International Journal of Modern Engineering Research (IJMER)

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-930-936 ISSN: 2249-6645

Performance Analysis of Spiral Tube Heat Exchanger used in oil extraction system

Kondhalkar G. E [(a)], Kapatkat V. N [(b)]

(a) *Head of Mechanical Engineering Dept. – Dyanganga polytechnic, Pune*

(b) *Professor in Mechanical Engg. Dept. – Sinhgad College of Engineering, Pune*

ABSTRACT

Energy saving is major matter in our global world, and heat exchanger is very useful for energy saving. Of course heat exchanger is most significant component for chemical reaction, distillation, dissolution, crystallization, fermentation etc. So the correct selection of heat exchanger is important in these processes. Spiral tube Heat Exchangers are known as excellent heat exchanger because of far compact and high heat transfer efficiency. This paper discusses about the effective use of spiral tube heat exchanger in oil extraction process. Paper gives the performance analysis of spiral tube heat exchanger over the shell and tube type heat exchanger.

Key words: Spiral heat exchanger, oil extraction

INTRODUCTION

An essential oil is a concentrated, hydrophobic liquid containing volatile aroma compounds from plants. Essential oils are also known as volatile or ethereal oils, or simply as the "oil of" the plant from which they were extracted, such as oil of clove. An oil is "essential" in the sense that it carries a distinctive scent, or essence, of the plant.

Essential oils are generally extracted by distillation. Other processes include expression, or solvent extraction. They are used in perfumes, cosmetics, soap and other products, for flavoring food and drink, and for scenting incense and household cleaning products.

Various essential oils have been used medicinally at different periods in history. Interest in essential oils has revived in recent decades with the popularity of aromatherapy, a branch of alternative medicine which claims that the specific aromas carried by essential oils have curative effects. Oils are volatilized or diluted in carrier oil and used in massage, diffused in the air by a nebulizer or by heating over a candle flame, or burned as incense.

Most oils are distilled in a single process. One exception is Ylang-ylang (Cananga odorata), which takes 22 hours to complete through a fractional distillation.

The recondensed water is referred to as a hydrosol, hydrolat, herbal distillate or plant water essence, which may be sold as another fragrant product. Popular hydrosols include rose water, lavender water, lemon balm, clary sage and orange blossom water. The use of herbal distillates in cosmetics is increasing. Some plant hydrosols have unpleasant smells and are therefore not sold.

Table: 1 Common Essential Oils and their Uses

Sr. No.	Essential Oil	Uses
1	Basil	Perfumery, aromatherapy, sharpening concentration, headache relief and migraines
2	Bergamot	Perfumery, insect repellent, helpful to the urinary and digestive tracts, useful for skin conditions linked to stress such as cold sores and chicken pox particularly when combined with eucalyptus oil, flavouring agent
3	Black pepper	Stimulation of the circulation, Healing muscular aches, pains, and bruises.
4	Citronella oil	Insect repellant and in perfumery.
5	Tea tree, eucalyptus and sandalwood oil	Antibacterial, antifungal, antiviral, or antiparasitic and used as antiseptics and disinfectants.
6	Clove oil	Topical analgesic, especially useful in dentistry. It is also used an antiseptic, antispasmodic, carminative, and antiemetic.
7	Lavender oil	Antiseptic

PRODUCTION OF ESSENTIAL OILS

To get essential oils the aromatic essence molecules of the plant must be captured by technical extraction methods. Essential oils are liquids stored in various places in plants that can be removed from the plant using extraction methods such as steam distillation, cold pressing, chemicals, or fat-absorption.

The most popular method for extraction is steam distillation and the majority of essential oils used in aromatherapy are distilled in this way, but as technology is advancing, more efficient and economical methods are being developed.

The extraction of an oil require large quantity of plant material and the method used to extract the oil is time

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-930-936 ISSN: 2249-6645

consuming, so requires a high degree of skill and care. Hence, pure essential oils are expensive, but they are also highly effective as only a few drops at a time are required to achieve the desired effect.

Essential oils are usually liquid, but can also be solid, like orris root or semi-solid according to temperature, like the rose. They dissolve in pure alcohol, fats and oils but not in water. Some of the distillation methods are as discussed below.

Distillation

In this, water is heated to produce water vapour, which carries the volatile chemical of the aromatic material with it. The water vapour is then condensed using a condenser and the resulting distillate is collected. The essential oil will normally float on top of the hydrosol (the distilled water component) and is separated out.

Various types of distillation methods are as follows,

a) Water Distillation
b) Steam Distillation
c) Hydro Diffusion
d) Fractional Distillation

a) Steam distillation method

Steam distillation was invented by the Persian chemist, Ibn Sina (known as Avicenna in the West), in the early 11th century.

Steam distillation is the most common method of extracting essential oils. Steam distillation is done in a still (The still is tall with a head and a well-insulated swan's neck proceeded by a mechanism to prevent fumes and impurities passing through). Fresh, or sometimes dried, botanical material is placed in a closed container of the still, and pressurized steam is generated which enters the container and circulates through the plant material. The heat of the steam forces the intercellular pockets that hold the essential oils to open and release them. The temperature of the steam should not be very high as it can damage the botanical material but should be high enough to open the pockets which hold the essential oil.

Tiny droplets of essential oil evaporate and attach to the steam. The steam which then contains the essential oil is passed through a cooling system to condense the steam, which form a liquid from which the essential oil and water is then separated by decantation. The oil forms a layer on the water surface as it does not dissolves in water and hence is separated easily. This method is not used for extraction of oils that are sensitive to heat.

Applications

Steam distillation is employed in the manufacture of essential oils, for instance, perfumes. In this method, steam is passed through the plant material containing the desired oils. It is also employed in the synthetic procedures of complex organic compounds. Eucalyptus oil and orange oil are obtained by this method on the industrial scale.

Steam distillation is also widely used in petroleum refineries and petrochemical plants where it is commonly referred to as "steam stripping".

The following figure provides an overview of the steam distillation process.

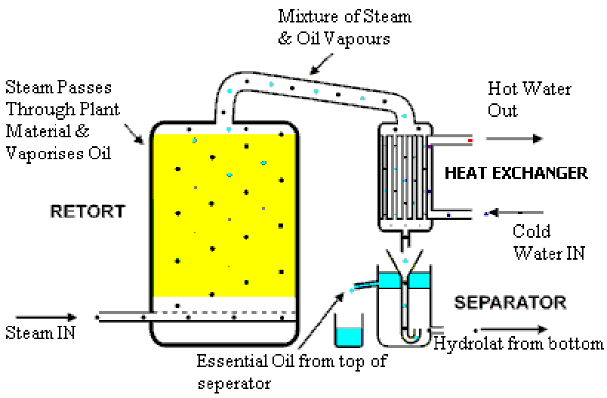

Fig. 1 Steam distillation method

PROBLEM DEFINITION AND SOLUTION

The experimentation is carried out in one of the oil extraction unit. They are dealing in extraction of herbal oils by using Field distillation unit and Steam distillation method.

The Field distillation (FDU) is used for the distillation and extraction of essential oils from herbs, shrubs, leaves, roots or whole plant by passing the saturated steam. The FDU consist of built-in-boiler tubes submerged in water for producing steam. The following oils extractions are done by company

- Lemon Grass Oil
- Sugandh Mantri Oil
- Shatavri Oil
- Manjishta Oil
- Turmeric Oil Steam Distilled
- Ashwagandha Oil

The company was using steam extraction method which is discussed earlier. Partly dry leaves of the tree are placed in a container. The steam is passed through this container, which is produced using boiler. As the steam passes through the leaves the oil is extracted and the mixture of oil and steam is passed through the condenser for condensation. After condensation it is collected in the separator vessel, where this mixture is kept to settle for some time. After settling time the oil can be separated from the water very easily.

In above mentioned equipments the company was using shell and tube type condenser. Mixture of oil vapour and steam enters in the condenser tube at high temperature and start condensing. As the tubes are straight and as condensate has to be collected, the process is very slow. Due to very low velocity the oil particles get stick up on the inner periphery of the pipe which makes the layer of oil forms at the inner periphery, which reduces the heat transfer rate and ultimately reduces the productivity.

Solution

As earlier discussed the problem of settling the oil at the inner periphery is due to the low velocity in the straight tube of shell and tube heat exchanger.

To solve this problem first the velocity of the mixture is increased but due to that the condensate collected is at higher temperature. The process at higher velocity (more

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-930-936 ISSN: 2249-6645

than 0.5m/s) was not suitable. So it is decided to keep the low velocity with more turbulences.

High turbulences results in increases the performance of the unit. Due to the turbulences the heat transfer rate increases as well as oil will not stick to the inner surface of the tubes.

This is achieved by using spiral tube heat exchanger instead of shell and tube type heat exchanger.

Advantages of spiral tube heat exchanger

Spiral tube heat exchanger consists of number of spirals attached to the header. One fluid flows from periphery to center of the casing while the other is moving from center to periphery, it has following advantages,

1 Because of the spiral flow paths imparted to the tube- and shell-side fluids, the effects of centrifugal force and secondary circulating flow enhance heat transfer on both sides in a counter flow arrangement.

2 The other fluid enters the unit at the periphery and moves towards the centre. The channels are curved and have a uniform cross section, which creates “spiraling” motion within the fluid.

3 The fluid is fully turbulent at a much lower velocity than in straight tube heat exchangers, and fluid travels at constant velocity throughout the whole unit, and thus the sticking of oil problem will be eliminated.

4 Spiral heat exchangers require small area for mounting resulting in lower unit installation cost compared with other.

5 Compared with other types of heat exchanger, spiral unit provides the best access to their heat transfer area with no special tools or lifting equipment required.

Literature Review

The heat transfer coefficients in a spiral plate heat exchanger are investigated by Rangasamy R. and K.Saravanan [1]. The test section consists of a plate of width 0.3150 m, thickness 0.001 m and mean hydraulic diameter of 0.01 m. The mass flow rate of hot water (hot fluid)is varying from 0.5 to 0.8 kg/s and the mass flow rate of cold water (cold fluid) varies from 0.4 to 0.7 kg/s. Heat transfer studies in two-phase flow streams are studied by S. Ramachandran, P. Kalaichelvi,[2]. The objective of the investigation was to evolve a correlation to predict two phase heat transfer coefficients with reasonable accuracy which will help to optimally design the heat exchanger. Experimental studies in laminar range were done in a spiral plate heat exchanger using the two-phase system of water- n-dodecane in different mass fractions and flow rates as the cold process fluid. The two phase heat transfer coefficients were related with Reynolds numbers and were fitted into a relation in the form h = a Rem . The heat transfer coefficients were also related to the mass fraction of n-dodecane for identical Reynolds numbers. Correlations were developed between the two-phase multiplier (ratio of the heat transfer coefficient of the two phase fluid and that of the single phase fluid - ΦL. *)* and the Lockhart Martinelli parameter (X tt2 }. This enables prediction of the two- phase heat transfer coefficients using single-phase data with an accuracy of ± 8 %.

The heat transfer characteristics and the performance of a spiral coil heat exchanger under cooling and dehumidifying conditions are investigated by P. Naphon, S. Wongwises [3]. The heat exchanger consists of a steel shell and a spirally coiled tube unit. The spiral-coil unit consists of six layers of concentric spirally coiled tubes. Each tube is fabricated by bending a 9.27 mm diameter straight copper tube into a spiral-coil of five turns. Air and water are used as working fluids. The chilled water entering the outermost turn flows along the spirally coiled tube, and flows out at the innermost turn. The hot air enters the heat exchanger at the center of the shell and flows radially across spiral tubes to the periphery. A mathematical model based on mass and energy conservation is developed and solved by using the Newton–Raphson iterative method to determine the heat transfer characteristics. The results obtained from the model are in reasonable agreement with the present experimental data. The effects of various inlet conditions of working fluids flowing through the spiral coil heat exchanger are discussed.

Rangasamy R. and K. Saravanan[4] experimentally investigated convective heat transfer coefficient for electrolytes using spiral plate heat exchanger. The test section consists of a plate width 0.315m, thickness 0.001m and mean hydraulic diameter of 0.01m. the mass flow rate of water (hot fluid) is 0.636kg/s and the mass flow rate of electrolytes (cold fluid) varying from 0.483kg/s to 0.704 kg/s. Experiments have been conducted by varying the mass flow rate, temperature and pressure of cold fluid, keeping the mass flow rate of hot fluid constant. The effect of relevant parameters on spiral heat exchanger is investigated. The data obtained from the experimental study are compared with theoretical data. A new correlation for Nusselts number

Nu = 0.04Re0.84Pr0.15 is developed.

SPIRAL TUBE HEAT EXCHANGER

The Spiral heat exchanger was developed in Sweden by Rosenblad Patenter in the 1930s to recover waste energy from contaminated water effluents in pulp mills.

Spiral heat exchanger is self cleaning equipment with low fouling tendencies, easily accessible for inspection or mechanical cleaning with minimum space requirement.

Due to the curvature of the tube, a centrifugal force is generated as fluid flows through the curved tubes. Secondary flows induced by the centrifugal force have significant ability to enhance the heat transfer rate. [3] Helical and spiral coils are known types of curved tubes which have been used in a wide variety of applications for example, heat recovery process, air conditioning and refrigerating systems, chemical reactors, food and dairy processes.

An advantage which the spiral coil heat exchanger has over conventional heat exchanger systems is its ability to accommodate differential thermal expansion. The system is more compact. For the same heat transfer surface, the spiral coil arrangement has a volume about 15% smaller than that of cross flow shell and tube heat exchanger.

Spiral tube heat exchanger uses multiple parallel tubes connected to pipe-like manifolds to create a tube-side flow

path. Refer fig. no. 2 cross sectional view of the spiral tube heat exchanger.
The square dimensional profile of the spiral tube heat exchanger allows the unit to have a smaller footprint than the long, rectangular shell-and-tube unit. This can be observed by comparing two heat exchangers.

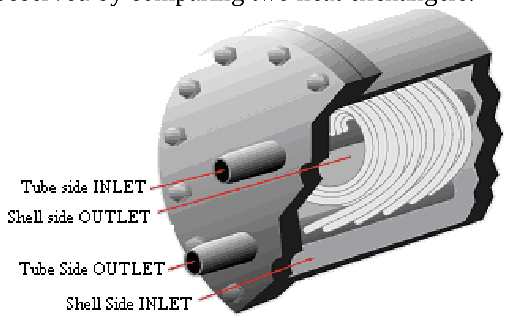

Fig. 2 Cross section of spiral tube heat exchanger

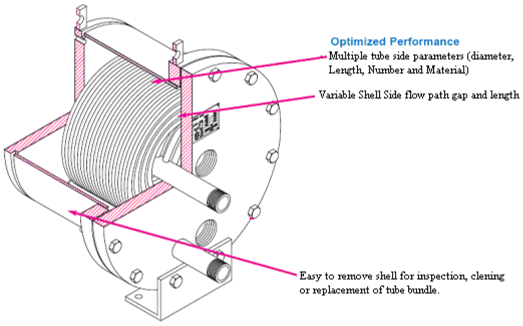

Fig. 3 Cross sectional view

A spiral tube heat exchanger is a coil assembly fitted in a spiral casing. The coil assembly is welded to a header and fitted in a compact shell. The spaces or gaps between the coils of the spiral tube bundle become the shell side flow path when the bundle is placed in the shell. Tube side and shell side connections on the bottom or top of the assembly allow for different flow path configurations. Refer fig no. 3 for the constructional details.
The spiral shape of the flow for the tube side and shell side fluids create centrifugal force and secondary circulating flow that enhances the heat transfer on both sides in a true counter flow arrangement. Advantage of spiral shape is to get tube side enhancement without the associated potential for plugging on both the shell and tube side of the heat exchanger. Since there are no baffles or dead spots to lower velocities and coefficients, heat transfer performance is optimized. Additionally, since there are a variety of multiple parallel tube configurations (diameter, number and length), efficiency is not compromised by limited shell diameter sizes as it is in shell and tube designs.
Since the tube bundle is coiled, space requirements for tube bundle removal are virtually eliminated. When exotic material is required, a spiral tube heat exchanger minimizes the material used since manifolds replace the channels, heads and tube sheets of a conventional shell and tube design. The shell side is usually smaller than a comparable shell and tube design and there are no requirements for tube supports or pass dividers.

Spiral tube heat exchanger uses single channel technology which means that both fluids occupy a single channel, which allows fully counter-current flow. One fluid enters the centre of the unit and flows towards the periphery. The other fluid enters the unit at the periphery and moves towards the centre. The channels are curved and have a uniform cross section, which creates “spiraling” motion within the fluid.
The fluid is fully turbulent at a much lower velocity than in straight tube heat exchangers, and fluid travels at constant velocity throughout the whole unit. This removes any likelihood of dead spots and stagnation. Solids are thus kept in suspension and the heat transfer surfaces are kept clean by scrubbing action of the spiraling flow.
Self-cleaning keeps cost down & the self cleaning properties of spiral heat exchangers ensure that the reliable performance of efficient heat transfer is guaranteed, within minimum down time for maintenance. Spiral heat exchangers require small area for mounting resulting in lower unit installation cost compared with other.

SPECIFICATIONS OF SPIRAL TUBE HEAT EXCHANGER

The specifications of the spiral tube heat exchanger as follows.
Surface Area: 0.45 m^2
Tube Diameter:
Outer diameter = 12 mm
Inner Diameter = 10 mm
No. Spirals : 06 with pitch as 30 mm

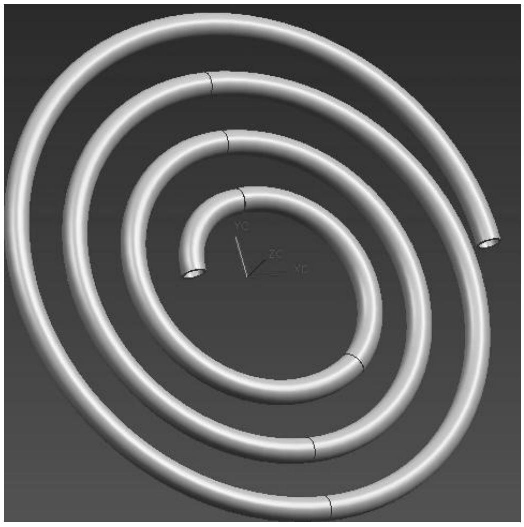

Fig. 4 Spiral Tube

Spiral of the spiral tube heat exchanger is made from copper tube with outer diameter 12mm and 10mm inner diameter , the outside diameter of the spiral is 248 mm and channel width is 30 mm, the length of the tube required is 1.88 m and the surface area available for heat transfer is 71186.83 mm2 (0.071187 m2). The hot water inlet is directed from the center of the spiral where as the hot fluid outlet is taken from the periphery of the spiral, the channels for coldwater are equi-spaced with pitch of 30 mm.

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-930-936 ISSN: 2249-6645

Fig. 5 Spiral tube bundle

Spiral tube bundle is an assemblage of six spiral sets, the inlets are connected to a common pipe 30mm outside diameter and 21mm inner diameter, the inlet pipe is provided with an end flange that receives the inlet connector. Similarly the outlets of the spirals are connected to a common pipe 30mm outside diameter and 21mm inner diameter, the inlet pipe is provided with an end flange that receives the outlet connector.

The flanges are mounted on the casing plates. The hot water spirals offer a net heat transfer area of 0.45 m2.The cold water channels are equally spaced with an overall spacing of 30mm pitch and width 80mm.

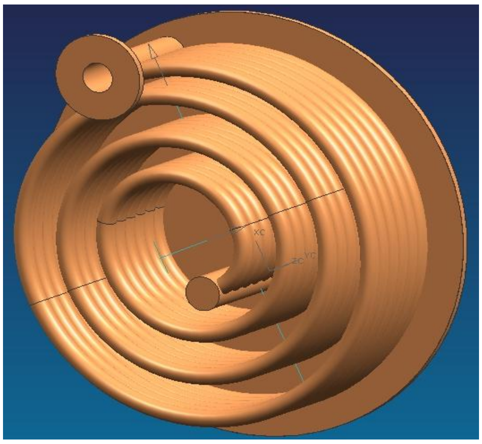

Fig. 6 Spiral Tube bundle with back plate

Casing primarily comprises of two end flanges and a circular pipe, the end flanges receive the flanges for hot water inlet and outlet as well as cold water outlet. The cold water inlet flange is welded to the periphery of the casing; overall casing is 300mm diameter and 100mm length.

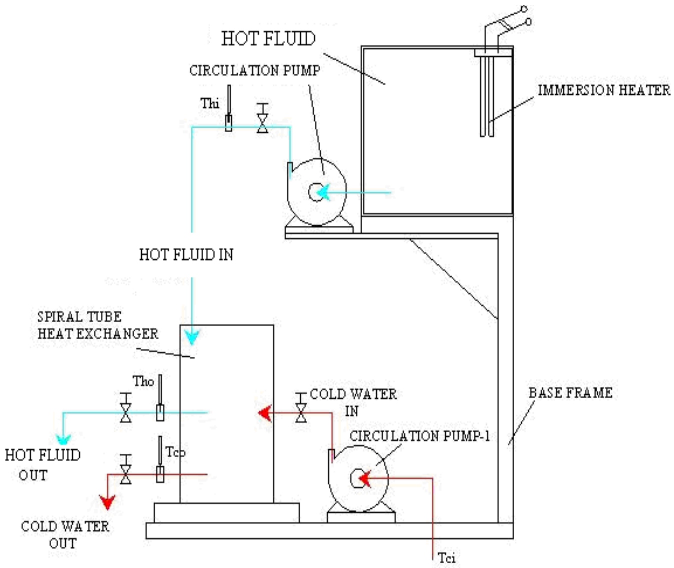

Fig. 7 Experimental set up

SUGGESTED PROCEDURE FOR EXPERIMENTATION

(a) Carefully check all the electrical and hydraulic connections before starting.
(b) Start the immersion heater supply to heat the oil in the overhead tank.
(c) Start the cooling water supply by opening the inlet valve to the heat exchanger
(d) After getting the certain temperature of the oil start the hot oil supply by opening the valve.
(e) Take the reading of inlet hot oil temperature, outlet hot oil temperature at steady state. Also take the cold water inlet and outlet temperature by temperature measuring instrument.
(f) Collect the hot oil and cooling water at the outlet of the heat exchanger in beaker. Check the time required for collection of oil and water in beaker for 1000 ml.
(g) Repeat the same procedure for different flow rates of the hot oil and cooling water.

Flow rate of hot oil is varied by opening the valve at different angles. The readings are taken to check the performance of the heat exchanger.

RESULTS & DISCUSSION

Following formulas are used to get the results tabulated to compare the performance of spiral tube heat exchanger with shell and tube type heat exchanger.

Reynolds Number

Re = $\rho v d / \mu = VD / \nu$

Prandtl Number

Pr = $\mu c_p / k$

Nusselt Number

Nu = $0.04\, Re^{0.74} Pr^{0.4}$ ----[4]

Effectiveness (ε)

ε = (Thi -Tho) / (Thi - Tci)

Properties of oil of lemon grass oil

μ = 0.547×10^{-3} Kg/ms

ν = $4.2\ 10^{-6}$ m2/Sec

Cp = 4060 J/Kg K

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-930-936 ISSN: 2249-6645

k = 0.505 W/mK

Performance graphs of spiral tube heat exchanger and shell and tube heat exchanger for sugandh mantri oil emulsion.

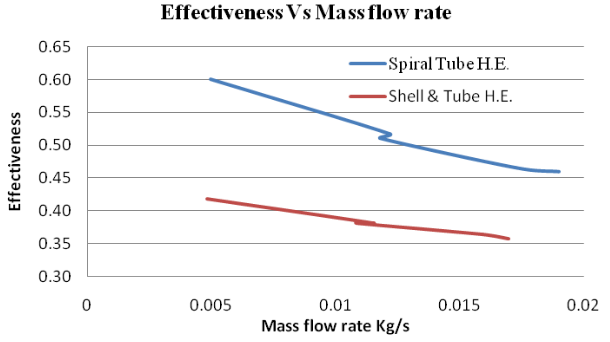

Fig. 8 Effectiveness Vs Mass Flow Rate

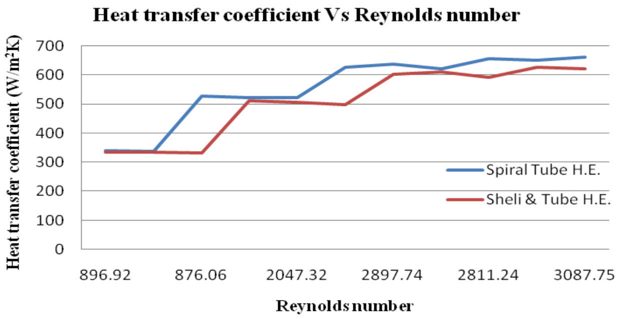

Fig. 9 Heat transfer coefficient Vs Reynolds number

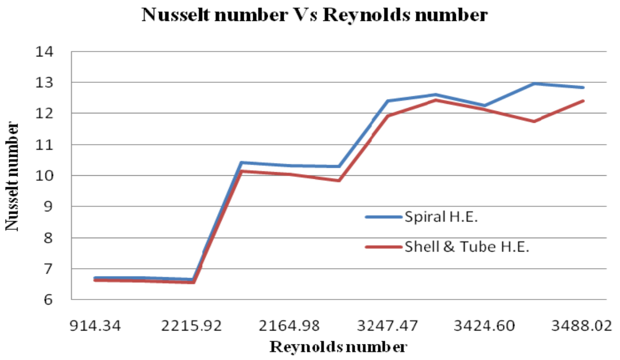

Fig. 10 Nusselt number Vs Reynolds number

Performance graphs of shell and tube heat exchanger and spiral tube heat exchanger for lemon grass oil emulsion.

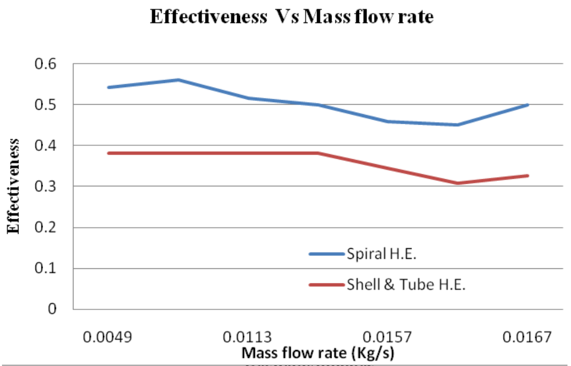

Fig. 11 Effectiveness Vs Mass Flow Rate

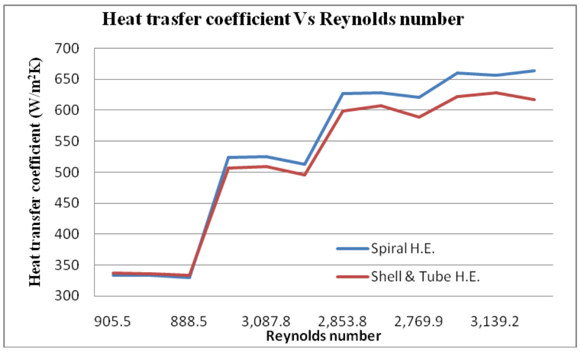

Fig. 12 Heat transfer coefficient Vs Reynolds number

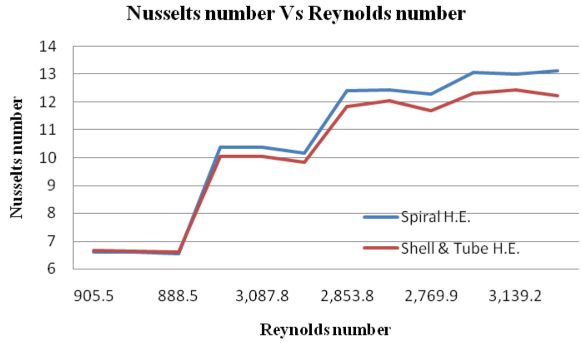

Fig. 13 Nusselt number Vs Reynolds number

- Graph 8 & 11 shows the trend for the mass flow rate and effectiveness. It is seen that as mass flow rate increases with decrease in effectiveness. It is observed that for the same mass flow rate effectiveness increases for the spiral tube heat exchanger.
- Graph 9 & 12 shows the relation between Reynolds numbers & Heat transfer coefficient. It is seen from the graph that the heat transfer coefficient increases with increase in Reynolds number. The nature of the graph is linear.
- Graph 10 & 13 shows the relation between Reynolds numbers and Nusselt number. It is seen from the graph that Nusselt number increases with increase in Reynolds number.
- From the test data available effectiveness of shell and tube heat exchanger for lemon grass oil and sugandh mantra oil is average 0.3 to 0.4 against for spiral it is 0.4 to 0.5, thus increase in the effectiveness.
- Heat transfer coefficient for shell and tube type heat exchanger is average 350 – 600 W/m2K against for spiral tube heat exchanger it's average value is 450 to 650 W/m2K, thus increase in the heat transfer rate due to use of spiral tube heat exchanger.

CONCLUSION

As prescribed in the chapter 5, for the experimental studied following can be concluded

- The continuously curved flow section contributes to improvement in overall heat transfer coefficient as compared to shell and tube type heat exchanger from 400 to 650W/m2K.
- The true concurrent flow increases the heat exchanger effectiveness from 0.3 to 0.5 for spiral heat exchanger.

- The cost saving using spiral tube heat exchanger is around 15 – 20 % as compared to shell and tube type heat exchanger apart from compactness and saving in size.
- The scrubbing effect of the fluids in both spiral passages inhabits deposition of slug and other deposits. Fouling factors for spiral heat exchangers are commonly one third the values of conventional shell and tube heat exchanger.
- By using spiral tube heat exchanger the oil sticking problem as in case of straight tube is reduced and total productivity is increased from 3.6 lit/day to 6.2 lit/day.

REFERENCES

1. R. Rajavel and K. Saravanan , “Heat transfer studies on spiral plate heat exchanger”, Journal of thermal science, vol. 12(3), pp 85-90, 2008
2. S. Ramachandran, P. Kalaichlvi, S. Sundaram, “Heat transfer studies for two phase flow in spiral plate heat exchanger”., Journal of the university of chemical technology and metallurgy, vol.41(4), pp 439-444, 2006
3. P. Naphon, S. Wongwises, “ A study of heat transfer characteristics of a compact spiral coil heat exchanger under wet-surface conditions”, Experimental thermal and fluid science, vol. 29, pp 511-521, 2005
4. R.Rajavel and K.Saravanan, “ An experimental study of spiral plate heat exchanger for electrolytes”, Journal of university of chemical and metallurgy, vol. 43 (2), pp 255-260, 2008
5. J.C.Ho and N.E. Wijeysundera, “Performance of compact, spiral coil heat exchanger”, Heat recovery system & CHP, Vol.15, pp 457-468, 1995
6. Deshpande P.M, “Spiral tube heat exchanger for heat recovery from gases”, Thermal Engineering Journal, pp 80-85, 2008
7. Kanaris A.G, Mouza K.A, Paras S.V., “Designing Novel Compact Heat Exchangers For Improved Efficiency Using A CFD Code”, Proceeding of 1st International Conference “From Scientific Computing to Computational Engineering, Athens, Sep. 8-10, pp 405-435, 2004
8. J.C.Ho and N.E. Wijeysundera, “ Study of a compact spiral coil cooling and dehumidifying heat exchanger”, A T E, vol. 16(10), pp 777-790, 1996
9. Brian Allen and Rich Zoldak,” Spiral heat exchangers preheat high solids black liquor without plugging”, pulp & paper, Feb. 1991
10. Olaf Strelow,“A general calculation method for plate heat exchanger”, Journal of thermal science, vol.39, pp 645-658, 2000
11. Hewitt G.F., Shires G.L. and Bott T.R., “Process Heat Transfer”, CRC Press, Begell House, Boca Raton, 1994.
12. G.Walker, “Industrial Heat Exchangers, a basic guide”, second edition , hemisphere publishing corporation, New York, , 7-47, pp 93-119,1990
13. John E. Hesselgreaves, “Compact Heat Exchangers, Selection, Design and operation”, Pergamon, First Edition, New York, 27-80, pp 275-300,2001
14. Yunus A. Cengel, “Heat and Mass transfer, third edition”, Tata McGraw-Hill Publishing company limited, pp 285-295, 2007
15. John E. Hesselgreaves, “Compact heat exchangers”, pergamon,Second edition, pp 290-315, 2001
16. Warren. M. R., J. P. Harthnett, “Handbook of Heat Transfer”, Third Edition, McGraw-Hill, pp 1.1- 1.36, 17.1-17.100 , 1998