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Design of heat recovery agent of producer gas byproduct system in limekilns

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ABSTRACT

ITC PSPD (Bhadrachalam) is one of the biggest and renowned paperboard manufacturers in India. The unit has 7 paper and board manufacturing machines powered by its own thermal power plant of total capacity 125 MW with a network of 7 turbines and a battery of 9s boilers, which include 3 no's soda recovery boilers and 6 no's Atmospheric Fluidized bed combustion type coal-fired boilers. The soda recovery plant is operated with 2 Rotary kilns of 200 and 300 TPH respectively with a lime purity of 79 ± 2.5 as a prime requirement with a firing system of fuel combination 60:40 ratio of producer gas and furnace oil. The producer gas plant is operated with 8 No's of gasifiers with a capacity of 1400 M3/Hr and coal as an input material. During the process, Coal tar is the byproduct of the producer gas. The outline of the project is to design a heat exchanger to reduce the Tar (Fuel) Viscosity so that it matches the physical properties of conventional fuel (Furnace Oil). This will be helpful in reducing the Furnace oil consumption by 40 percent after substituting furnace oil with Tar. Hence the cost of production is optimized.

Keywords— *Limekiln, Coal tar, Viscosity, Submerged heating coil vessel*

1. OBJECTIVE OF THE PROJECT

With the increase in demand for petroleum products, the price level in the international market has shot up in present market condition. There was an inequillibrum in the demand and supply of petroleum products in the market which was base for an increase in price level.Due to this increase in price levels, the cost of production is increasing, to address this issue an alternate fuel which is lesser price, safe and feasible for the operation were explored. An alternative fuel has been identified in the inbound process of the department. It was studied and found that it can be used with the Furnace Oil as fuel because of its encouraging Calorific Value.

So to match the physical properties of Furnace oil and Tar the Viscosity of the Tar has to be reduced and matched with Furnace oil. This can be achieved by heating the Tar in a specially designed Heat Exchanger, hence a suitable heat exchanger developing is the Objective of this Project.

1.1. Correlation of properties with furnace oil

Table 1: Properties comparison

S. No	Property	UOM	Furnace Oil	Coal Tar
1	Density	Kg/m^3	0.96	1100
2	Gross calorific value	Kcal/Kg	9859	9200
3	Viscosity @ 50 °C	Cp	50	80

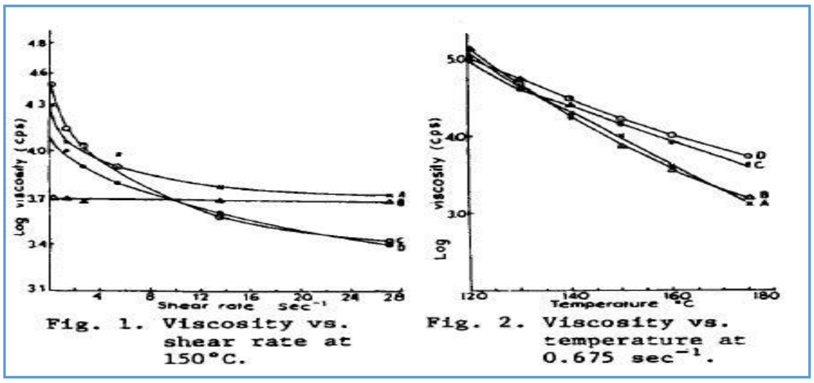

Fig. 1: Coal tar viscosity vs. temperature chart

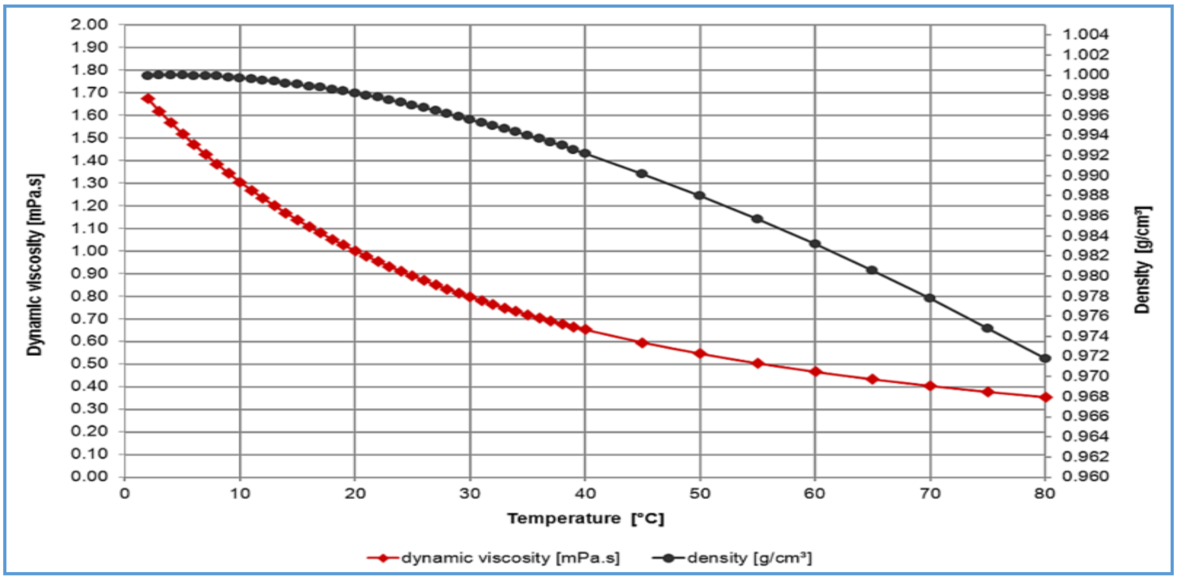

Fig. 2: Furnace oil viscosity vs. temperature chart

For effective mixing of the coal tar and furnace oil, they need to have equivalent viscosities of both liquids. Coal tar viscosity at Viscosity at 50ºC (outlet of the PG Plant)-80 Cp. To make arrangement for synchronizing the viscosity of the coal tar to furnace oil by increasing the temperature of the fluid up to 120ºC. So according to a detailed study of the coal tar present, fuel oil system needs to be modified.

1.2. Selecting the type of heat exchanger

1.2.1 Material to be handled: Heat exchangers are commonly made of conventional straight empty tubes. The laminar build-up on the tube walls from the process fluid inhibits and creates inefficiencies in the heat transfer process. Many of these liquids are difficult to handle at ambient temperatures due to their viscosity. Steam heated coils are used to raise the temperature of these liquids, lowering their viscosity so that they become easier to pump and for maintaining the viscosity gradient.

1.2.2 Availability coal tar: Producer gas plant was far away from the lime kilns. It is difficult to transfer the coal tar through the pipes due to viscosity constraint from producer gas plant to lime kilns. Tar transferring through tankers from producer gas plant every day is possible. So the process is called batch flow process. In view of material property and availability of the tar submerged heating coil design was selected.

2. EXPERIMENTAL METHODOLOGY

Vessels can be heated in a number of different ways, which will deal with indirect heating. In these systems, the heat is transferred across a heat transfer surface. **Submerged steam coils** are a widely used a form of heat transfer involves the installation inside a tank of a steam coil immersed in a process fluid. This team heated coils are used to raise the temperature of the liquids, lowering their viscosity.

2.1 Heat transfer rate

The first stage of this process we will decide the tank dimensions and volume flow rate for maintaining the temperature gradient throughout the tank. For accommodating the 7.7 m^3 of coal tar 3-meter diameter and 1.5-meter height of the tank need to consider and 6543 secs required while using pump capacity of 4 m3/hr. Then the energy rate required to raise the temperature of the liquid from the initial temperature 50°c to final temperature 120°c and the vessel material, and the heat absorbed by any cold articles dipped into the process fluid, can be found by using the equation (1).

$$Q = m\ Cp\ \Delta T$$

Due to rise in temperature of the process, tank material also heated up, considered the energy required for tank material heats up while determining required the heat transfer rate for raising the temperature of the liquid. During the heat exchanging process hot fluid having 4 kg/cm^2 and 120˚C temperature low-pressure steam selected. According to the heat transfer rate and low-pressure steam pressure and superheated steam enthalpy@4, kg/ cm^2 determine the steam flow rate required for the total liquid thermal gradient from equation (2).

$$Q = U \times A \times \Delta Tm \qquad (2)$$

2.2 Steam coil sizing

Having determined the energy required and with knowledge of the steam pressure/temperature in the coil, the heat transfer surface area may be determined using equation (2). To calculate the heat transfer area, a value for the overall heat transfer coefficient, U, must be chosen. This will vary considerably with the thermal and transport properties of both fluids and a range of other conditions. On the product side of the coil, a thermal boundary layer will exist in which there is a temperature gradient between the surface and the bulk fluid. Assisted circulation that is forced convection, will also result in higher coefficients. As convection is partially dependent on the bulk motion of the fluid, the viscosity (which varies with temperature) also has an important bearing on the thermal boundary layer. Another variable is the coil material itself. The thermal conductivity of the coil material may vary considerably. However, overall heat transfer is governed to a large extent by the heat-resistant films, and the thermal conductivity of the coil material is not as significant as their combined effect, so figure 3 will provide typical overall heat transfer coefficients for various conditions of submerged steam coil application due to the way in which viscosity varies with temperature. 'U' values for steam pressures between 2 bar g and 6 bar g should be found by interpolation of the data in the figure3.

	Medium pressure steam	(2 - 6 bar g) with natural liquid convection	U ($W/m^2{}^\circ C$)
	Light oils		170
	Heavy oils		80 - 110
*	Fats		30 - 60
	Medium pressure steam	(2 - 6 bar g) with forced liquid convection	U ($W/m^2{}^\circ C$)
	Light oils	(200 sec Redwood at 38°C)	550
	Medium oils	(1 000 sec Redwood at 38°C)	340
	Heavy oils	(3 500 sec Redwood at 38°C)	170
**	Molasses	(10 000 sec Redwood at 38°C)	85
*	Fats	(50 000 sec Redwood at 38°C)	55

* Certain materials such as tallow and margarine are solid at normal temperatures but have quite low viscosities in the molten state.

** Commercial molasses frequently contains water and the viscosity is much lower.

Fig. 3: Heat Emission rate of the submerged steam coil for miscellaneous liquids

Thereby the values of maximum steam flow rate and the maximum steam velocity for the superheated steam obtained from the ASTM standards will determine the steam coil diameter by using following equations3, 4 and 5.

$$\text{Steam velocity} = \frac{\text{Volume flow (m/sec)}}{\text{cross setional area}} \tag{3}$$

$$\text{Volume flow /sec} = \frac{\text{mass flow (kg/hr)x Specific volume (m3/kg)}}{3600} \tag{4}$$

$$\text{Cross sectional area} = \pi x D^2/4 \tag{5}$$

2.3 Thermal insulation

We have known how heat transfer is important in various situations. It indicates that we are all the time interested in the flow of the heat from one point to another point. However there are many systems, in fact, it is a part of the system, in which we are interested to minimize the losses through heat transfer. In this system heat from the tank walls area losing, however, we do not want any heat loss through the wall. Thus to prevent the heat transfer from the wall to the atmosphere a bad heat conductor or a very good heat insulator is required. In case of the tank, the wall is prepared by layers of glass wool (presently using in the mill) materials to minimize the heat losses. Properties of the glass wool were taken from the table 3.

Table 2: Insulation material properties

Material	Temperature (°C)	Approximate thermal conductivity(W/(m°C))	Density (kg/m^3)
Asbestos	-200 to 0	0.074	469
Glass wool	−7 to 38 38 to 93	0.031 0.041	64 64
Fiber insulating board	21	0.049	237
Hard rubber	0	0.151	2000
Polyurethane foam	−170 to 110	0.018	32

Let us consider a thick insulation layer which is installed around a cylindrical pipe using equation 6. Let the pipe radius be r_1 and the insulation radius is r_2. This (r_1-r_2) will represent the thickness of the insulation. If the fluid carried by the pipe is at a temperature T and the ambient temperature is Ta. The insulation of the pipe will alter the pipe surface temperature T in the radial direction. That is the temperature of the inner surface of the pipe and the outer surface (below insulation) of the pipe will be different. However, if the thermal resistance offered by the pipe is negligible, it can be considered that the temperature (T) is same across the pipe wall thickness and it is a common insulation case (please refer the previous discussion). It can also be assumed that the heat transfer coefficient inside the pipe is very high as compared to the heat transfer coefficient at the outside of the insulated pipe.

$$Q = 2 x \pi x N x k x \frac{T2 - T1}{Ln(\frac{r2}{r1})} \tag{6}$$

2.4 Steam control valve sizing

Before discussing the sizing of control valves for steam systems, it is useful to review the characteristics of steam in a heat transfer application. Steam is supplied at a specific pressure to the upstream side of the control valve through which it passes to a heat exchanger, also operating at a specific pressure. Steam passes through the control valve and into the steam space of the equipment where it comes into contact with the heat transfer surfaces. Steam condenses on the heat transfer surfaces, creating condensate. The volume of condensate is very much less than the steam. This means that when steam condenses, the pressure in the steam space is reduced. The reduced pressure in the steam space means that a pressure difference exists across the control valve, and steam will flow from the high-pressure zone (upstream of the control valve) to the lower pressure zone (the steam space in the equipment) in some proportion to the pressure difference and, ideally, balancing the rate at which steam is condensing. The rate of steam flow into the equipment is governed by this pressure difference and the valve orifice size. Should, at any time, the flow rate of steam through the valve be less than the condensing rate (perhaps the valve is too small), the steam pressure and the heat transfer rate in the heat exchanger will fall below that which is required; the heat exchanger will not be able to satisfy the heat load. If a modulating control system is used, as the temperature of the process approaches the controller set point, the controller will close the valve by a related amount, thereby reducing the steam flowrate to maintain the lower pressure required to sustain a lower heat load.

The flow and expansion of steam through a control valve is a complex process. There are a variety of very complex sizing formulae available for globe valves throttling supersaturated steam by using equations 7&8. Based on Kvr value will select the valve size.

$$\text{ms} = 12 \text{ x Kv xP1}\sqrt{1 - 5.67(0.42 - \aleph} \tag{7}$$

$$\text{Critical pressure ratio} = \aleph = \left(\frac{2}{\text{ɣ} + 1}\right)^{\text{ɣ}} / (\text{ɣ} - 1) \tag{8}$$

For confirming the suitability of the valve size need to compare valve outlet steam velocity and superheated stream sound velocity valve outlet by using following equations 9 &10.

$$\text{Outlet steam velocity of the valve} = \frac{volumetric\ flow\ rate}{outlet\ cross\ section\ area} \tag{9}$$

$$\text{Sound velocity of superheated steam C} = 31.6\sqrt{\text{ɣ}} \text{ x R xT} \tag{10}$$

3. DESIGN OUTCOMES

a) Determine heat required to raise the coal tar temperature from its initial temperature to operating temperature.

$$Q = m\ Cp\ \Delta T = 1172080\text{KJ}$$

b) Calculate the time required for reaching the temperature gradient: $\frac{\text{Total liquid volume}}{\text{Assumed volume flow rate}} = 6543\ secs$

c) Calculate the heat required during heating time: $Q = \frac{m\ Cp\ \Delta T}{t} = 179.1 \text{ kw}$

d) The heat required for raising the vessel material fheatsscold to its operating temperature: $Q = \frac{m\ Cp\ \Delta T}{t} = 12.2\text{kw}$

e) Calculate the average steam mass flow rate during start-up: $\frac{\text{Heat transfer rate}}{\text{superheated enthalpy}} = 245.1 \text{ kg/hrs.}$

f) Determine the heat transfer area required for raising the temperature. Q = U x A x ΔTm=11.7 m2

g) Calculation of the Diameter and length of the coil 15 mm and 248 meters respectively.

h) Insulation thickness of the tank= 80mm.

i) Sizing the control valve in steam service= DN 25.

j) Total steam consumption heating coal tar = 246.4 kg/hr.

Furnace oil consumption per ton of lime will reduce without affecting the purity of the lime by providing submerged heating coil design heat exchanger.

Anticipating coal tar consumption values:

Total production of coal tar per day= 8000kg

Consumption of coal tar per ton of lime = 8000/200 = 40 kg

4. RESULTS

4.1 Financial results

- Earlier production cost per ton of lime: Rs 4828 /-
- After modification production cost per ton of lime: Rs 3468/-
- % of substitute tar as fuel: 40%
- Improved the consistency in the purity of the product.
- Reduced nonrenewable energy usage
- Maintenance activity reduced by avoiding jamming of the heater by decreasing the viscosity.

4.2 Logistics issues addressed

- Storage and transportation of furnace oil have been reduced.
- Traffic movement was controlled due to a decrease in the quantity into the system.
- Tar selling to outside part has been avoided and reduced logistic issues.

4.3 Operational stability

- Fuel line jamming issues were addressed by providing a heater
- Oil burner jamming was avoided

- Oil heater jamming reduced due to raising in viscosity
- The flame profile was stabilized and improved the quality of the product.

5. CONCLUSION

Upon the exploration of coal tar as an alternate source of fuel for the kiln which was a by-product of the producer gas plant. The coal tar having the same calorific value. So to optimize the furnace oil consumption coal tar was a substitute for certain %. So that the kiln operation not disturbed and economic feasibility.

Table 3: Cost comparison of furnace oil

S. No	DESCRIPTION	UOM	BEFORE	AFTER
1	Furnace consumption / ton of lime	kgs	142	102
2	Cost of furnace oil per kg	Rs /-	34	34
3	The total cost of furnace oil per ton of lime	Rs /-	4828	3468
4	Cost of furnace oil for producing 200 ton of lime	Rs /-	965600	693600

Total Cost saving for producing 200-ton lime production per day= Rs 272000/-

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