CFD Analysis of A Heat Exchanger used in a Sugar Mill

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***Abstract* - A single-phase fluid flow inside a sugar mill heat exchanger vessel called juice heater is analysed in CFD using solidworks flow simulation. The Heat exchanger geometry is multi pass tubular heat exchanger. Juice heating is the vital process involved in the sugar industry as this determines the quality and their efficiency at the earlier stage of production. Factors affecting the evaporation process are mass flow rate, temperature, pressure and velocity. Since flow of the sugar solution within the Juice Heater has a major impact on its overall performance a detailed study on it will be much useful to improve the efficiency. So a detailed study is made on the flow of the fluid inside the heat exchanger. By analyzing the heat exchanger we are capable of predicting trends in the fluid flow properties for processing conditions normally experienced in the vessel of a Juice heater. The analysis shows that the design of the velocity at the inlet and on the tubes of the vessel has a major influence on the flow field in the remainder of the vessel. Velocities at the top and bottom headers plays a major roles in achieving the desired at the tubes, in this analysis we found a flow patterns in the header and found lot of swirls and vortex at the header region, which will affect the thermal performance of the heat exchanger.**

I. INTRODUCTION

Juice heating is the vital process involved in the sugar industry as this determines the quality and their efficiency at the earlier stage of production. Factors affecting the evaporation process are mass flow rate, temperature, pressure and velocity. Since flow of the sugar solution within the Juice Heater has a major impact on its overall performance a detailed study on it will be much useful to improve the efficiency. So a detailed study is made on the flow of the fluid. This analysis is performed using Cosmos Express 2013 in solidworks software

II. OBJECTIVE OF JUICE HEATING

Juice leaving the extraction plant is close to ambient temperature if a milling tandem is installed or at about 60 in the case of a Filtrate is either returned to the raw juice tank, thus inflating the juice temperature somewhat, or to an intermediate tank after primary juice heating.

The quantity of filtrate can vary from 5 25 % of the raw quantity, depending largely on the suspended solids content of the juice and the consistency of the mud withdrawn from the objective is to heat the juice up to a temperature a few degrees above boiling point just before the clarifier. The juice is then flashed in a flash tank, so that the juice temperature to the clarifier is always constant and dissolved gas in the juice is removed

The juice is generally heated in two or more stages, making use of lower pressure vapour in the first stage to improve steam economy. Thus most of the heat transfer considered here involves condensing vapour to achieve the required, though in the case of raw juice at lower temperature from a milling tandem, the first stage could be heating the cold juice with condensate from the evaporators. This saves steam and is useful in cooling down condensate if cooled imbibition water is and in providing cooled condensate for flocculent preparation.

III. JUICE HEATER GEOMETRY DETAILS

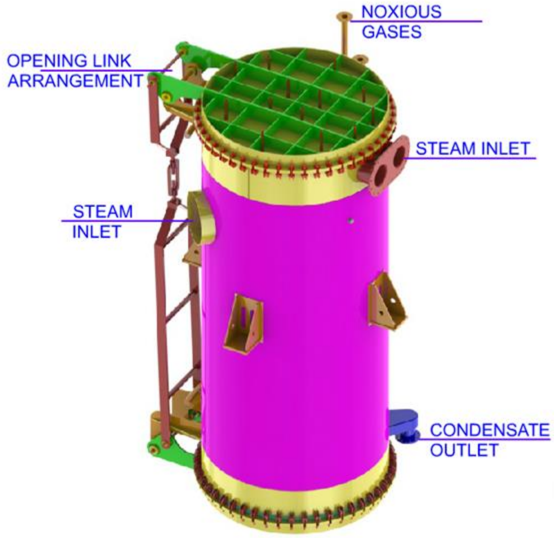
Fixed tube sheet heaters are generally used for heating sugar juice. Tubes are expanded into the tube sheets, with best results obtained starting with a 0.25 mm and a smooth clean hole. Tubes are normally arranged on a pitch with a pitch typically times the tube diameter. Square pitch arrangements permit fewer tubes to be used in the same area and are not normally used.

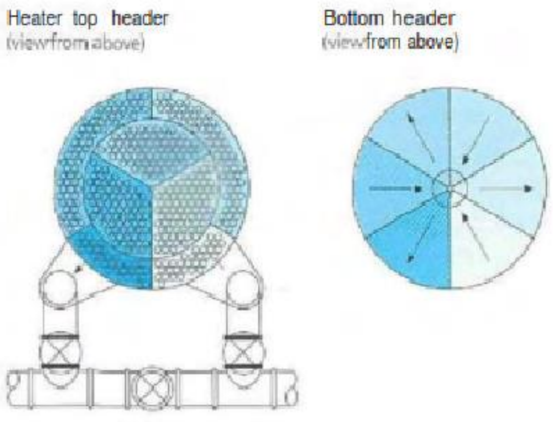
Tubes. Tubes have a diameter in the range of 38 to mm. Tube lengths may vary between 3 m and 7.5 m. Longer tube designs lead to lower pressure drops at the same liquid velocity because of the reduced number of passes. Copper and brass tubes were often used, but generally stainless steel tubes are chosen in new heaters, as they are harder, more abrasion resistant, more cost-effective and need less frequent replacement. Austenitic stainless steel, typically grade 304, and stainless steels such as 430 and 439 are used. Type 304L is often specified to minimize problems with ration in the seam weld and is sufficiently ductile for expansion into the tube sheets. The high chrome steel 3CR12 shows promise as a cheaper replacement for AISI 430 tubes.

Tubes may be chosen to be the same diameter and same length as those used in the evaporators to minimize spares holdings; or they may be specified to be slightly so that tubes that are removed from evaporators may be down and reused in the heaters.

Tube passes. Specific forms of shell and tube heaters differ according to the number of tube passes. The number of tubes/pass is chosen to give a velocity in the required range Spaces need to be between rows of tubes to allow for the arrangement of tube passes. The nest of tubes in each pass may be rectangular or arranged in a pie slice, depending on the pass arrangement adopted. Each pass the same number of tubes and an even number of passes is usually chosen to simplify the pipework. A typical arrangement of tubes in a heater is shown in Below Figure (FIG.1 & FIG.2). Numerous other options are possible.

Typical Arrangement of tube passes in a Juice Heater (FIG.1)





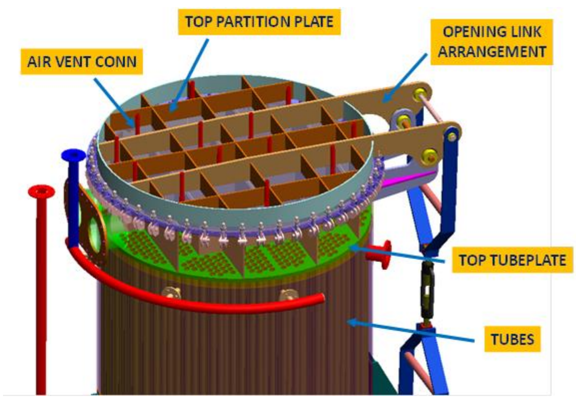
Header of Juice Heater (FIG.2)

Horizontal or vertical and tube heaters may be used. The latter can often lead to lower installation costs with long and an easier arrangement for mechanical tube cleaning. There is a in terms of heat transfer but this is insignificant in relation to the large effect of scaling. In either design space needs to be allowed to enable tubes to be removed and replaced.

Shell. The shell of the heater is made of mild steel. It is designed withstand exhaust pressure and an allowance is added for corrosion. No allowance is made for differential expansion between shell and tubes; it is safer to use 430 or 439 than 304 stainless steel or copper or brass if long tubes are used, since 430 and 439 have thermal expansion coefficients closer to that of mi l d steel. The juice side headers are for maximum liquid pressure under closed valve conditions. Pressure relief valves are generally attached to both shell and tube sides to protect against over-pressurization. And the different views of the typical juice heater are given in forth coming diagrams. FIG's (J, K, L & M)

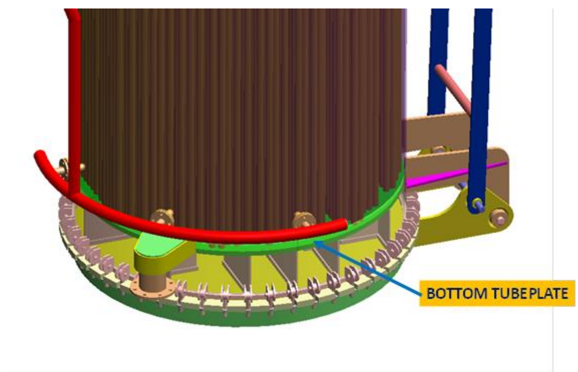
(FIG.J)

Which shows the external outfit of the entire Juice heater, which is going to be analysed here.



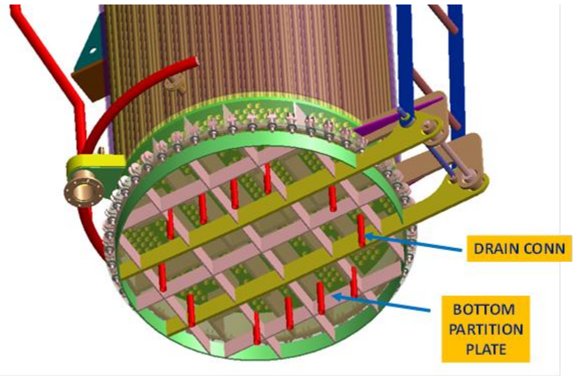
(FIG.K)

And the above figure (FIG.K) shows the header part of Juice heater.



(FIG. L)

The figure (FIG.L) gives the view of the bottom plate of the juice heater.



(FIG.M)

The figure (FIG.M) shows the Bottom portion of the juice heater having the Partition plate & Drain connections.

IV. JUICE HEATER GEOMETRY DETAILS

The flow of fluids in pipes is expressed by the same laws, whether liquid or gas is concerned. This may appear strange at first sight, but it is due to the important role played by viscosity of the fluid; and since viscosity is defined in terms of resistance to flow, it is due to its effect that the formulae become unified. Since most problems of gas flow in a sugar factory may be easily resolved by the adoption of recommended velocities, we shall be concerned here mainly with flow of liquids. However, once the viscosity is known, problems can be solved in either case by completely analogous methods. In this case, we are concerned mainly with the following fluids: water, juice,

V. GOVERNING EQUATIONS

A. The flow and its mathematical descriptions:

The term 'fluid dynamics' stands for the investigation of the interactive motion of a large number of individual particles. These may be molecules or atoms and it can be approximated as a continuum. It implies that even an infinitesimally small element of the fluid still contains a sufficient number of particles, for which mean velocity and mean kinetic energy can be specified. In this way velocity, pressure, temperature, density and other important quantities at each point of the fluid can be defined. The derivation of the principal equations of fluid dynamics is based on the fact that the dynamical behavior of a fluid is determined by the following conservation laws, namely:

1. the conservation of mass,
2. the conservation of momentum and
3. the conservation of energy.

The conservation of a certain flow quantity means that its total variation inside an arbitrary volume can be expressed as the net effect of the amount of the quantity being transported across the boundary, any internal forces and sources, and external forces acting on the volume. The amount of the quantity crossing the boundary is called flux. The flux can be in general decomposed into two different parts: one due to the convective transport and the other one due to the molecular motion present in the fluid at rest. This second contribution is of a diffusive nature and it is proportional to the gradient of the quantity considered and hence it will vanish for a homogeneous distribution. The discussion of the conservation laws leads quite naturally to the idea of dividing the flow field into a number of volumes and to concentrate on the modeling of the behavior of the fluid in one such finite region. For this purpose, the so-called finite control volume is defined and development is made on a mathematical description of its physical properties.

B. conservative laws

a. The continuity equation

For single-phase fluids, the law of mass conservation expresses the fact that mass cannot be created in such a fluid system, nor can disappear from it. There is also no diffusive flux contribution to the continuity equation, since for a fluid at rest; any variation of mass would imply a displacement of fluid particles. And it is given below

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

The mass flow of a fluid through some surface fixed in space equals to the product of density, surface area and velocity component perpendicular to the surface.

b. The Momentum equation

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)$$

$$\rho\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

The derivation of the momentum equation is done from the particular form of Newton's second law which states that the variation of momentum is caused by the net force acting on a mass element.

c. The Energy equation

The underlying principle that is applied in the derivation of the energy equation is the first law of thermodynamics. Applied to the control volume, it states that any changes in time of the total energy inside the volume are caused by the rate of work of forces acting on the volume and by the net heat flux into it.

$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)$$

For periodic fully-developed fluid flow, if temperature change was limited and physical property was constant, periodic flow should have the following characteristics which are periodic boundary conditions:

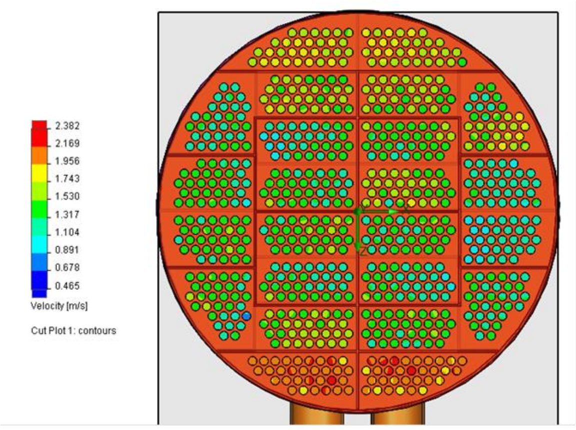
u +*x*, *y*, *z*, _ *u*(*x*, *y*, *z* _ *s*)
v + *x*, *y*, *z*, _ *v*(*x*, *y*, *z* _ *s*)
w+ *x*, *y*, *z*, _ *w*(*x*, *y*, *z* _ *s*)

p(*x*, *y*, *z*) _ *p*(*x*, *y*, *z* _ *s*) _ *p*(*x*, *y*, *z* _ *s*) _ *p*(*x*, *y*, *z* _ 2*s*)

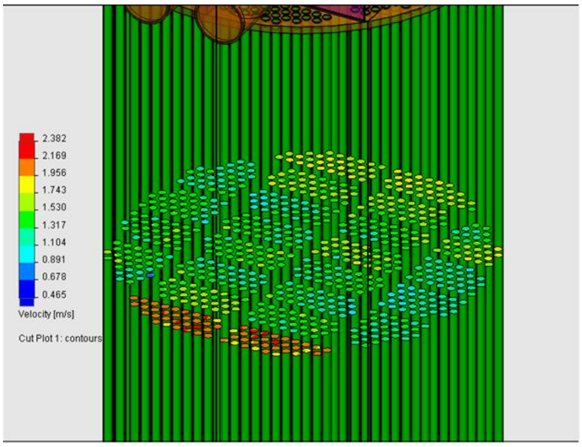
In the periodic model, pressure drop can be expressed as pressure gradient. Pressure gradient means pressure drop per unit length. It is defined as Equation 8, and the unit for it is Pa/m in the SI units system.

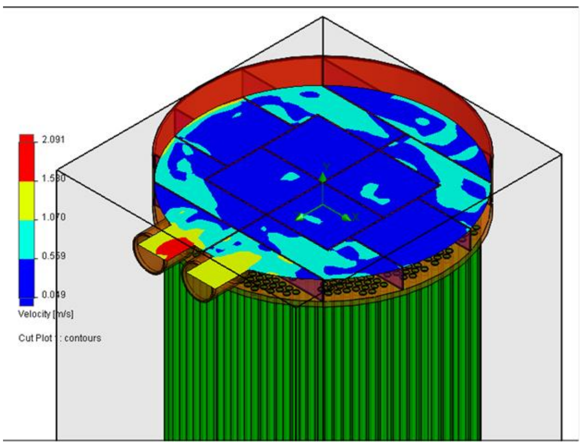
$$\Delta P = p(x, y, z) - p(x, y, z + s)$$

VI. RESULT & DISCUSSIONS

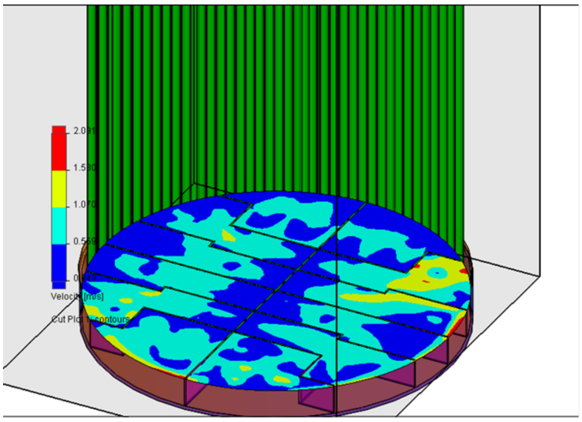


Velocity plots in tube sections, it shows that velocity was higher (2 m/s) at inlet and it was gradually reducing to about 1 m/s in the middle paths,

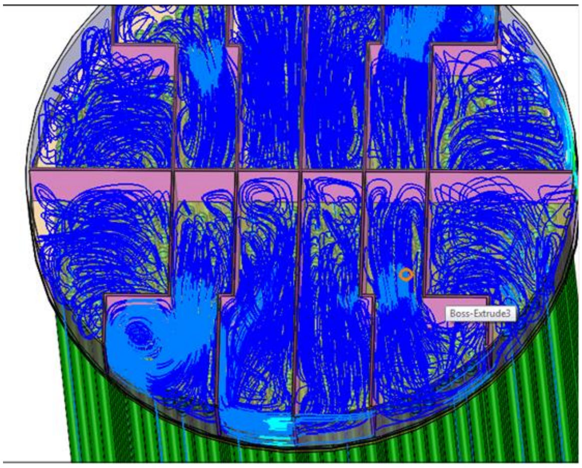




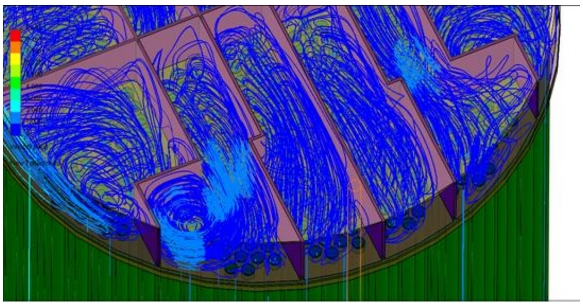
Velocity plot at the top header, it shows the partitions are having lower velocities, because of increased area



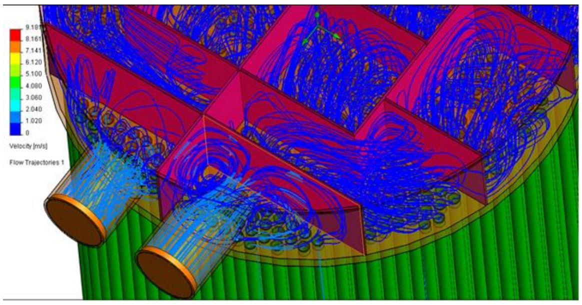
Velocity plot at the bottom header, it shows the partitions are having lower velocities, Because if Increased area



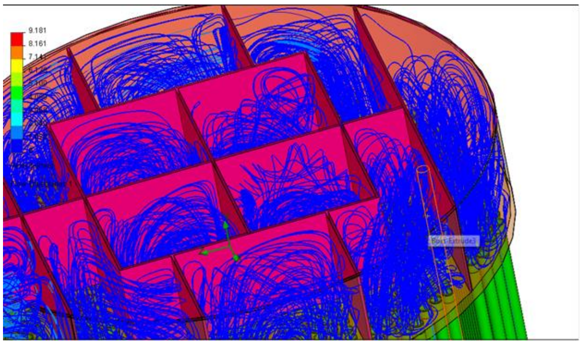
Flow pattern in the Bottom header shows a vortex, heat transfer will be reduced because of this design flaw



F1low pattern in the one of the partition reveals that there was a vortex in the fluid flow region, which is a design flaw



Flow pattern in the Top header reveals no vortex or swirls



Flow pattern in the Top header reveals no vortex or swirls

VII. CONCLUSION

In this work, simulation analysis is done in a sugar mill heat exchanger for flow rates with cosmos xpress software. Following conclusions are drawn from the computational analysis in this present work

I. Velocities at the tubes are within the allowable limit of 1.5 to 2 m/s for a sensible heat exchanger
II. Velocities are quite low on the top and bottom header, this is because flow area is designed for the tubes, as there is no heat transfer occur at the we might take this factor lightly
III. There is no swirls or vortex in the top header, where is bottom header there is a huge swirl at one of the partition which will make no flow in those which will reduce the heat transfer as well as reduce in outlet temp at this tubes
IV. As there is no flow in some of the tubes because of vortex present at the top of the tubes, there is a possibility of these tubes gets over heat and failure may occur on these tubes

VIII. FUTURE WORK

In this paper we have analyzed only flow pattern across different paths in the heat exchanger, a future work might be done with a conjucate heat transfer from the steam to juice, so that we might reveals the temperature profile for different paths, temperature drop because of vortex and swirls and pressure drop across the heat exchanger on multiple paths of jucie flow

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