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Study on Design of Single Pass Backwash Cooler (SDSPBC)

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ABSTRACT: *Circular tubes with circular fin heat exchanger, because of their compactness, and high effectiveness are widely used in oil refinery also known as backwash cooler. While aluminium is the most commonly used material, stainless steel construction is employed in high pressure and high temperature applications. The performance of circular fin heat exchanger is determined, among other things, by the geometry of the fins. Hydro cracking is a type of catalytic cracking which is done in hydro cracking unit by the help of backwash cooler. Hydro cracking is similar to fluid catalytic cracking, but uses a different catalyst, lower temperatures, higher pressure, and hydrogen gas. It takes heavy oil and cracks it into gasoline and kerosene (jet fuel). Here we have designed circular tube with circular fins heat exchanger. We have assumed some data and based on them we have designed heat exchanger. The flowing fluid in heat exchanger is hydrocarbon and material of heat exchanger is Al. A characteristic of heat exchanger design is the procedure of specifying a design, heat transfer area and pressure drops and checking whether the assumed design satisfies all requirements or not. The purpose of this thesis is how to design the backwash cooler (heat exchanger) especially for compact heat exchanger which is the type of liquid-to-air heat exchanger. General design considerations and design procedure are also illustrated in this thesis. In design calculation, the Borlando C++ software are used. The primary aim of this design is to obtain a high heat transfer rate without exceeding the allowable pressure drop.*

KEYWORDS: *Hydrocracking, Backwash cooler, Borlando C++ software.*

I. INTRODUCTION

In any power generating or refrigeration cycle, heat has to be discharged. This is also true in many chemical and process plant cycles, internal combustion engines, computers, and electronic systems. The efficiency of a modern automobile engine is such that most of the energy contained in the fuel is rejected through the exhaust and the radiator. In a fossil-fired power plant with an efficiency of about 40%, more than 40% of the heat input has to be rejected through the cooling system. Even more heat has to be rejected in less efficient nuclear plants. Considerably less heat is rejected in a modern combined cycle power plant.

Air-cooled heat exchangers are found in the electronics industry, vehicles, air-conditioning, and refrigeration plants as well as chemical and process plants where fluids at temperatures of approximately 60^0C or higher are to be cooled. The use of air-cooled or dry-cooling systems in industry or in power plants is often justified where cooling water is not available or is very expensive. In certain applications, dry/wet or wet/dry cooling systems offer the best option according to Bartz [1] and Mitchell [2]. The development, practice, and performance of evaporative cooling systems or cooling towers have been described in numerous publications such as Mckelvey [3], Berliner [4], Burger [5], Cheremisinoff [6],and Hill [7].

Small air-cooled heat exchangers (Compact heat exchangers as described by Kays [8]) find application in many areas including computers and others and other electronic equipment, vehicles (radiators, oil coolers, and intercoolers), air-conditioning and refrigeration plants (condensers), etc. These are illustrated in works by U.S. Army Material Command, Plank [9] and also Mcquiston [10]. Larger air-cooled heat exchangers are found in refrigeration and chemical plants, various process industries, and power plants. Movement of the cooling air is achieved by mechanical means, fans, or buoyancy effects, e.g., natural draft dry-cooling towers. Although the capital cost an industrial air-cooled heat exchanger is higher than a water-cooled alternative, this is not always the case. The cost of providing suitable cooling water and other running expenses may be such that the former is more cost effective over the projected life of the system. Other considerations are also of importance depending on the process or application according to maze[11]. In arid areas where insufficient or no cooling water is available, air cooling is the only effective method of heat rejection.

II. CONSTRUCTION FEATURES

The American Petroleum Institute's standard API 661, "Air-cooled heat exchangers for general refinery services" [12], outlines the minimum requirements for design, materials, fabrication, inspection, testing, and preparation for shipment of ACHEs, Although this standard is intended specifically for the petroleum refining industry, its use is widespread in the petrochemical, fertilizer, and general chemical industries as well. In fact, it is considered to be a standard for all ACHEs. The construction feature for ACHE is described by Mukherjee [13], Shah [15] and Kuppan [18].

A discussion of construction feature should begin with a few basic definitions: Tube bundle- assembly of tubes, headers, tube supports, and frames. Bay or section- the smallest independent part of an ACHE, complete with its tube bundles, fans, drives, motors, supporting structure, and so on. Unit- One or more bays (sections) for an individual service, such as a condenser or a cooler. Bank- two or more units located one after another on the same continuous structure. A bank consists of two or more units, a unit consists of two or more bays, and a bay consists of two or more bundles. Induced draft- tube bundles located on the suction side of fans as illustrated in figure 1.1. Forced draft- tube bundles located on the discharge side of fans.

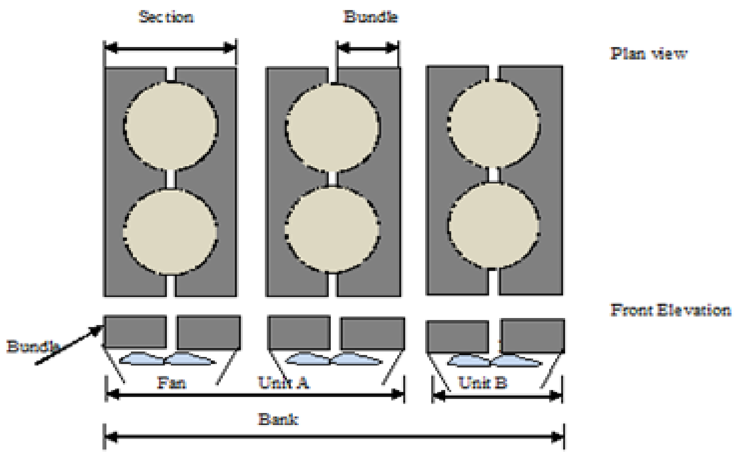

Fig. 1.1 ACHEs consist of bundles combined into bays,

Major headings are to be column centered in a bold font without underline. They need be numbered. "2. Headings and Footnotes" at the top of this paragraph is a major heading.

III. BACKWASH COOLER

The process of heat exchange between two fluids that are at different temperatures and separated by a solid wall occurs in many engineering applications. The device used to implement this exchange is termed a heat exchanger, and specific applications may be found in space heating and air conditioning, power production, waste heat recovery, and chemical processing.

The problem of heat transmission is encountered in many industries and because of the diversity in the fields of application there exist countless difference in detail.
Backwash cooler is used in hydrocracking unit for cracking the hydrocarbon into smaller ones in oil refinery. There are several types of cracking:

- Thermal cracking- Steam, visbreaking, coking.
- Catalytic cracking- fluid catalytic, hydro cracking.

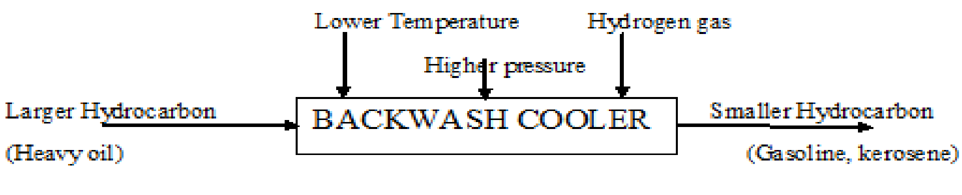

Fig.1.6 Hydrocracking by backwash cooler in hydrocracking unit

In figure shows, the process of breaking larger hydrocarbon (heavy oil) into smaller hydrocarbon (gasoline, kerosene) with the help of lower temperature, higher pressure, hydrogen gas is known as hydrocracking. Hydrocracking is a type of catalytic cracking which is done in hydrocracking unit by the help of backwash cooler. Hydrocracking is similar to fluid catalytic cracking, but uses a different catalyst, lower temperatures, higher pressure, and hydrogen gas. It takes heavy oil and cracks it into gasoline and kerosene (jet fuel). Hydrocracking was first developed in Germany as early as 1915 to provide liquid fuels derived from their domestic coal deposits. The first plant that might be considered as a commercial hydrocracking unit began operation in Leuna, Germany in 1927. Similar efforts to convert coal to liquid fuels took place in the Great Britain, France and other countries.

Between 1925 and 1930, Standard Oil of New Jersey collaborated with I.G. Farbenindustrie of Germany to develop hydrocracking technology capable of converting heavy petroleum oils into fuels. Such processes required pressures of 200 – 300 bar and temperatures of over 375 °C and were very expensive.
In 1939, Imperial Chemical Industries of Great Britain developed a two-stage hydrocracking process. During World War II (1939 – 1945), two-stage hydrocracking processes played an important role in producing aviation gasoline in Germany, Great Britain and the United States. After World War II, hydrocracking technology became less important. The availability of petroleum crude oil from the Middle East removed the motivation to convert coal into liquid fuels. Newly developed fluid catalytic cracking processes were much more economical than hydrocracking for converting high-boiling petroleum oils to fuels.

Hydrocracking enjoyed rapid growth in the United States during the late 1960s and the early 1970s. By the mid-1970s, hydrocracking had become a mature process and its growth began to moderate. From then on, hydrocracking growth in the United States proceeded at a slow pace. However, at the same time, hydrocracking enjoyed significant growth in Europe, the Asia-Pacific region and the Middle East. As of 2001, there were about 155 hydrocracker units operating worldwide and processing about 4,000,000 barrels (550,000 metric tons) per day of feedstock. As of 2009, The feedstock processing capacity of the hydrocrackers in the United States was 1,740, 000 barrels (238,000 metric tons) per day.

IV. J AND F FACTORS

Air cooled heat exchangers are the most widely used type of heat exchangers and range in size from less than a square meter of surface to hundreds of thousands square meters. The most common applications are household refrigerators, air conditioners, and automobile radiators but they are also extensively used in power plants and process industries. The general characteristics of air cooled exchanger are that process fluids flow inside of tubes and the cooling air flows across the tubes. The poor heat transfer coefficients of air are compensated by using fins on the tubes to increase the surface exposed to the air. In addition, the low specific heat and density of air requires using large volume of air; hence, the face area of the tube bundles is large and the bundle depth is low. The air flow may be by natural convection or by forced flow and in special applications at high air temperatures water sprays are used to reduce the air temperature or in case of high freezing point fluids or very low air temperatures air recirculation is used. The cooling requirements and the physical limitations for the exchanger results in many types of designs. A standard reference for the heat transfer and friction data of circular fin with circular tube heat exchanger surfaces is the book by Kays and London [14]. The j factor and fanning f factor are defined rather consistently in the literature by the following equations.

The j factor and fanning factor are defined.

$$j = \frac{h \times Pr}{G \times c_p} \quad \text{..................................} \; (1.1a)$$

$$= \frac{h}{G \times c_p} \times \left(\frac{\mu \times c_p}{k}\right) \text{.............................} (1.1b)$$

$$h = \frac{j \times G \times c_p}{\left(\frac{\mu \times c_p}{k}\right)} \quad \text{or} \quad h = \frac{Nu \times k}{D_h} \text{.................} \; (1.2)$$

$$\Delta p = 4f \times \frac{L_2}{D_h} \times \frac{G_{max.}^2}{2 \times g_c \times p} \quad \text{………......} (1.3)$$

Where $G_{max.}$ is given by

$$G_{max.} = \rho \times \frac{A_{fr}}{A_o} \quad \text{........................} \; (1.4)$$

And $G_{max.}$ is based on the minimum free flow area within the tube bundle. This minimum free flow area includes the gaps between the outermost tubes and the sides walls of the tube bundle. In equation (3), contraction and expansion losses and momentum losses are neglected, only flow friction effect is taken into account.

The Reynolds number is defined as

Re = $\frac{G\times d_r}{\mu}$ or Re = $\frac{G\times d_o}{\mu}$ or Re = $\frac{G\times D_h}{\mu}$ .... (1.5)

Where, d_r is the fin root diameter on the tube outside diameter, which depends on the tube manufacturing techniques, and D_h is the hydraulic diameter. The j factor is related to Stanton number and Prandtl number by

j = St × Pr$^{2/3}$ .... (1.6)

Where the Stanton number is given by

St = $\frac{Nu}{Re\times Pr}$ ……….......................... (1.7)

From equation (6) & (7), expression for j is given by

j = $\frac{Nu}{Re\times Pr^{1/3}}$ .... (1.8)

Robinson and Briggs Correlations [23]:

<u>For equilateral triangular pitch with high finned tubes</u>

f = 9.465 × $Re_d^{-0.316}$ × $\left(\frac{P_t}{d_o}\right)^{-0.927}$..... (1.9)

with a standard deviation of 7.8%. This is applicable for the following parameter definitions:

Re = 2,000-50,000 d_f = 1.562-2.750 P_t = 1.687-4.50

<u>For isosceles triangular layout</u>:

F =9.465×$Re_d^{-0.316}$×$\left(\frac{P_t}{d_o}\right)^{-0.927}$ × $\left(\frac{P_t}{P_l}\right)^{0.515}$ ....(1.10)

This is applicable for

d_o(mm)=18.6-40.9, $\frac{h}{d_o}$ = 0.35-0.56, $\frac{h}{p}$ = 4.5-5.3

σ = 13.3-17.4, $\frac{P_l}{d}$ = 1.8-4.6 $N_r \geq 6$

Rabas, Eckels, and Sabatino Correlation [24]:

For the tube banks arranged on an equilateral triangular pitch with low finned tubes

j = 0.292 × Re_d^{-m} × $\left(\frac{s}{d_f}\right)^{1.116}$ × $\left(\frac{s}{l_f}\right)^{0.257}$ ×$\left(\frac{t_f}{s}\right)^{0.666}$ × $\left(\frac{d_f}{d_r}\right)^{0.473}$ × $\left(\frac{d_f}{t_f}\right)^{0.7117}$ × α_h × α_n

.... (1.11) m = 0.415- 0.03461 × n × $\left(\frac{d_f}{s}\right)$ ....(1.12)

f=3.805×$Re_d^{-0.234}$×$\left(\frac{s}{d_f}\right)^{0.251}$×$\left(\frac{l_f}{s}\right)^{0.759}$×$\left(\frac{d_r}{d_f}\right)^{0.729}$ × $\left(\frac{d_r}{P_t}\right)^{0.709}$ ×$\left(\frac{P_t}{P_l}\right)^{0.379}$ …..................... (1.13)

$l_f \leq 6.35mm$ 800≤ $Re \leq 800{,}000$ $20^0 \leq \theta \leq 40^0$

$X_t \leq 4$ and $N_f \geq 4$

V. DESIGN OF TUBE FIN HEAT EXCHANGER

The design of air cooled heat exchanger or Compact heat exchanger is well described by Muller [14] and Hesselgreaves [16]. Based on bare-tube heat transfer area, air-cooled heat exchangers (ACHEs) cost two or three times more than water-cooled heat exchangers for the same duty. There are two main reasons for this. First, the thermal conductivity of air is considerably lower than that of water, which results in a much lower heat transfer coefficient. Second, since ambient temperatures are always higher than design water temperatures, the mean temperature difference (MTD) is always lower for an ACHE, especially at relatively low process-fluid outlet temperatures. As a result of these two factors, the heat transfer area of an ACHE is considerably larger than that of a water-cooled heat exchanger for the same duty. In addition, the larger area requires an elaborate structural support system, which increases the cost further. The operating costs for water cooling are much higher than those for air cooling. These include the costs of the initial raw water itself, makeup water, and treatment chemicals, the apportioned cost of the plant cooling tower, and the pumping cost. For ACHEs, the operating cost is just the cost of the power required to make the air flow across the tube bundles. Xie, Wang and Sunden [19] have developed a more sophisticated model to predict the characteristics of j and f factors for tube-fin heat exchanger. As water becomes scarcer, the operating costs of water-cooled heat exchangers increase, thereby tilting the economics further in favour of air cooling. The analytical approach for convective heat transfer coefficient well presented by Khan.

- In design of ε-NTU as well as LMTD method have been used for design of heat exchanger and figure 1.10 shows the design methodology of heat exchanger.
- Hudson is the leading vendor manufacturing meeting the global demand of ACHE.

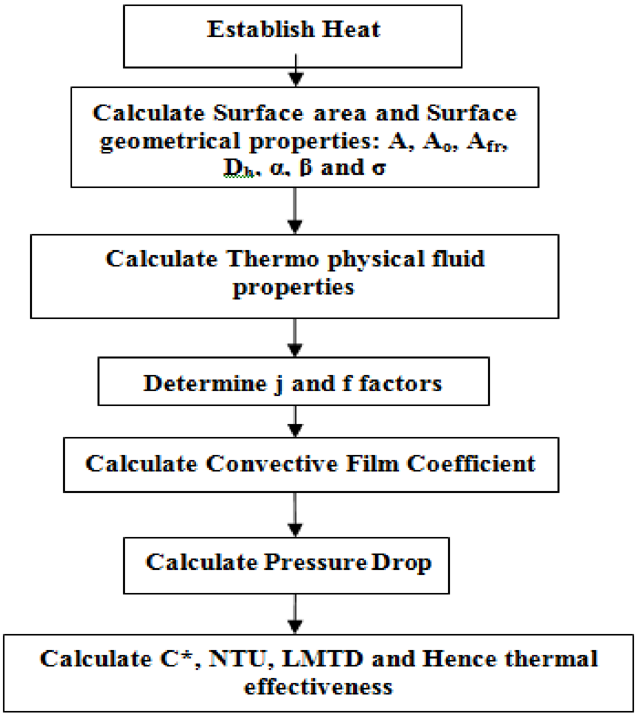

Fig. Heat Exchanger Design Methodology well described by Kuppan [18]

VI. OBJECTIVE

From above study, following are influences drawn, thus:

1) Air-cooled heat exchanger (ACHE) design studies are not available.
2) Few vendors are available.
3) ACHE/Backwash cooler design is sophisticated.
4) In case of non-availability of water (eg. In dry area), air cooled heat exchanger could be used.
5) Design data of ACHE/Backwash cooler is of propriety in nature.

VII. OBJECTIVES FOR THIS WORK:

1) Design of backwash cooler for catalytic cracking in Hydrocracking unit.
2) Parametric study of effect of tube length, fin density, Tube diameter, fin height, Tube pitch.

In this work design study of backwash cooler used for cooling of hydrocarbon (oil) with individual circular fin have been dealt.

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