CFD ANALYSIS OF HORIZONTAL ELECTROSTATIC DESALTER-INFLUENCE OF HEADER OBSTRUCTION PLATE DESIGN ON CRUDE-WATER SEPARATION

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Abstract: This paper attempts to design a horizontal electrostatic desalter to study the flow profile of crude in horizontal desalter. The presence of salt in the crude oil is a problem to the refineries. It caused increased corrosion and will cause increased fouling of equipment and hinder certain chemical & physical reactions. Since the salt present in the oil is contained in the water phase, the removal of salt and water simultaneously by electrostatic oil dehydration is simple solution.Liquid flow behaviour, such as velocity distribution, in the electrostatic desalter is of considerable importance in determining desalter performance. Using the volume-averaged method, a computational fluid dynamics (CFD) model was proposed to describe the liquid flow behaviour in a structured electrostatic desalter. The values of the geometrical parameters and operation Reynolds number that mark the transitions of flow regime in the Desalter are reported, and the impact of the geometry on such transitions is analysed. Variations in desalter design have been done to analyse the change in crude flow. The proposed study of flow in a desalter has been done in Fluent.

Keywords: Electrostatic Desalter, Mixing, Turbulent flow, Fluid Mechanics, Gambit, Fluent, CFD.

I. INTRODUCTION

The presence of salt in the crude oil is a problem to the producer. It causes increased corrosion and will cause increased fouling of equipment and hinder certain chemical and physical reactions. Since the salt present in the oil is contained in the water phase, the removal of salt and water simultaneously by electrostatic oil dehydration is a simple solution. The treating principle is almost the same as the heat treater with the exception of applying an electric field for more complete dehydration. However, as we cannot remove all the water some salt will remain. Where high salt concentrations are present in the emulsion water phase, it would be necessary to dilute this with fresh water to lower the salt concentration before removing the water. Dilution water, which has low salinity, is used to lower the salt concentrations.

The electrostatic desalter is provided with electrodes to impart an electrical field in the desalter. This serves to polarize the dispersed water molecules. The so formed dipole molecules exert an attractive force between oppositely charged poles with the increased attractive force increasing the speed of water droplet coalescence by from 10 to 100 fold. The water droplets also move quickly in the electrical field, thus promoting random collisions that further enhance coalescence.Upon separation of the phases which are two immiscible crude and water phases, the crude is commonly drawn off the top of the desalter and sent to the fractionator tower in crude units or other refinery processes. The water phase containing water soluble metal salt compounds and the sediment is discharged as effluent. The process flow sheet showing the process mechanism of the electrostatic desalter has been shown in Figure.1…

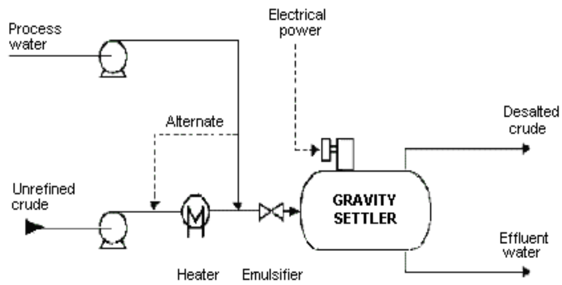

Figure.1: Flow sheet showing the process mechanism of the electrostatic desalter.

The electrostatic oil dehydration effect employed for the separation by the horizontal electrostatic desalter had not been considered in the CFD simulation done for the crude-water emulsion separation in desalter. The crude-water emulsion feed is introduced into desalter through an inlet header which is a long pipe which has 69 small diameter holes on the top of it. The inlet header provideseven distribution of the crude-water emulsion across the entire vessel length and produces a laminar profile. This emulsion is injected just above the crude-water interface, thereby maximizing crude oil residence time and improving upset tolerance. An obstruction plate is introduced above inlet header which is at a distance 100mm above the inlet header. The obstruction plate is introduced above inlet header to provide the better feedentry of the crude-water emulsion in the desalter as it resists the inlet feed to go to the top of the desalter due to its momentum and thus providing decreased turbulence in the crude phase above crude-water interface. The inlet feed through header holes collides with the obstruction plate right above the header and the plate atomizes the crude-water emulsion into small droplets which is the first essential step for the crude separation.

In computational fluid dynamics, the volume of fluid (VOF) method is a numerical technique for tracking and locating the free surface.The volume of fluid method is based on earlier Marker-and-cell (MAC) methods. First accounts of what is now known as VOF have been given by, where fraction function C appeared, {which is defined as the integral of fluid's characteristic function in the control volume. Basically, when the cell is empty, with no traced fluid inside, the value of C is zero; when the cell is full, C=1; and when the inter-phasal interface cuts the cell, then $0 < C < 1$. C is a discontinuous function, its value jumps from 0 to 1 when the argument moves into interior of traced phase.}, although first publication in a Journal was by. Since VOF method surpassed MAC by lowering computer storage requirements, it quickly became popular. Early applications include [3] from Los Alamos, who created VOF codes for NASA (1985,1987). First implementations of VOF suffered from imperfect interface description, which was later remedied by introducing a Piecewise-Linear Interface Calculation (PLIC) scheme. Using VOF with PLIC is a contemporary standard, used in number of computer codes, including ANSYS Fluent.

The VOF model is designed for two or more immiscible fluids, where the position of the interface between the fluids is of interest.In the VOF model, a single set of momentum equations is shared by the fluids, and the volume fraction of each of the fluids is tracked throughout the domain. Applications of the VOF model include the prediction of jet break-up, the motion of large bubbles in a liquid, the motion of liquid after a dam break, or the steady or transient tracking of any liquid-liquid interface.

Computational Fluid Dynamics (CFD) is increasingly used in the process industry to design and optimize desalters and other process vessels. It is an effective tool to analyse fluid flow and also the liquid-liquid separation in various systems. It is based on the following governing equations of fluid flow, namely,

1. Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{v}) = S_m$$

2. Momentum equation

$$\frac{\partial(\rho \vec{v})}{\partial t} + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla P + \nabla \cdot (\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F}$$

3. Energy equation

$$\frac{\partial(\rho E)}{\partial t} + \nabla \cdot (\vec{v}(\rho E + P)) = \nabla \cdot (K_{\text{eff}} \nabla T - \sum_j h_j \vec{J}_j \sum + (\bar{\bar{\tau}}_{\text{eff}} \cdot \vec{v})) + S_h$$

4. Separation equation

$$u \frac{\partial u}{\partial s} = -\frac{1}{\rho} \frac{dp}{ds} + \nu \frac{\partial^2 u}{\partial y^2}$$

In this work, the commercial Computational Fluid Dynamics (CFD) software FLUENT is used to simulate the horizontal electrostatic desalter for the crude-water phase separation. This paper includes a three dimensional CFD model of a desalter with different designs of obstruction plate above the inlet header which is used to provide even distribution of crude-water emulsion into the desalter using large number of hole outlet on inlet header pipe.

The aim of the present work was to obtain a CFD model to predict the amount of separation done in a desalter, and to study the hydrodynamic behaviour of crude in a desalter by analysing the velocity magnitude contours taken from Fluent 6.3.26. And the study of the change in hydrodynamic behaviour of crude on use of different designs of obstruction plate above the inlet header of the desalter is done.

II. MODEL DESCRIPTION AND BOUNDARY CONDITIONS

The hydrodynamic flow of crude in a horizontal desalter was studied using CFD analysis. The non-uniformity of flow distribution through the desalter is found to be more severe in models with no obstruction plate above the inlet headers. Hence, the objective of the study was to analyse the flow distribution through desalter for different designs of obstruction plate above the inlet header and to develop an optimized obstruction platedesign providing a better flow distribution in the desalter.
The inlet and desalter geometries are in many cases symmetrical. This symmetry could be exploited in reducing the size of the numerical model by one half. The 3-D CFD model developed of a desalter used for simulation is the half symmetrical part of a full desalter. The symmetrical desalter model developed for the CFD analysis is as shown in Fig. 2.

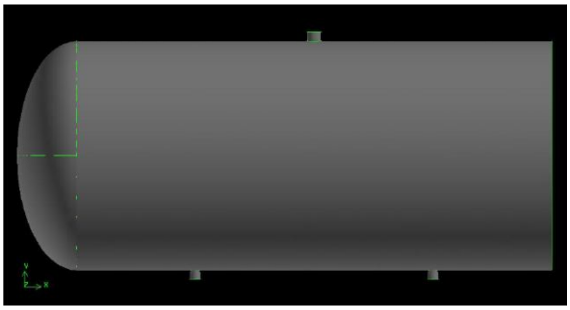

Figure.2. Symmetrical desalter model developed

The simulation of this geometry was done using a commercial CFD software FLUENT. The design, meshing and boundary definition of the geometries were done using the pre-solver software, GAMBIT.Hexagonal mesh scheme with interval spacing 50 was used for the mesh generation. The grid elements in each geometrical model were approximately 2 millionfinite volume elements and the processing time for the simulation was noted to be four hours. Grid independence test was carried out to determine the best mesh spacing for the geometrical model. Figure, 3 shows the meshed symmetrical desalter model developed.

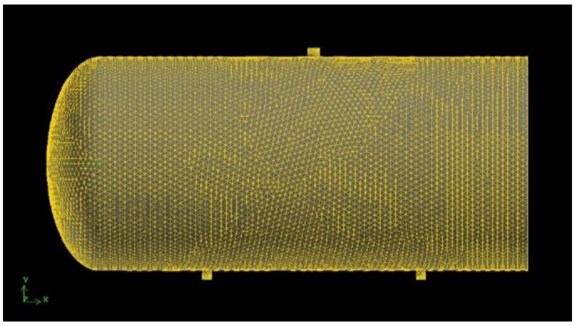

Figure.3: Meshed symmetrical desalter model developed.

The simulation was performed for two different obstruction plate designs and one no obstruction plate design. The boundary conditions used for the simulation are shown in Table 1.

Table. 1: Boundaries and boundary conditions.

Boundary	Position	Boundary Condition (BC)
Crude-water inlet	Cross section through nozzle, some diameters upstream	Uniform velocity profile, typical turbulence intensity and length scale
Crude Outlet	Cross section through the column, some space above the packing bed	Free outlet
Water Outlet	Liquid surface considered flat	Symmetry, no shear
Walls	Column wall, nozzle wall	Adiabatic for mass and energy, log-law for turbulence

Two different fluids, the dispersed water (salt in water) and the continuous fluid (crude) were taken as two immiscible phases which were used for the simulations. Inlet flow velocity of the emulsion to the inlet header was 4.43 m/sec. Pressure-based solver was used for this steady state analysis.During the analysis, energy balance equation was neglected as solutions were ideal and the heat of mixing was negligible. The simulation was performed for a convergence criterion of 1*e-03.

Volume of fluidmultiphase model was adopted for simulations of horizontal desalter. A three-dimensional steady state model was developed to analyse the crude flow and separation in a horizontal desalter with obstruction plate above the inlet header of desalter. Different designs of obstruction plate are modelled to study there influence on amount of separation and hydrodynamic behaviour of crude in desalter. These different designs of obstruction plate have an influence on the separation of crude-water emulsion intocrude and water streams and also it has an effect on the hydrodynamic behaviour of the crude in the desalter for a crude-water emulsion feed stream.

III. FLOWGEOMETRY

The design of a desalter is varied by changing the design of obstruction plate provided above the inlet header of desalter. Three such designs are taken in considerations and are shown in following figures 4, 5…The three different desalter designs which had been modelled are mentioned below:

1. A desalter design having a capped obstruction plate above the inlet header which has been shown in figure.4.
2. A desalter design having a horizontal obstruction plate above the inlet header.
3. A desalter design having no obstruction plate above the inlet header which has been shown in figure.5.

Figure.4: desalter design having a capped obstruction plate over inlet header

The design specifications for the desalter with capped obstruction plate are:
The inlet header size is 12". There are 69 holes on the inlet header pipe with 50mm diameter. Distance between holes is 100mm. And they are located at the top of the inlet header. Obstruction plate distance to holes is 100mm. There is a 15 degree angle with horizontal line for the obstruction plate which makes it a capped obstruction plate. The design specifications for horizontal obstruction plate desalter design are same as that for the capped obstruction plate but the angle provided in capped obstruction plate is not provided in horizontal plate desalter design.

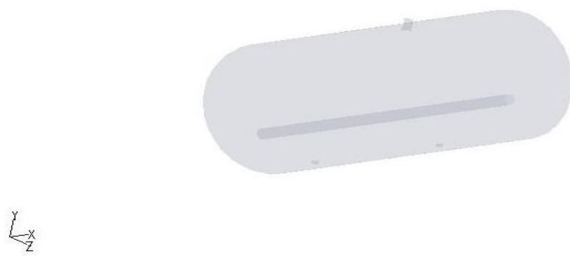

Figure.5: desalter design having no obstruction plate over inlet header.

The design specifications for desalter design with no obstruction plate are same as the two desalter designs with obstruction plate but for design shown in figure, 6, there is no obstruction plate provided above the inlet header.

(4) Results and discussion (Simulation of desalter)

After the model is developed, the nature of the feed and the physical properties of the feed material had been specified. Three different designs of desalter have been simulated to examine the effect on the flow distribution and the amount of separation done, where feed introduced was a crude-water emulsion feed. Table, 2 shows the physical properties of crude oil and water used to form the emulsion.And the ambient media above the outlet was assumed to be stagnant gas (air).

Density of Crude	0.22 Kg/m^3
Surface Tension	0.02 N/m
Re	1022236
Viscosity	0.000011 kg/(m·s)
Turbulent Intensity	2.84
Backflow Turbulent Intensity	2.837436
Velocity of Inlet	4.43 m/s
Pressure	1 atm

Table.2: Physical properties of crude oil and water.

In the Table, 2 the crude oil properties taken into consideration have been shown and the water properties taken are the default properties stored in Fluent 6.3.26...

The model described above was implemented into the commercial CFD code Fluent, where the governing equations are solved using Volume of fluid (multiphase) solver algorithm. Second order upwinddiscretization scheme was used for the momentum and volume-fraction differencing scheme for simulations. The solution of the pressure from the momentum equations uses a pressure correction equation that corrects the pressure and velocity after every iteration according to the simplecalgorithm.

In Section 4.1, the effects of capped obstruction plate above the inlet header on crude flow distribution and amount of separation have been explained and in Section 4.2, the effects of horizontal obstruction plate on hydrodynamic behaviour of crude and amount of separation have been explained. And later in Section 4.3 the effects on flow distribution of crude and amount of separation have been explained for desalter with no obstruction plate above the inlet header.

(4.1) Capped obstruction plate design:

By varying the under-relaxation factors and discretization schemes a number of times and after some 1100 iterations, convergence of order 1*e-3 had been reached. After reaching the convergence, developed system had been considered as stable and hydrodynamic behaviour of crude in the desalter had been analysed by finding out the crude flow velocity magnitude pathlines.

Figure, 6 shows a residual plot between various convergence deciding parameters and number of iterations. The different y- ordinate parameters correspond to different colours.

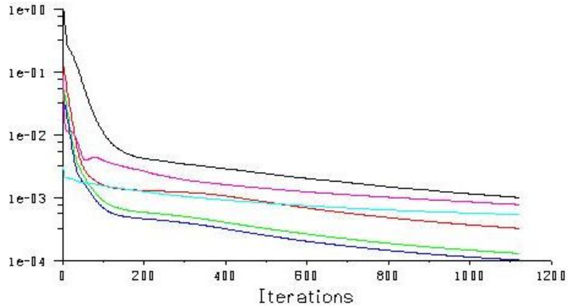

Figure. 6. Residuals for capped obstruction plate design. (Black- continuity, Red- x.velocity, Green- y.velocity, Blue- z. velocity, Sky Blue- k, Pink- epsilon).

Velocity magnitude Pathlines (side view- parallel to direction of the flow) for crude in a desalter with capped obstruction plate have been taken which are shown in figure, 7. From this figure showing crude pathlines we can trace the path through which a crude will flow in a desalter. And through a close lookthe action of capped obstructionplate can also be seen. The flow have been blocked by the obstruction plate which prevents the emulsion to go to the crude outlet directly, and improve the amount of separation. And the turbulence in the crude phase region has also been reduced providing an even distribution of crude phase in the desalter. Figure, 8 shows velocity pathlines (front view- perpendicular to direction of the flow) for crude which shows all the crude is going to the crude outlet above and a very less amount of crude is coming out from the liquid outlet below which is desirable as maximum amount of separation is encountered. In both the figures 7, 8, the blue colour refers to stationary conditions and red refers to 4.43 m/s.

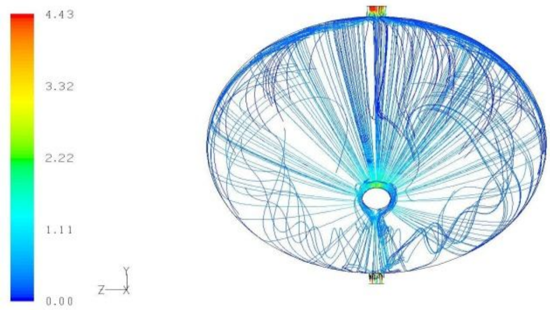

Figure. 7. Velocity magnitude pathlines (side view) for crude. (Top- Crude outlet, Bottom- Water outlet)

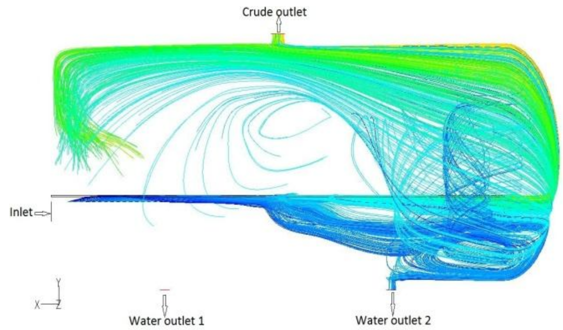

Figure. 8. Velocity magnitude pathlines (front view) for crude. (Top- Crude outlet, Bottom- Water outlet)

(4.2) Horizontal obstruction plate design:

By varying the under-relaxation factors and discretization schemes a number of times and after some 3500 iterations, convergence of order 1*e-3 had been reached. After reaching the convergence, developed system had been considered as stable and hydrodynamic behaviour of crude in the desalter had been analysed by finding out the crude flow velocity magnitude pathlines.

Figure, 9 shows a residual plot between various convergence deciding parameters and number of iterations. The different y- ordinate parameters correspond to different colours.

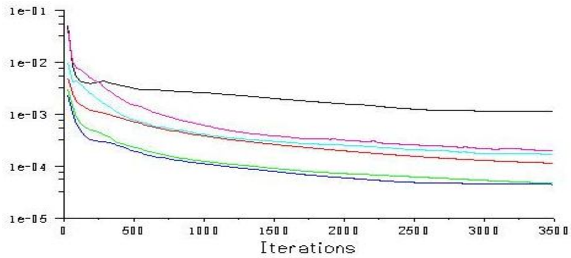

Figure. 9. Residuals for horizontal obstruction plate design. (Black- continuity, Red- x.velocity, Green- y.velocity, Blue- z. velocity, Sky Blue- k, Pink- epsilon).

Velocity magnitude Pathlines (side view- parallel to direction of the flow) for crude in a desalter with horizontal obstruction plate have been taken which are shown in figure, 10. Figure, 11 shows velocity pathlines (front view- perpendicular to direction of the flow) for crude in a desalter with horizontal obstruction plate. In both the figures 10, 11, the blue colour refers to stationary conditions and red refers to 4.43 m/s.

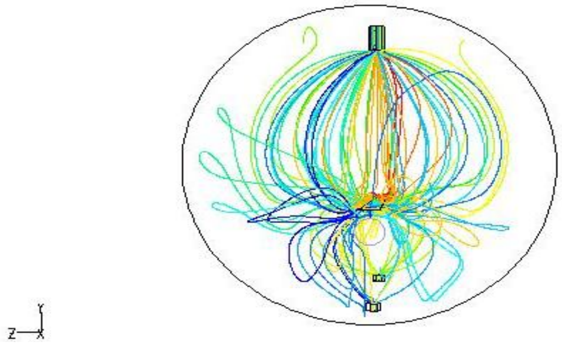

Figure. 10. Velocity magnitude pathlines (side view) for crude. (Top- Crude outlet, Bottom- Water outlet)

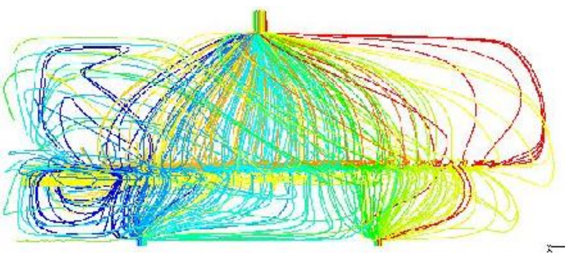

Figure. 11. Velocity magnitude pathlines (front view) for crude. (Top- Crude outlet, Bottom- Water outlet)

(4.3) No obstruction plate design:

By varying the under-relaxation factors and discretization schemes a number of times and after some 4500 iterations, convergence of order 1*e-3 had been reached. After reaching the convergence, developed system had been considered as stable and hydrodynamic behaviour of crude in the desalter had been analysed by finding out the crude flow velocity magnitude streamlines Figure, 12 shows a residual plot between various convergence deciding parameters and number of iterations. The different y-ordinate parameters correspond to different colours.

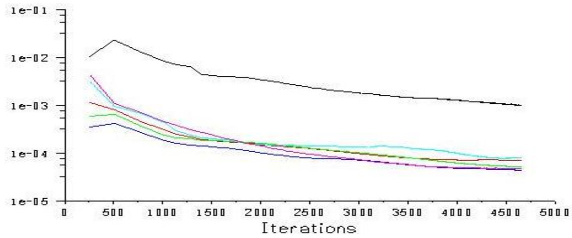

Figure. 12. Residuals for no obstruction plate design. (White-continuity, Red- x.velocity, Green- y.velocity, Blue- z. velocity, Sky Blue- k, Pink- epsilon).

Velocity magnitude Pathlines (side view- parallel to direction of the flow) for crude in a desalter with no obstruction plate have been taken which are shown in figure, 13. From having a close look of this figure the disadvantage of having no obstruction plate can also be seen. The flow have not been blocked here because of no obstruction plate which causes the emulsion to go to the crude outlet directly, and reducing the amount of separation. And the turbulence in the crude phase region has also been increased causing an uneven distribution of crude phase in the desalter. Figure, 14 shows velocity pathlines (front view- perpendicular to direction of the flow) for crude in a desalter with no obstruction plate. In both the figures 13, 14, the blue colour refers to stationary conditions and red refers to 4.43 m/s.

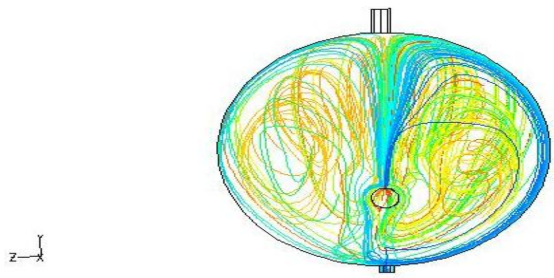

Figure. 13. Velocity magnitude pathlines (side view) for crude. (Top- Crude outlet, Bottom- Water outlet)

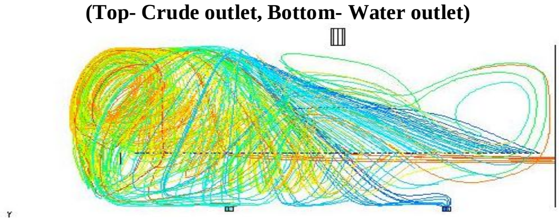

Figure. 14. Velocity magnitude pathlines (side view) for crude. (Top- Crude outlet, Bottom- Water outlet)

CONCLUSION

In this study, a 3-D two phase model was developed to predict the separation in a horizontal desalter provided with different designs of obstruction plate above the inlet header of desalter. Three designs with capped obstruction plate, horizontal obstruction plate and no obstruction plate had been simulated in Fluent 6.3.26 and the separation of crude-water emulsion had been carried out and then the crude velocity magnitude streamlines were further analysed. Basically, the effect of obstruction plate above the header inlet on crude flow distribution is investigated. The simulation study done explains that the application of obstruction plate above the inlet header gives an even distribution of the emulsion and a good separation as it helps to decrease the turbulence created by inlet feed in the crude phase, which shows that the desalter design with an obstruction plate located above the inlet header is better than the desalter design with no obstruction plate. It have been concluded that the obstruction plate having some angle with the horizontal would provide better obstruction to emulsion outflow from holes provided on inlet header, providing even flow distribution of the two phases in thedesalter, which further results in better and uniform separation of crude and water.

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