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INDIRECT HEATERS - DESIGN AND SIZING

GENERAL:

Indirect Water Bath Heaters have useful application for both natural gas and oil and water emulsion streams. They may be used at wellheads, in flow lines, tank batteries, and refineries. Indirect heaters may be readily sized from standard models for specific applications by using the procedures discussed in this bulletin, along with the associated charts and tables.

GAS STREAMS:

A major problem which occurs in the handling and transporting of natural gas is the formation of hydrates which will plug lines and equipment. For specific conditions of temperature and pressure, hydrates will form in natural gas streams (see hydrate formation curves on Figures 1 and 1A). These hydrates consist of a loose association of water and liquid hydrocarbons present in the gas streams which collect to form solid particles. These particles usually collect in any convenient restriction or obstruction in a gas pipeline such as valves, drips, return bends, elbows, et cetera, and will eventually form a large enough mass to block the gas flow. A collection of these hydrates often resembles ice in appearance and has caused the term "freezing up" to be used. However, hydrates will form in gas streams for most flowing pressures encountered at temperatures well above 32°F.

High pressure natural gas is produced from the wellhead at usually some pressure in excess of the sales or transmission line operating pressure. It is therefore necessary to reduce this pressure before the gas enters the line. This pressure reduction may be easily accomplished by expanding the gas through a small orifice or choke. The expansion of natural gas in a choke follows the Joule-Thompson or throttling effect which is an irreversible adiabatic process. Briefly, this is a process where the heat content of the gas remains the same across the choke (constant enthalpy), but the pressure and temperature of the gas is reduced. This reduction in temperature is the cause of the hydrate problem. If the reduced temperature after choking is below the hydrate formation temperature for the line pressure, then hydrates will tend to form downstream from the choke. However, if the temperature of the gas is raised by heating in an indirect heater and then the pressure reduced by expansion through a choke, the final reduced temperature will be above the hydrate formation temperature and no problem will be encountered.

Indirect heaters are also used on gas transmission lines where the ground temperature may drop below the hydrate formation temperature of the gas at the line pressure. Gas flowing in buried lines will rapidly approach the ground temperature. It may then be necessary to place indirect heaters along the pipeline to periodically reheat the gas so that it will remain above the hydrate temperature at all times.

OIL AND WATER STREAMS:

Indirect heaters are often used in conjunction with gunbarrel settling tanks to heat pressure oil and/or water emulsion streams to aid in separation of the oil and water. They are also sometimes placed in flow lines ahead of free water knockouts to raise the temperature of the fluid streams to assist in the settling of the free water and oil within the vessel. Since the oil and water emulsion streams are generally of a corrosive nature, these heaters are generally constructed using cast iron coils instead of steel. For a more detailed discussion on crude oil systems see Technical Bulletin No. 133.

HEATER CONSTRUCTION:

The standard horizontal oilfield indirect water bath type heater consists of a cylindrical atmospheric pressure shell with a direct fired firetube in the lower portion of the shell and a pipe coil in the top (See Figure 7). Although the basic design is the same, many configurations of pipe coils are available for indirect heaters. The size, weight and number of tubes in a coil will vary with the specific requirements of the heater. Table 5 and 6 in the Appendix list the specifications of standard size indirect heaters as well as the various tube coils available with each basic BTU/hr rating. Table 3 and 4 list the properties of the steel pipe and cast iron pipe used in indirect heater coils. Table 7 lists the specifications for indirect heaters designed for use with 10,000 psi W.P. steel coils for extremely high pressure gas streams.

The standard heater specifications do not indicate the placement of the choke on the heater as would be required for wellhead use. A single pass coil with the pressure reducing choke on the outlet is generally recommended. Sometimes it is desirable to heat the gas, expand it through a choke, and then reheat the gas to a higher temperature to further prevent hydrate formation downstream in the line or equipment. This can easily be done in a single heater by using a split pass coil, i.e., putting the choke between two coils. Generally, a long nose heater choke is used with the seat of the choke immersed in the water bath portion of the heater to further assist in hydrate prevention directly at the choke.

Another type of heater configuration is to use one heater to heat two or more separate well streams by placing separate coils in the same water bath. This type of heater is also referred to as a split pass heater. It may be easily sized by considering each pass as a separate heater and then combining the requirements for firebox and coil area to arrive at the indirect heater size required.

Another method is to put the choke on the coil inlet or near the inlet after only a few tubes preheat. This is not recommended because in actual cases freezing of the choke will occur. Not enough heat can be put into the gas to keep the temperature from dropping far below the hydrate temperature immediately downstream from the choke. This can happen even if long nose chokes are used. For a further discussion and illustrations on the recommended placement of chokes in heater coils refer to Technical Bulletin No. 130 on "Indirect Heater Operation."

INDIRECT HEATER SIZING:

Indirect Heaters for wellhead or flow line installations may be sized from standard models by using the following procedures. There are two main items that must be determined to select an indirect heater and they are the total heat required (BTU/hr) to raise the temperature of the fluid and the amount of heat transfer coil area required (sq ft).

Before the heat and coil required can be determined the following information must be available on the fluid stream to be heated.

A. High Pressure Gas Streams

1. Gas flow rate, MMSCFD
2. Specific gravity of gas
3. Inlet flowing pressure, psig
4. Inlet temperature, °F
5. Shut-in pressure or maximum working pressure, psig
6. Outlet reduced or choke pressure, psig
7. Outlet temperature required, °F
8. Flow line size and length

B. Low Pressure Oil and Water Streams

1. Total flow rate, bbls per day
2. Percent water in the fluid stream
3. Inlet temperature, °F
4. Outlet temperature required, °F
5. Operating pressure, psig
6. Maximum working pressure, psig
7. Oil gravity, °API
8. Specific gravity of water

Some of the above items may not be required for a specific installation depending upon the use of the indirect heater. Before any calculations can be made, a tube size must be selected. This can be done for high pressure gas streams using Tables 1 and 2. These tables have been extracted in part from API Standard 12K, "API Specifications for Indirect Type Oilfield Heaters." With the inlet gas flowing pressure, the well shut-in or maximum working pressure, and the daily flow rate, a tube size can be selected. If the choke is to be mounted on the coil outlet or in a split pass coil, the well shut-in pressure should be used in determining the tube weight required in the heater. However, the flowing pressure is used in determining the maximum coil size for a recommended gas thruput. The maximum gas thruputs listed in the table are not the maximum that can be put through the tube coil, but this is what is recommended by the API Standard.

Another factor which may have a bearing on the tube size used is the pressure drop in the coil. However, if a choke is being used to reduce the gas pressure downstream from the heater by at least several hundred psi, as is usually the case, then a small pressure drop of 5 to 20 psi in the coil is of no consequence.

The pressure drop can be determined for the heater selected if desired by the procedure described in a following section. If the heater is to be used for reheating gas in a transmission line then the pressure drop is of major importance to maintain line efficiency and should be considered in selecting the tube size.

BASIC HEAT TRANSFER EQUATION:

The basic heat transfer equation that is used in indirect heating sizing is as follows:

$$Q = U_o (A) (T_m) \quad \text{or} \quad A = \frac{Q}{U_o (T_m)}$$

Where Q = Total heat transfer (heat required), BTU/hr
U_o = Overall film coefficient, BTU/hr - sq ft °F
A = Total heat transfer area (coil area), sq ft
T_m = Log mean temperature difference, °F

HEAT REQUIRED:

For high pressure gas streams, the heat required may be determined from Figures 1, 1A, and 2. Figure 1 or 1A is used to determine the outlet gas temperature required (if not given) based on specific gravity and the enthalpy difference of the gas between the inlet and outlet conditions. In the case of wellhead heaters this is the outlet gas temperature before choking. A 5 to 10°F increase in outlet gas temperature can be allowed to give a safety factor to keep the gas slightly above the hydrate formation temperature after choking. Figure 2 is used with the enthalpy difference and the gas flow rate to determine the heat input required to the gas stream. The heat input can also be calculated from the following equation:

$$Q = 109.9 (G) (h_2 - h_1)$$

Where: Q = Heat required, BTU/hr
G = Gas flow rate, MMSCFD
$h_2 - h_1$ = Enthalpy difference, BTU/lb-mol

For low pressure oil and/or water liquid streams the heat required may be determined from the following equation:

$$Q = W (6.25 + 8.33X) (T_2 - T_1)$$

Where: Q = Heat required, BTU/hr
W = Total liquid flow rate, bbl/day
X = Percent water in liquid
T_2 = Outlet temperature, °F
T_1 = Inlet temperature, °F

OVERALL FILM COEFFICIENT:

The overall film or heat transfer coefficient for high pressure gas streams may be found from Figure 3 using the gas flow rate and tube size selected.

The overall film or heat transfer coefficient for water may be found from Figure 3A, and the coefficient for oil may be found on Figure 3B, based on liquid flow rate and tube size. For liquid streams that are a mixture of oil and water the overall coefficient may be averaged and calculated as follows:

$$U_o\ (mix) = U_o\ (oil) + \left[U_o\ (water) - U_o\ (oil) \right] (X)$$

Where: X = Percent of water in liquid mixture

These film or heat transfer coefficients are based on clean tubes; in other words, no allowance is made for any fouling factors. If any fouling is to be expected excess coil area should be allowed in the heater selection.

LOG MEAN TEMPERATURE DIFFERENCE:

$$t_m = \frac{GTD - LTD}{Log_e\ GTD/LTD}$$

Where: T_m = Log mean temperature difference, °F
GTD = Greater temperature difference = water bath temperature-inlet fluid temperature
LTD = Least temperature difference = water bath temperature-outlet fluid temperature, °F

A water bath temperature must be assumed for the calculations. Usually 180°F is the maximum designed temperature recommended for indirect water bath heaters.

COIL AREA:

The coil area required for an indirect heater can be calculated from the basic heat transfer equation after all of the above factors have been determined. An indirect heater may be then selected from the standard models listed in Tables 5, 6 or 7 based on the heat required and the coil area required. A heater should be selected which has a firebox rating and a coil area at least equal to or preferably slightly greater than that calculated. It must be noted that the heat required as determined from Figure 2 is only the heat input required to the gas stream. No provision is made for heat loss from the vessel which is usually small compared to the heat input in this chart. Since coil area calculations are generally based on 180°F water bath temperature and clean tubes, the coil area calculated will be the minimum required. By selecting a heater with a larger heat capacity and coil area than that calculated, sufficient excess will be provided to allow for heat loss from the vessel, any fouling that may occur within the tubes, and will allow the heater to be operated at less than the maximum design water bath temperature.

COIL WORKING PRESSURE: (pp 6)

$$t_m = \frac{PD}{2(S + PY)} + C \quad \text{or} \quad P = \frac{2S(t_m - C)}{D - 2Y(t_m - C)}$$

$$t_n = \frac{t_m}{0.875} \quad \text{or} \quad t_m = t_n(0.875)$$

Where: P = Maximum internal pressure, psig
D = Outside diameter of pipe, in.
d = Inside diameter of pipe, in.

S = Allowable stress, -20 to 250°F, psi

S = 20,000 for A-53B, A-106B, API-5L-B seamless pipe
S = 23,300 for A-106C seamless pipe

t_m = Minimum design wall thickness, in.

t_n = Nominal design wall thickness, in.

C = Corrosion allowance plus thread depth if applicable, in.

Y = Temperature coefficient = 0.4 when $t_n < \frac{D}{6}$
when $t_n \geq \frac{D}{6}$ then $Y = \frac{d}{d+D}$

PRESSURE DROP IN COILS:

The pressure drop in high pressure gas coils, not including any choking, may be determined from Figure 5 and the following equations:

$$P2 = \left[P1^2 - (P1^2 - P2^2) \frac{L_e}{100} \right]^{1/2}$$

$$\Delta P = P_1 - P_2$$

Where: ΔP = Pressure drop, psia

P_1 = Inlet pressure, psia

P_2 = Outlet pressure, psia

L_e = Effective length of pipe from Table 5 or 7, ft.

$(P_1^2 - P_2^2)$ = Pressure drop factor from Figure 5

HEAT LOSS IN TRANSMISSION LINES:

It is sometimes necessary to calculate the heat loss in gas transmission lines or flow lines and the length of line in which it occurs in order to determine the spacing and size required for indirect heaters to prevent hydrate formation and freezing of the lines. The sizing and placement of these indirect heaters can be determined by the same procedures as described above, by a rearrangement of the basic heat transfer equation. First the following information is necessary on the gas stream and pipeline.

1. Gas flow rate, MMSCFD
2. Specific gravity of the gas
3. Initial temperature of the gas entering the line, °F

Generalized minimum ground temperatures at a depth of 18" for various locations in the Mid-Continent area are as follows:

1. Lower Rio Grande Valley of Texas---------------- 50 to 60°F
2. Upper Gulf Coast of Texas and Louisiana--------- 50 to 55°F
3. Permian Basin, East Texas, Northern Louisiana--- 45°F
4. Hugoton, Panhandle of Oklahoma and Texas-------- 25 to 30°F

Using the curves on Figures 1 or 1A the hydrate formation temperature at the line pressure can be located. The gas can be allowed to cool down to this temperature by heat loss to the ground but no lower or hydrates will form in the line. The total heat loss may be determined from Figures 1 or 1A and 2 in the same manner as heat required for wellhead heaters. The log mean temperature difference may be determined from Figure 4 as previously described using the minimum ground temperature as the constant temperature. The outside surface area of the pipe per foot of length may be determined from Table 3. The following form of the heat transfer equation can then be solved to determine the length of line in which the gas will drop to the minimum desired temperature. The gas can then be reheated to any desired temperature in an indirect heater and the procedure calculated again to determine the spacing for the next heater. These conditions may be evaluated along the entire length of a transmission line to determine the heater spacing and sizes.

$$Q = U_o\,(L)\,(a)\,(T_m) \qquad \text{or} \qquad L = \frac{Q}{U_o\,(a)\,(T_m)}$$

Where:
- Q = Heat required or heat loss, BTU/hr
- U_o = Overall film coefficient, BTU/hr - sq ft - °F
  - U_o = 2.0 for bare pipe
  - U_o = 1.0 for doped and wrapped pipe
- L = Length of line, ft
- a = Surface area of pipe, sq ft/ft
- T_m = Log mean temperature difference, °F
- GTD = Inlet temperature of gas-minimum ground temperature, °F
- LTD = Outlet temperature of gas-minimum ground temperature, °F

GAS STREAMS - EFFECT OF FREE LIQUID:

The above described procedures for sizing indirect heaters for natural gas streams do not take into account the effect of any free liquid that may be present in the gas stream. Any free liquid present in the gas stream will materially add to the heat load required, since it too must be heated up to the same temperature as the gas is heated. This additional heat required can be added to the heat required for the gas in determining the total heat required for the indirect heater.

However, in the case of wellhead heaters this free liquid offers a benefit, which in most cases, will cancel out the necessary increase in heat input required. The liquid will pass through the choke without any drop in temperature since it does not follow the same Joule-Thompson effect as the gas. Immediately downstream of the choke the liquid at the increased temperature will combine with the cold gas coming through the choke and they will both seek the same combined temperature.

This will raise the outlet temperature of the gas downstream of the choke and further aid in prevention of hydrates. The combined stream temperature downstream of the choke can be calculated by a material heat balance which is presented in the following equation.

$$T_c = \frac{14.6\ (L)\ (G_L)\ (C_L)\ (T_L) + 3185\ (G_g)\ (C_g)\ (T_g)}{3185\ (G_g)\ (C_g) + 14.6\ (L)\ (G_L)\ (C_L)}$$

Where: T_c = Combined final stream temperature, °F
L = Liquid loading, bbl/MMCF
C_L = Specific heat of liquid, BTU/lb-°F
C_g = Specific head of gas, BTU/lb-°F
G_g = Specific gravity of gas
T_L = Temperature of liquid thru choke, °F
T_g = Dry gas temperature downstream of choke, °F

The effect of high liquid loadings in the gas stream should be examined as it will materially decrease the amount of heat required for the gas stream prior to choking, since the combined outlet gas temperature from the choke will be higher than would be predicted for a dry gas stream. However, the heat input required to the stream ahead of the choke will be increased, since the liquid must also be heated along with the gas. However, for normal gas condensate wells where the produced liquid is 20 barrels per MMCF or less, this liquid will have very little effect on the gas stream and the heater may be sized as if there were no liquid present. Calculations of the above material heat balance procedure indicate that the outlet combined liquid-gas temperature downstream of the choke will be approximately 1 to 2°F higher than would be expected from dry gas per each 5 barrels per MMCF liquid in the gas stream.

RAPID SIZING CHART FOR NATURAL GAS INDIRECT HEATERS:

Indirect Heaters for heating natural gas streams prior to choking (pressure reduction to pipeline pressure) to prevent hydrate formation may be readily sized by using the chart in Figure 6. The use of this chart can be best explained by an example. (The following example is worked out on the sizing chart by the dotted lines.)

Gas Condition:

Gas Flow Rate = 1.0 MMSCFD
Gas Specific Gravity = 0.7*
Inlet Pressure = 2500 psi
Choke Pressure (Line Pressure) = 750 psi

Required:

Determine the heat transfer required (BTU/hr) and the coil area required (sq ft) in order to select a standard size heater to use.

Assumptions:

Coil Size = 2" X-Hvy steel pipe
Water Bath Temperature = 180°F (Good for all heater sizing)

Inlet Gas Temperature at or near the hydrate temperature for the inlet pressure.

Solution:

1. Determine the final gas temperature required before choking from the small graph inset on Figure 6. Use the inlet gas pressure (2500 psi) and the choke pressure (750 psi).

   Outlet Temperature Required = 140°F

2. Read the inlet temperature (Hydrate temperature) of the gas, opposite the inlet pressure, on the left hand side of the sizing chart.

   Inlet Temperature = 73°F

3. Determine the average temperature difference between the gas and the water bath by the following equation:

$$\text{Average Temperature Difference} = \frac{(T_b - T_1) + (T_b - T_o)}{2}$$

   Where: T_b = Temperature of Water Bath, °F
   T_1 = Inlet Gas Temperature, °F
   T_o = Outlet Gas Temperature, °F

   Average Temperature Difference = (180-73) + (180-140) = 73.5°F

4. Determine the heat transfer required by reading right from the inlet pressure (2500 psi), to the choke pressure (750 psi), up to the gas flow rate (1.0 MMCFD), then right to the heat required.

   Heat Required = 110,000 BTU/hr

5. To determine the coil area required, start at the bottom of the chart at the gas flow rate (1.0 MMCFD), read up to the coil size (2"), right to the average temperature difference (73.5°F), then up to intersect a line extended from the heat required. Extend up parallel to the guide-lines from this intersection to read the coil area required.

   Coil Area Required = 25 sq ft

6. Select a standard size indirect heater from Table 5 with at least a 110,000 BTU/hr firebox rating and a 2" X-Hvy steel pipe coil with at least 25 sq ft of coil area.

Model Recommended - 30" x 6'

Firebox Rating - 250,000 BTU/hr

Coil Area & Size - 8 - 2" X-Hvy Tubes, 28.9 sq ft

The heat required and coil area required as determined from this chart are the minimum requirements based on the inlet gas at or near the hydrate temperature and the outlet gas after choking at or near the hydrate temperature. By selecting a standard size indirect heater with slightly more firebox and coil required, there will be sufficient excess capacity to raise the outlet gas temperature above the hydrate temperature. Also, the inlet gas temperature may be higher than the hydrate temperature which will reduce requirements as determined from the chart.

*The gas specific gravity is held constant on the sizing chart at 0.7. The indirect heater sizing will not be appreciably affected if the gas specific gravity varies from 0.6 to 0.8.

FREEZING OF WATER BATHS:

To prevent freezing of the water baths in indirect heaters when the vent is not to be turned on, glycol may be added to the water bath solution. Ethylene glycol is usually used since it has a lower freezing point than the other glycols. The approximate freezing point of ethylene glycol-water solutions for various concentrations of glycol is shown in Table 9.

To determine the amount of glycol necessary to prevent freezing, multiply the desired concentration selected from Table 9 by the water bath volume of the heater as shown in Table 8.

CONCLUSION:

The above described sizing procedures and accompanying charts and tables offer an accurate method for sizing standard indirect heaters for natural gas or liquid service. Of course, the charts or equations can be used in any reverse manner for evaluating and determining the capacity or performance of existing equipment. The following examples will further illustrate the precise manner and methods to be used in sizing indirect heaters.

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EXAMPLE PROBLEMS

Example 1: Size an indirect heater for wellhead use with a single pass coil and a choke on the coil outlet. The following conditions are given.

Gas Flow Rate: 3.0 MMSCFD
Gas Sp Gr: 0.7
Inlet Flowing Pressure: 200 psi
Line Pressure: 750 psi
Well Shut-in Pressure: 3000 psi

From Table 1, for a maximum coil working pressure of 3000 psi, a 2" X-Hvy pipe coil should be used with a maximum of 3372 psi W.P.

Since no inlet temperature was known, it can be assumed to be at the hydrate temperature for the flowing pressure. From Figure 1 (for 0.7 sp gr).

Inlet temperature (hydrate temperature) for 2000 psi = 71°F
Hydrate temperature for 750 psi = 61°F
Outlet temperature required to choke 2000 psi to 750 psi so that the temperature will be 61°F = 125°F
(Vertical line from inlet point to intersect horizontal line from outlet point)

Enthalpy difference between 2000 psi at 71°F and 2000 psi at 125°F = 900 BTU/lb-mol

From Figure 2, for an enthalpy difference of 900 BTU/lb-mol and a flow rate of 3.0 MMSCFD.

Heat required Q = 300,000 BTU/hr

From Figure 3, for a flow rate of 3.0 MMSCFD and a 2" X-Hvy pipe coil;
U_o = 94 BTU/hr sq ft -°F

From Figure 4, assuming a water bath temperature of 100°F for design conditions.

GTD = Water temperature - inlet gas temperature = 180-71 = 109°F
LTD = Water temperature - outlet gas temperature = 180-125 = 55°F
T_m = 80°F

Solving the heat transfer equation for the coil area required.

$$A = \frac{Q}{U_o(T_m)} = \frac{300{,}000}{(94)(80)} = 39.9 \text{ sq ft}$$

From Table 5, select a standard size indirect heater.

Size: 30" x 10'
Firebox Rating: 500,000 BTU/hr (300,000 BTU/hr required)
Type and Coil Size: 8 = 2" X-Hvy tubes
Coil Area: 48.8 sq ft (39.9 sq ft required)

Example 2: Size an indirect heater for wellhead use given the same flowing conditions as in Example 1, except with a split pass coil using a long nose heater choke. The choke will be installed with most of the coil upstream of the choke and two tubes downstream.

This type of problem may be solved exactly as Example 1 with a single pass coil. However, in this problem a small portion of the required coil area will be downstream of the choke instead of all being upstream as in Example 1. This will mean the gas temperature may drop slightly below hydrate downstream of the choke, but will be reheated in the expansion portion of the coil to arrive at the same outlet temperature from the heater as in Example 1. This small drop in temperature below hydrate can be tolerated by using a long nose heater choke in the split pass coil.

Example 3: Size an indirect heater with a split pass coil using the same flowing conditions as in Example 1. However, the gas temperature must leave the heater at 120°F to prevent hydrate formation downstream of the heater.

Gas Flow Rate: 3.0 MMSCFD
Gas Sp Gr: 0.7
Inlet Flowing Pressure: 2000 psi
Inlet Flowing Temperature: 71°F (assumed at hydrate for the flowing pressure as in Example 1)
Line Pressure: 750 psi
Outlet required Temperature: 120°F
Well Shut-in Pressure: 3000 psi

This heater can be sized as two separate heaters and then the coil and heat requirements combined to select a single heater with a split pass coil.

	Coil No. 1 Preheat (upstream of choke)	Coil No. 2 Expansion (downstream of choke)
Required working pressure, psi	3000	750
From Table 1:		
Tube size required	2" X-Hvy	2" X-Hvy*
From Figure 1 and given data:		
Flow pressure, psig	2000	750
Inlet temperature, °F	71	61
Outlet temperature, °F	125	120
Enthalpy difference, BTU/lb-mol	900	750
From Figure 2 and given data:		
Gas flow rate, MMSCFD	3.0	3.0
Heat required, BTU/hr	300,000	240,000
From Figure 3:		
U_o, BTU/hr-sq ft-°F	94	94

From Figure 4 with 180°F water bath:

GTD	180-71 = 109	180-61 = 119
LTD	180-125 = 55	180-120 = 60
T_m	80	85

Heat transfer equation:

$$A = \frac{Q}{U_o\ T_m},\ \text{sq ft} \qquad \frac{300{,}000}{94\ (80)} = 39.9 \qquad \frac{240{,}000}{94\ (85)} = 30.0$$

Total heat required Q = 300,000 + 240,000 = 540,000 BTU/hr

Total coil area required A = 39.9 + 30.0 = 69.9 sq ft

Care must be taken in selecting a heater with a split pass coil. The total number of tubes can only be split in even numbers as both inlets and outlets must be on the same end of the heater. The total coil area available in a heater can be split percentage wise with the number of tubes in each pass and checked with the area required.

From Table 5:

Heater Size: 36" x 10'
Firebox Rating: 750,000 BTU/hr
Coil Data: 14 - 2" X-Hvy tubes split 8/6
Coil Area: 85.3 sq ft total
Split Areas: 48.7 sq ft/36.6 sq ft

*The 2" X-Hvy tubes are not actually required for the line pressure in the expansion coil but the type tubes used in small heaters are usually kept the same throughout. This provides a more versatile heater which may be used for other applications at little extra initial cost.

<u>Example 4</u>: Size an indirect heater for three separate well streams, each to have a choke on the coil outlet.

	Well No. 1	Well No. 2	Well No. 3
Given data:			
Gas flow rate, MMSCFD	3.0	4.0	9.0
Gas sp gr	0.6	0.7	0.6
Flowing pressure, psig	4500	4000	3500
Inlet temperature, °F	80	85	90
Shut-in pressure, psig	5000	5100	5350
Line Pressure, psig	1000	1000	1000
From Table 1:			
Coil size and weight	2" XX-Hvy	2" XX-Hvy	2" XX-Hvy
From Figure 1:			
Inlet temperature °F	80	85	90
Inlet pressure, psig	4500	4000	3500
Outlet temperature required before choking, °F	150	155	140
Enthalpy difference, BTU/lb-mol	925	1025	700

From Figure 2:			
Heat required, BTU/hr	310,000	450,000	700,000
From Figure 3:			
U_o, BTU/hr - sq ft - °F	98	106	125
From Figure 4 with 180°F water bath:			
GTD	100	95	90
LTD	30	25	40
T_m	59	53	63
Heat transfer equation:			
$A = \frac{Q}{U_o (T_m)}$, sq ft	53.6	80.0	88.9

Total heat required, Q = 310,000 + 450,000 + 700,000 = 1,460,000 BTU/hr

Total coil area required, A = 53.6 + 80.1 + 88.9 = 222.6 sq ft

From Table 5:

Heater Size: 72" x 12'
Firebox Rating: 2,000,000 BTU/hr
Coil Data: 38 - 2" XX-Hvy tubes split 8/14/16
Coil Area: 278.0 sq ft total
Split Areas: 58.5 sq ft/102.4 sq ft/117.1 sq ft

Example 5: Given the following data on a well stream leaving an indirect heater, determine where down the line another heater should be placed and the size required.

Gas Flow Rate: 10.0 MMCFD
Gas Sp Gr: 0.6
Gas Temperature entering Line: 80°F
Line Pressure: 1000 psi
Line Size: 6" std. steel pipe, doped and wrapped
Location of Line: Permian Basin
Maximum Allowable Temperature in Line: 130°F

From Figure 1: The hydrate temperature for 1000 psi is 60°F. If the gas temperature is allowed to drop to within 5°F of the hydrate temperature or 65°F, the enthalpy difference between the inlet and downstream conditions is 225 BTU/lb-mol.

From Figure 2: Heat loss = 240,000 BTU/hr

From Figure 4:
GTD = Inlet gas temperature = min. ground temp = 80 - 45 = 35°F
LTD = Downstream gas temperature = min. ground temp = 65 - 45 = 20°F
T_m = 27°F

Other factors:
U_o = 1.0 BTU/hr - sq ft - °F for doped and wrapped line
a = 1.735 sq ft/ft for 6" pipe

Heat transfer equation:

$$L = \frac{Q}{U_o(a)(t_m)} = \frac{240,000}{(1.0)(1.735)(27)} = 5123 \text{ ft downstream}$$

In the next indirect heater the gas will be reheated from 65°F to 130°F at 1000 psi. Use a heater with 3" standard coil to hold the pressure drop down.

From Figure 1:
Enthalpy difference = 700 BTU/lb-mol

From Figure 2:
Heat required = 760,000 BTU/hr

From Figure 3:
U_o = 104 BTU/hr-sq ft-°F

From Figure 4:
GTD = Water bath temperature-inlet temperature = 180-65 = 115°F
LTD = Water bath temperature-outlet temperature = 180-130 = 50°F
T_m = 80°F

Heat Transfer equation:

$$A = \frac{Q}{U_o(T_m)} = \frac{760,000}{(104)(80)} = 91.3 \text{ sq ft}$$

From Table 5:
Heater Size: 48" x 10'
Firebox Rating: 1,000,000 BTU/hr
Coil Data: 14 - 3" X-Hvy tubes
Coil Area: 126.4 sq ft

Example 6: Determine the pressure drop in the coil of the heater sized in Example

From Figure 5:
$P_1^2 - P_2^2$ = 10800 psi/100 ft

From Table 5:
Equivalent length of pipe in heater coil, L_e = 200.7 ft

Outlet Pressure:

$$P_2 = \left[P_1^2 - (P_1^2 - P_2^2)\frac{L_e}{100}\right]^{1/2} = \left[(1000)^2 - \frac{(10800)(200.7)}{100}\right]^{1/2}$$

P_2 = 989 psi

Pressure drop in coil:
$P = P_1 - P_2$ = 1000 - 989 = 11 psi

Example 7: Given the following data, size oil and water stream.

Given data:

Oil Flow Rate: 2000 bbl/day
Water Flow Rate: 1500 bbl/day
Inlet Temperature: 60°F
Outlet Required Temperature: 110°F
Coil Size Required: 3" cast iron

Heat required:

Percent water in total stream, $X = \frac{1500}{3500} = 43\%$

Heat required, $Q = W\,(6.25 + 8.33X)\,(T_o - T_i)$
$= 3500\left[6.25 + 83.3\,(0.43)\right]\,(110-60)$
$= 1{,}720{,}583$ BTU/hr

From Figures 3A and 3B:

Water flow rate $= \frac{1500}{24} = 62.5$ bbl/hr

Oil flow rate $= \frac{2000}{24} = 83.3$ bbl/hr

U_o for water portion = 120.5 BTU/hr - sq ft - °F

U_o for oil portion = 33.0 BTU/hr - sq ft - °F

$U_o\,(mix) = U_o\,(oil) + \left[U_o\,(water) - U_o\,(oil)\right]\,(X)$

$= 33.0 + \left[120.5 - 33.0\right]\,(0.43) = 70.6$ BTU/hr - sq ft - °F

From Figure 4 using 180°F water bath:

GTD = Water bath temperature-inlet temperature = 180-60 = 120°F
LTD = Water bath temperature-outlet temperature = 180-110 = 70°F
T_m = 95°F

Heat transfer equation:

$$A = \frac{Q}{U_o(T_m)} = \frac{1{,}720{,}583}{(70.6)(95)} = 256.5 \text{ sq ft}$$

From Table 6:

Heater Size: 72" x 12'
Firebox Capacity: 2,000,000 BTU/hr
Coil Data: 38 - 3" cast iron tubes
Coil Area: 377.1 sq ft