refrigerant cycle
Q_{total}	Aerial cooling heat exchanger total heat load, KJ/s
Q_I	Aerial cooling heat exchanger heat load in the desuperheating zone , KJ/s
Q_{II}	Aerial cooling heat exchanger heat load in the condensation zone , KJ/s
%RH	Relative humidity percentage of the air.
r_{dirt}	($1/h_{dirt}$) scale resistance, m^2 K/W
r_1, r_2	inner and outer radius of the circular fin, m
R	universal gas constant , $\frac{(KPA)\times(m^3)}{(Kmole)\times(°K)}$

Re	Reynolds number
t_{in}	air inlet temperature, ℃
t_{out}	air outlet temperature, ℃
t_{sv}	Saturated vapor temperature, °F
t_s	Surface temperature, °F
T_{in}	propane inlet temperature, ℃
$T^{/}$	The intermediate temperature of propane between two zones,℃
$t^{/}$	The intermediate temperature of air between two zones ,℃
U_{ox}	extended surface overall heat transfer coefficient, J/m^2 s ℃
W_{air}	Aerial mass flow rate, kg/s
$W_{propane}$	propane mass flow rate, kg/s
$W_{Cond.}$	The condensate flow rate, lb./hr.
N_t	Number of effective tubes in condensation
y	fin thickness, m
$(\lambda)_{propane}$	latent heat of vaporization of propane, kJ/kg
$(\mu)_{air}$	dynamic viscosity of air, mPas
$(\mu)_{propane}$	dynamic viscosity of propane, mPas
(μ_s)propane	propane dynamic viscosity of propane at wall surface, mPas
ϕ	fin efficiency
$\rho_{Propane\ liq.}$	Propane liquid density, (Ib/ft^3)
$\rho_{Propane\ vap.}$	Propane vapor density, (Ib/ft^3)
P	air pressure, (Kpa)
Z	Compressibility factor, for air at ambient atmospheric temperature and pressure $\cong 1$

Abstract

An analytical approach is developed for evaluating the hourly performance of an aerial cooling heat exchanger during winter and summer times, as it's in operation into propane pre-cooling mixed refrigerant cycle (PPMRC) at Liquefied natural gas (LNG) plant located at Damietta, Egypt. This analytical approach is taking into consideration the effect of varying two main important variables, the ambient air input temperature (t_{in})and the aerial mass flow rate (W_{air}) on the design and rating of the aerial cooled heat exchanger .

First, the studying is carried out for searching the effect of varying the aerial mass flow rate (W_{air}) at a constant ambient inlet temperature on several operating parameters such as : the overall heat transfer coefficient (U_{OX}) , the weighted corrected mean temperature difference $(CMTD_{weighted})$, the total extended surface area (A_X), and the layout configuration of the aerial heat exchanger from face area , tube bundle width , and length are included .

Secondly, the effect of varying aerial mass flow rate at a constant temperature on the total power required and the total energy consumed by all of the fans is investigated. The objective of this complex calculations is estimating the total annual cost curve, a curve which is based on an economic function. The annual total cost of an aerial cooler is the summation of operational and fixed cost which annually charged. A list of basic thermodynamics and heat transfer equations are to be demonstrated.

Thirdly, the optimum conditions of an aerial cooler in operation are investigated, as the optimal design conditions are the conditions which the best performance, better operability, the efficient and eventually cost-effective operation of the aerial cooler. The optimum conditions are estimated for different surrounding air input temperature.

Finally, the hourly impact of varied surrounding air temperature on the operation aerial mass flow rate of an aerial cooler is also investigated. As the hourly variations of air temperature during winter and summertime is being represented by simple periodic relations.

An interrelation between the mass flow rate of air (W_{air}) and the ambient temperature (t_{in}) is providing a way for adjustment of process fluid exit temperature. Also, it's a control method for the required amount of aerial mass flow that is displaced and the moved through daily operation and further the seasonally operation. The controlling system is either to be manually via operated louvers or pneumatically through activated automatic variable pitch fan or Variable frequency fan drive (VFD).

Numerical results are obtained showing the performance of the aerial cooling heat exchanger operated in propane pre-cooling which cools both NG (natural gas) and MR (Mixed refrigerant) streams in the LNG plant located at Damietta, Egypt. The input air temperature variation in the summertime has a considerable effect on the required air mass flow rate (W_{air}), while its influence becomes relatively less pronounced in winter. Two algorithms describing the analytical approach derived are presented.