STUDY OF FACILITY DESIGN FOR CONVERSION OF GLUCOSE TO HIGH FRUCTOSE CORN SYRUP

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ABSTRACT: *Sucrose from natural product or nectar has been a part of the human eating routine for centuries. High-Fructose Corn Syrup (HFCS) has replaced table sugar (sucrose) as the primary artificial sweetener found in consumer food products. It is a mixture of glucose and fructose produced by breaking down corn starch. The demand for High-Fructose Corn Syrup is increasing day by day. The objective of this research is to design the equipment for the production of HFCS with minimum production cost. The designing of pump, reactor, mixer, evaporator, condenser and heat exchanger are the equipment used for the production of HFCS has been carried out in this research. All the equipment has been designed including the calculations of all the essential parameters concerned with each equipment.*

Key Words: Glucose; Fructose; Corn syrup; Sucrose; Carbohydrate.

1. INTRODUCTION

Sucrose from sugar stick has been a part of the human eating regimen for many years. Sucrose keeps on being the benchmark against which different sweeteners were estimated. In any case, sucrose has presented critical technological issues in specific applications: it hydrolyzes in acidic frameworks, changes the sweetness and flavour attributes of the product, and it is a granular component that must be broken down in the water before use in numerous applications [1, 2].

Moreover, the sugar stick was customarily developed in central districts, well for both political and climatic precariousness. The accessibility and cost of sugar varied uncontrollably in response to upsets in either one. HFCS is quickly proved itself an appealing option in contrast to sucrose in fluid applications since it is steady in acidic nourishments and refreshments. Since it is a syrup, HFCS can be pumped from conveyance vehicles to stowage and blending tanks, requiring just straightforward weakening before use as an ingredient got from corn, a reliable, sustainable, and plentiful agricultural crude material of the Midwest US. HFCS has stayed safe from the cost and accessibility limits of sucrose. It was mainly thus that HFCS was so promptly acknowledged by the nourishment business and delighted in such staggering development [3, 4].

Preceding the improvement of the overall sugar industry, dietary fructose was constrained to just a couple of things. Meats, milk and most vegetables, the staples of various early eating regimens, have no fructose and only 5– 10% fructose by weight is found in natural products, for example, apples, grapes and blueberries. Molasses and natural dried organic products have a substance of under 10% fructose sugar [5].

Initial formative work was done during the 1960s, with shipments of the primary business HFCS product to the edibles business happening in the late 1960s. Advance development over the resulting at least 35 years made HFCS an exceptional amongst the best sustenance ingredients in present-day history. HFCS was utilized in relative obscurity for a long time. On the whole, its compositional likeness to sucrose recommended that it would be processed similarly. Its security was never genuinely questioned as scientific panels inconsistently since the 1960s made the same inference: fructose, sucrose, glucose and currently HFCS did not represent a critical wellbeing hazard, with the single particular case of advancing dental caries [6, 7].

Even though there was an impressive hypothesis during the 1980s that fructose was in charge of a few metabolic anomalies, persuading evidence this was a critical wellbeing hazard was never pending. It came as incredible amazement to numerous when, apparently medium-term, HFCS was changed from an everyday ingredient into the essential focal point of researchers and customers worried about the emerging occurrence of obesity in the United States and around the globe. From 1970 to 2000 there has been a 25% expansion in "included sugars" [8].

HFCS is made out of either 42 percent or 55 percent fructose, with the rest of the sugars being principally glucose and higher sugars. As far as the creation, HFCS is almost identical to table sugar (sucrose), which is made out of 50 percent fructose and 50 percent glucose is represented in Table 1. In this way in spite of the name, HFCS isn't exceptionally high in fructose contrasted with glucose [2, 9]. HFCS, like honey and table sugar, are natural. HFCS is produced using corn, a specific grain item. HFCS contains no artificial or manufactured ingredients or colour substances and meets the Food and Drug Administration's strategy for utilization of the expression "normal."

2. PROCESS SELECTION (METHODOLOGY)

The preliminary raw material in the HFCS production is corn starch, over a series of four foremost preparing steps; the starch is changed over to 42 percent HFCS. The real steps is the change of starch to dextrose feedstock. At that point, preparation of high-quality dextrose feedstock for isomerization. The isomerization of the feedstock to fructose. Secondary, fructose refining, whenever need a fifth stage can be included with further refining of the 42% solution can be utilized to create 55 to 90 percent fructose syrups [10, 11].

2.1. First Enzymatic Step

The primary step changes over the starch slurry to dextrose. The starch slurry is at first a blend of 15-30% amylase and 70-85% amylopectin. A few stages are engaged with the manufacture of dextrose from starch. Firstly, the starch slurry is exposed to a high temperature in which the starch granules breaks and starch progresses toward becoming gelatinized. This gelatinized starch is then diluted by both hydrolysis and high temperature with alpha-amylase. This progression produces liquid, less thick and low molecular weight dextrins products and takes roughly 130 mins [12, 13].

2.2. Second Enzymatic Step

This liquefaction and dextrinization items are like this exposed gradually to hydrolysis procedure by amyloglucosidase to make a glucose syrup. This is suggested to as saccharification, a persistent procedure take up to 75 hours, contingent upon the measure of catalyst present. The final product of the scarification procedure is a 94-96% high dextrose hydrolyzate additionally elegant in stage 2 [14, 15]. In the second step, the dextrose is refined to make a high-quality feedstock essential for the isomerization procedure in step 3. The refining procedure lessens the pollutants, for example, ash and proteins that can impede the proficiency of the isomerization catalyst in step 3. In this procedure, the dextrose is exposed to a progression of filtration ventures to clear the oil and protein. Next, the color of the liquor is removed by a sequence of granulated carbon segments. At that point, the liquor is exposed to ion exchange system which is de-ionized. Finally, the liquor is vaporized to the proper level for the third step then treated with magnesium particles to restrain any calcium particles that may inhibit the isomerase action in step 3 [2].

2.3. Third Enzymatic Step

In the third stage, the dextrose liquor is isomerized to HFCS, is the core procedure. The isomerization organizes changes over the glucose too much sweeter and therefore progressively important fructose yield. The critical advancement that creates this upgraded value possible is the business improvement of immobilized glucose isomerase, a bound enzyme can raised temperatures of the procedure. The expense of the isomerization enzymes is an essential part of the total operating budget in the HFCS procedure. Along these lines, many research exertion has been dedicated to the economics of the enzyme activity and particularly its decay rate [16].

The utilization of immobilized enzyme reactor frameworks is the typical structure in the industry. In this stage, the primary variable is the movement of the enzyme that controls the conversion rate of dextrose to fructose to determine the quality of fructose content in the product. The movement of the enzyme decays with respect to time in an ordinary way. Because of this decay, the reactor framework is structured and worked to limit the fluctuations in action [17].

In step 4, powder and color are removed from the 42% HFCS over ion exchange and carbon filtration systems. The cation and anion exchange resins which are especially helpful for the removal of color framing bodies and different polluting influences from the fermented polyhydroxy liquor solutions in the present development are the strongly acidic cation and basic anion exchange resins. Among the cation exchange resins of the above kind which can be utilized in the current development are Amberlite IR-112, Aberlite IR-120, and Dowex 50 which are copolymers arranged by responding styrene with different compositions of divinylbenzene and sulfonating the aromatic nucleus [12]. The anion exchange resins which can be utilized in the present innovation are the essential anion exchange resins containing quaternary ammonium groups and which thus can split salts, also, having the absorbing capacity concerning acids. It also include evaporation of the 42% resolution for shipment of solids [18, 19].

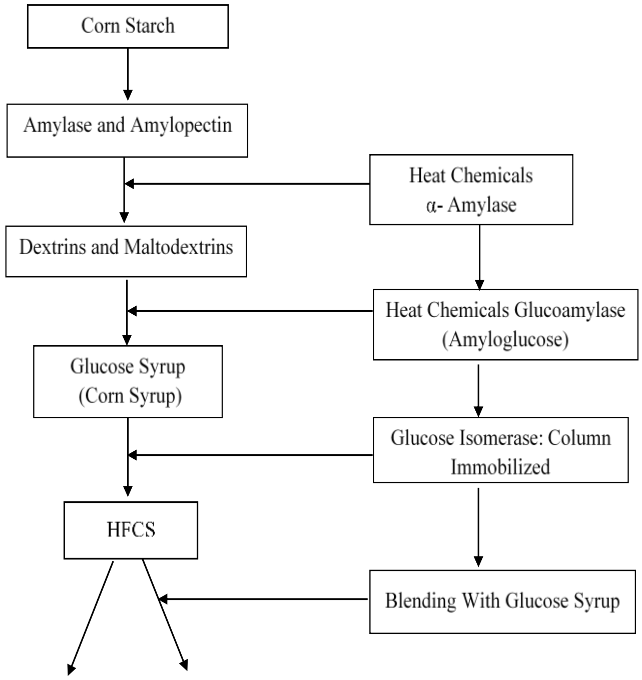

Figure 1: Flow diagram of HFCS production

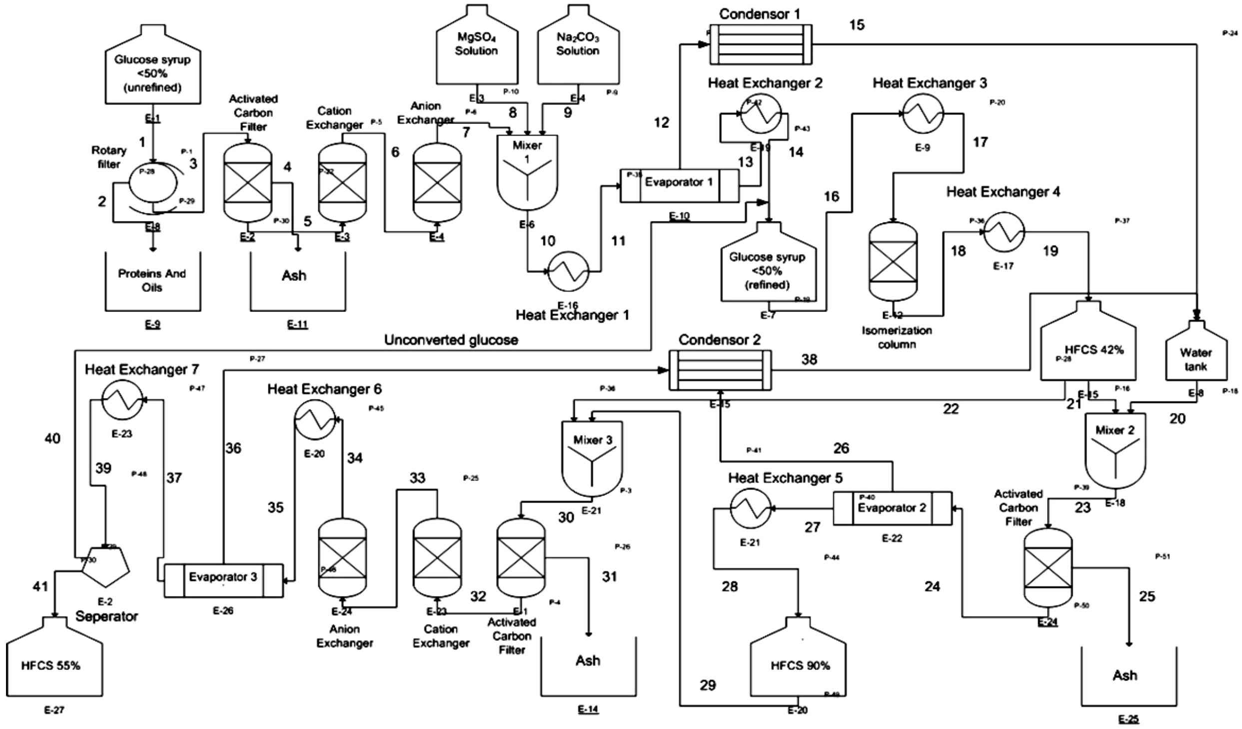

Figure 2: Process flow diagram of HFCS production

3. EQUIPMENT DESIGNING

The plant design involves a wide variety of skills. In plant designing after the inception and the need for this project and after carrying out material and energy balance, more inclined towards the designing of the equipment. The equipment designed involve pumps, heat exchangers, condensers, reactor, mixers and evaporator.

3.1. Designing of Pump

In case of pumps, we have calculated out the energy requirements. The power in hp has been calculated out. The available and required NPSH has been calculated and we have selected a pump model based on our calculation as shown in Figure 3. The specification of the pump is calculated in Table 1.

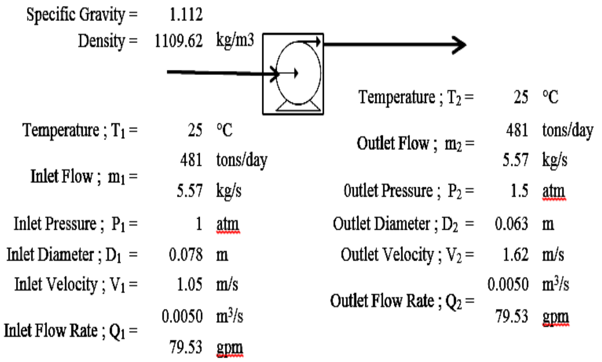
Specific Gravity = 1.112
Density = 1109.62 kg/m3
Temperature ; T_1 = 25 °C
Inlet Flow ; m_1 = 481 tons/day 5.57 kg/s
Inlet Pressure ; P_1 = 1 atm
Inlet Diameter ; D_1 = 0.078 m
Inlet Velocity ; V_1 = 1.05 m/s
Inlet Flow Rate ; Q_1 = 0.0050 m³/s 79.53 gpm
Temperature ; T_2 = 25 °C
Outlet Flow ; m_2 = 481 tons/day 5.57 kg/s
Outlet Pressure ; P_2 = 1.5 atm
Outlet Diameter ; D_2 = 0.063 m
Outlet Velocity ; V_2 = 1.62 m/s
Outlet Flow Rate ; Q_2 = 0.0050 m³/s 79.53 gpm

Figure 3: Parameters of pump

Table 1: Calculated specification of pump

Parameter	Operating condition
Frictional losses ; ΔP_f	19948.88 Pa =19.948 KPa
Work done ; W_0	259.636 m^2/s^2
Power ; P	3212.05 W =4.31 hp
Static head	6.66 m
Dynamic head	1.83 m
Total head; H	8.49 m
NPSH	11.03 m
Best Operating Point	
Flow rate ; Q	113 gpm = 0.0071 m^3/s
Total head ; H	76 ft = 23.16 m
Efficiency, η	45 %
Head coefficient; C_H	0.147
Capacity coefficient; C_Q	0.0017
Power coefficient ; C_P	0.00053
Suction head coefficient; C_{NPSH}	0.0623
Pump specific speed; N_{sp}	0.175
Pump specific speed; $N_{sp, Eur}$	0.02791

3.2. Designing of Mixer

To calculating out the specifications for the mixer. The retention time and the type of impeller used in mixing were also evaluated as shown in Figure 4.

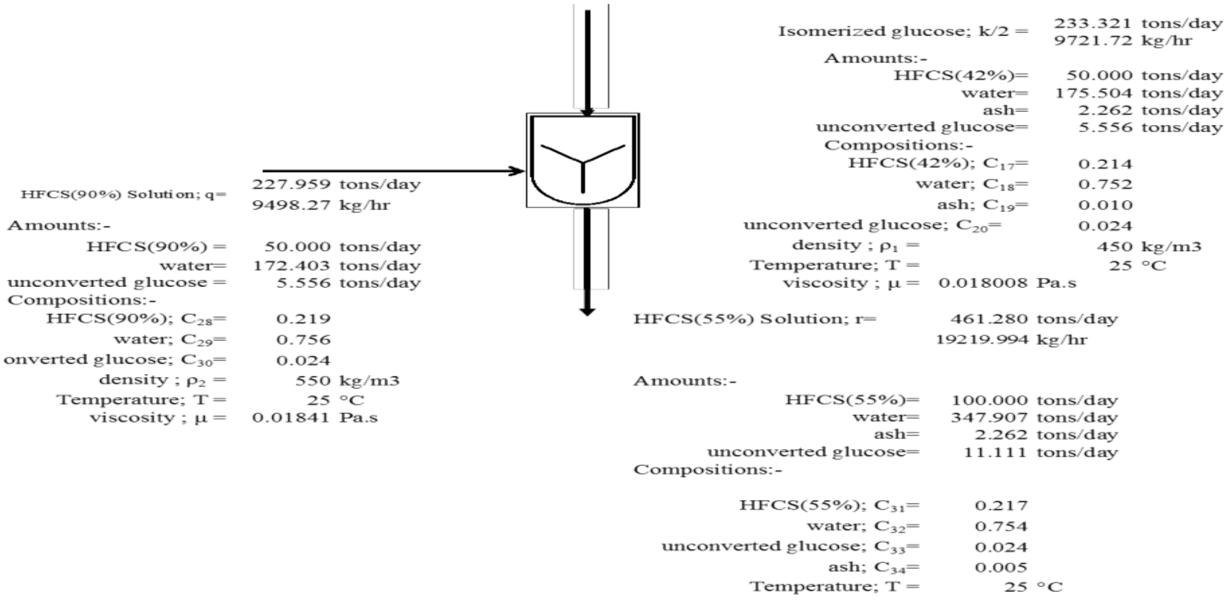

Figure 4: Parameters of mixer

The specification of the mixer is calculated in Table 2.

Table 2: Calculated specification of mixer

Parameter	Operating condition
Inlet flow rate ; Q_1	$38.873 m^3/hr = 0.011 m^3/s$
Time is taken to fill the mixer	0.0067 hrs
The volume of the fluid; V_f	$0.259\ m^3$
The inner diameter of the mixer	0.548 m
Length of mixer	1.097 m
Liquid head; h	1.010 m
Pressure drop due to liquid head	4954.44 Pa = 4.954 KPa
Total allowable pressure ; P	106279.44 Pa = 106.28 KPa
Material	Carbon steel
Working stress of carbon steel; S	94408.84 KPa
The thickness of the cylindrical shell; t_m	0.0014 m
Outer diameter	0.551m
Volume of the cylindrical shell; V_s	$0.003\ m^3$
The volume of the top and bottom Ellipsoidal head; V	$0.079\ m^3$
Total volume	$0.081\ m^3$
The density of Carbon Steel	$7855.42\ kg/m^3$
Mass of the tank; W	639 kg
Reynold Number; Re	27597.67 (Turbulent flow)
Power ; P	1310 W = 1.310 KW
Time required to fill the mixer; t_T	24 s = 0.0067 hr

3.3. Designing of Reactor

To design a PBR reactor operating isothermally. The reaction kinetics was first order which simplified our calculations a great deal. The weight of catalyst was our basic requirement in the designing of the reactor. The pressure drop and other factors were also calculated and they met the essential requirement as shown in Figure 5. The specification of the reactor is calculated in Table 3.

Table 3: Calculated specification of the reactor

Parameter	Operating condition
Residence time	0.5 hr
Number of reactors	4
Velocity through bed	0.002 m/s
Height left above the bed	0.25 m
Height left below the bed	0.25 m
The density of catalyst; ρ_c	$333\ kg/m^3$
Porosity; φ	0.3 hr
The diameter of catalyst pellet; D_p	0.007 m
ϵ	0
Specific rate constant; k	$1.28E-03\ dm^3/kg\text{-}s$
Initial total flow rate (F_{TO})	237.201 g-mol/s
Concentration (C_{TO})	$49333.11\ g\text{-}mol/m^3 = 49.33\ g\text{-}mol/dm^3$
The flow rate of each reactor F'_{TO}	59.3 g-mol/s
Design equation for first-order PBR; W	2162.35 kg
The volume of catalyst each bed; V	$1.016\ m^3$
Bed height; Z	3.600 m
The radius of bed; r	0.758 m
Column height; L	4.546 m
Packing density; ρ_b	$233.1 kg/m^3$
Volume of void	$1.948\ m^3$

Volume of solid catalyst; V_s	4.545 m^3
The cross-sectional area of catalyst bed; A_c	1.804 m^2
Superficial velocity; u	0.0027 m/s
Superficial mass velocity; G	2.994 $kg/m^2.s$
Pressure drop; ΔP	949.7514 Pa

3.4. Designing of Evaporator

Multiple effect evaporators were used and we calculated the area as well as the steam economy and all the other variables involving the mass of steam and the mass of vapours. The different operating temperatures were obtained from the patent and enthalpies were calculated on these temperatures by the available data as shown in Figure 6. The specification of the evaporator is calculated in Table 4.

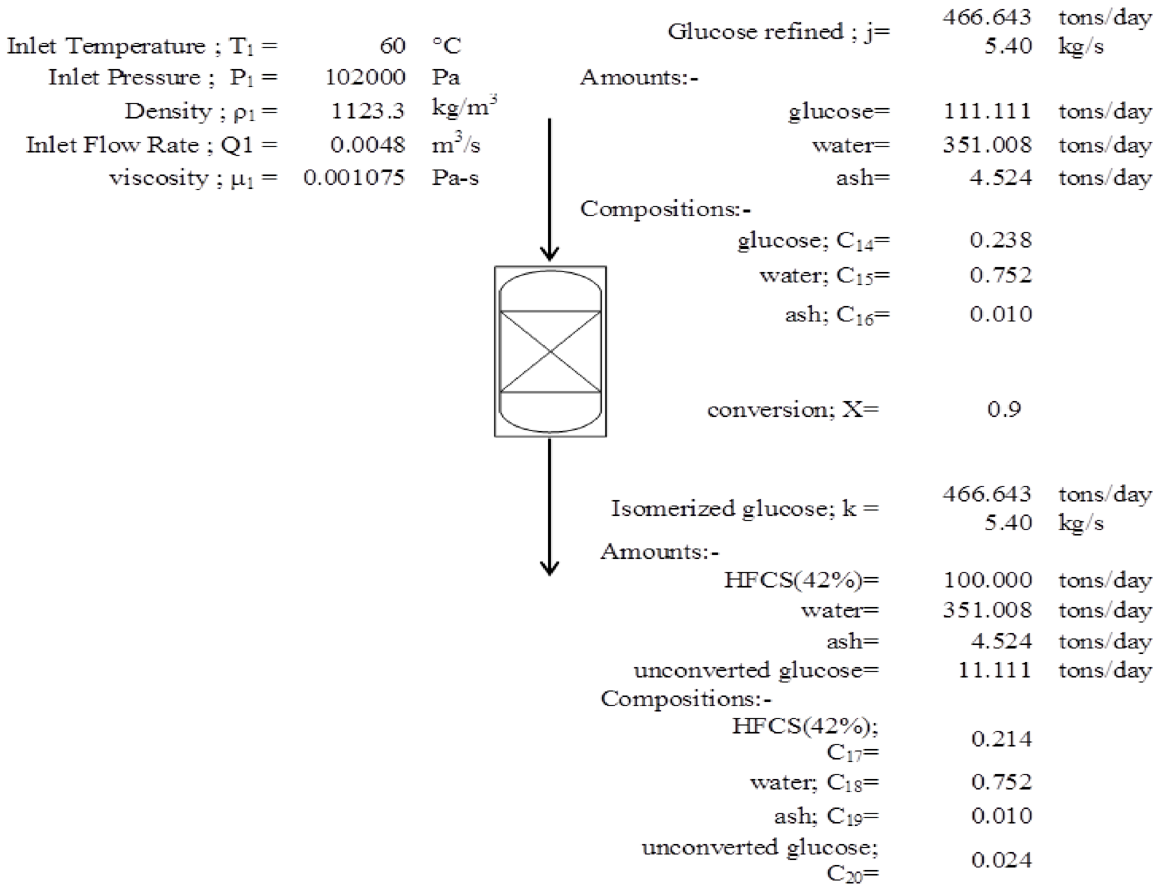

Figure 5: Parameters of the reactor

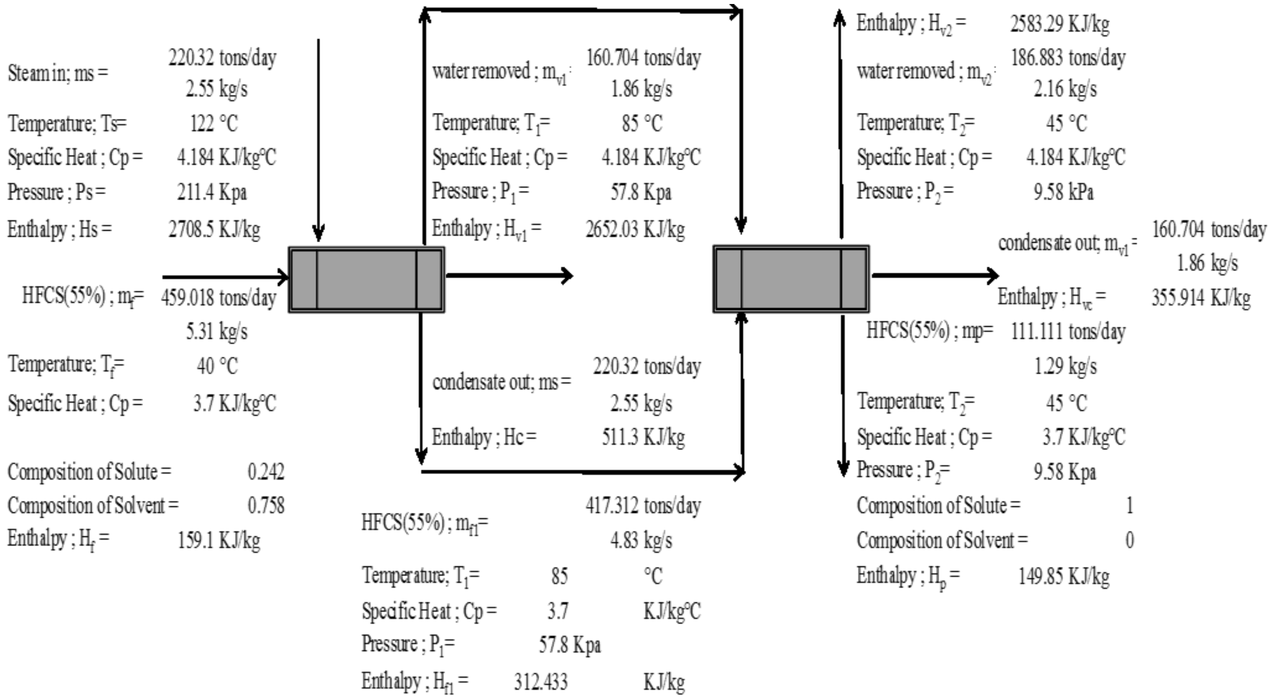

Figure 6: Parameters of the evaporator

Table 4: Calculated specification of the evaporator

Parameter	Operating condition
Overall material balance (m_{v1} + m_{v2})	4.03
Applying energy balance first effect	2652.03 m_{v1} + 312.433 m_{f1} - 2197.2 m_s = 845.29
Applying energy balance second effect	2296.116 m_{v1} - 2583.29 m_{v2} +312.433 m_{f1} =193.3065
Overall heat transfer co-efficient in first effect = U_1	1.7 $KW/m^2.K$
Overall heat transfer co-efficient in second effect = U_2	1.2 $KW/m^2.K$
Water removed ; m_{v1}	1.86 kg/s
Water removed ; m_{v2}	2.16 kg/s
Steam in; m_s	2.55 kg/s
Glucose unrefined ; m_{f1}	4.83 kg/s
Steam Economy	1.578
Heat Duty first effect Q_1	5602.86 KW
Heat Duty second effect Q_2	4270.78 KW
Area	89.08 m^2

3.5. Designing of Condensor

In condensers, we have carried out calculations using both latent and sensible heat. Similarly to the heat exchanger, the pressure drops are calculated out and the mass of condensing media is also an essential variable in condenser designing as shown in Figure 7.

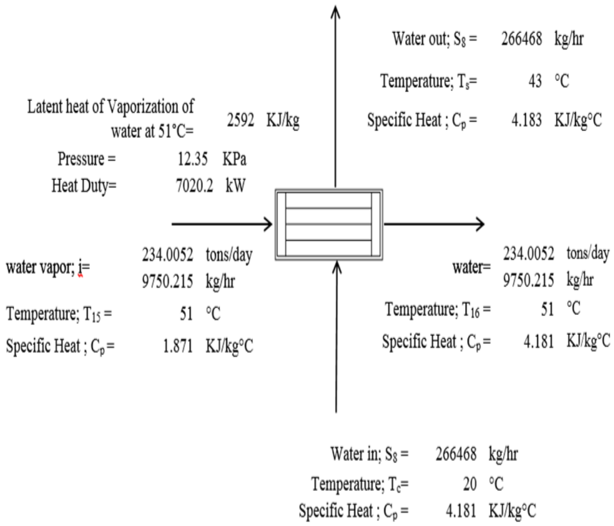

Figure 7: Parameters of condensor

The specification of the condenser is calculated in Table 5.

Table 5: Calculated specification of the condenser

Parameter	Operating condition
Outer diameter = 7/8 in ;	18 BWG
Cleanliness factor; C_{cl}	0.85
Maximum steam loading	8 $lb/hr\ ft^2$
Water velocity; v	7.5 fps
Length of the tube; L	26 ft
Number of passes; n	2
Design overall coefficient; U_D	612.22 $Btu/hr.ft^2.^oF$
Clean overall coefficient; U_c	720.26 $Btu/hr.ft^2.^oF$
Area; A	2684.53047 ft^2

Outlet terminal water temperature; T_2	43 °C
Circulation rate; G_o	1173.87 gpm
Amount water at outlet m; S_8	586934 lb/hr
Tube side pressure; ΔP_t	0.3658
Number of tubes; N_t	451

3.6. Designing of Heat Exchanger

In case of a heat exchanger, we have opted for shell and tube type of exchanger. The dirt factor, the pressure drops, and the required heat exchanger area have all been calculated and found acceptable. All the calculations are based on sensible heats and none on latent heats. The mass of coolant was another essential variable which was determined for different heat exchangers bringing the desired variation in temperatures as shown in Figure 8.

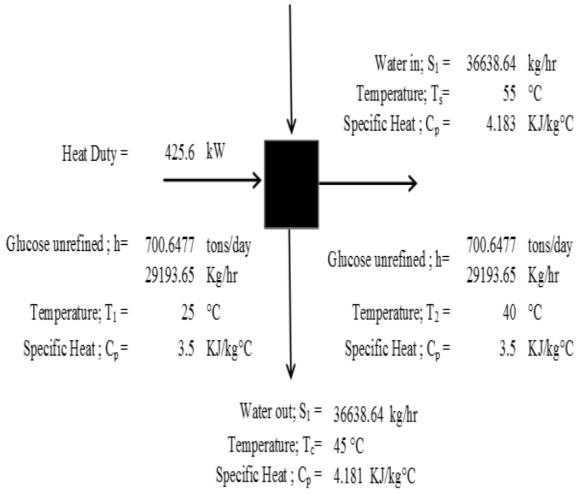

Figure 8: Parameters of the heat exchanger

The specification of the heat exchanger is calculated in Table 6.

Table 6: Calculated specification of the heat exchanger

Parameter	Operating condition
Heat balance glucose unrefined; ΔQ	1452349 Btu/hr
Heat balance hot water; m	36638.64 Kg/hr
U_D	300 Btu/hr.ft^2.°F
Corrected LMTD	15.99 ^{o}C
Shell side inner dia	10 inch = 0.254 m
Shell side baffle space	10 in
Shell side passes	1
Tube side length	16 ft = 192 inch
Tube side passes	2
Tube side pitch	1
Tube side, for 3/4 in tube O.D, 16 BWG, corrected a number of tubes Nt	52
Shell I.D	10 in
Area, A	163.3216 ft^2
U_D	308.97 Btu/hr.ft^2.°F
Hot fluid: tube side, water at'	0.0545 ft^2
G	1480013.744 lb/hr.ft^2
Properties of water, ρ	62.28 lb/ft^3
Properties of water, μ	1.452 lb/fthr
Properties of water, v	6.6 fps
D	0.0517 ft
Re	52697.459
h_i	1720 Btu/hr.ft^2.°F
h_{io}	1421.87 Btu/hr.ft^2.°F
Cold fluid: Shell side, Glucose solution; a_s	0.1736 ft^2
G_s	370386.4388 lb/hr.ft^2
C_p	0.885 Btu/lb.°F
μ	2.018 lb/hr.ft
k	0.427 Btu/hr.ft°F
ρ	70.42 lb/ft^3
D_s	10 in = 0.833 ft
D_e	0.0608 ft
Re	11165.432
j_H	60
h_o	678.552 Btu/hr.ft^2.°F
Clean overall coefficient; U_c	459.342 Btu/hr.ft^2.°F
Dirt factor; R_d	0.0011
Pressure drop; Tube side; ΔP_t	7.3 psi
ΔP_r	1.68 psi
ΔP	9.0 psi
Allowable; ΔP	10 psi
Pressure drop; Shell side ΔP_s	1.28 psi

4. CONCLUSION

High-fructose corn syrup (HFCS) is a substitute to sucrose. It was mainly because of its sweetness as compared to sucrose, functionality, improved stability and ease of use. HFCS is economical and attracted by most food formulators and its use grew in the mid of 1970s to mid-1990s. The plant design for the production of HFCS involves a wide variety of skills. The equipment designed involve pumps, heat exchangers, condensers, reactor, mixers and evaporator including the calculations of all the essential parameters concerned with each equipment. The starch is converted to HFCS 42%, through four main treating stages. Secondary the refining of the fructose product if required; a fifth stage can be added up in which extra refining of the 42% HFCS solution can be used to produce 55% and 90% high-quality fructose syrups.

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