445 Windy Hill Road, Marietta, GA 30060 - Phone (770) 801-8884 - FAX (770) 801-8985

Process heating systems: Steam or thermal fluid?

Design and economic comparisons aid system selection

K. K. Dotiwalla, Larsen & Toubro Ltd., Bombay, India

It has generally been assumed that thermal fluid heating systems can be used for process temperatures beyond the range of steam, say 200°C. It is often overlooked that thermal fluid systems are economical compared to steam heating, even at temperatures where steam can be used easily. The features of this fascinating system are compared to other types of heating systems.

As the steam temperatures increase, so does pressure. For a steam temperature of 187°C, the steam pressure is 10.54 kg/cm^{2}g (150 psig). This increases to 30 kg/cm^{2}g for steam temperatures of 230°C. Such high pressure steam systems can be expensive to install and operate. This is the main selection criteria for thermal fluid heating versus steam.

Before we compare the relative merits of different heating systems, let us review each system.

Steam heating. The boilers available today have high fuel efficiencies of about 88% on NCV (net calorific value) basis. The NCV of typical liquid fuels is about 9,650 kcal/kg. Though the boiler efficiencies are high, it is often forgotten that one should consider the efficiency of the whole system instead of just one piece of equipment.

Steam is generated from good quality, preferably demineralized, water. The steam sent to the process gives up only its latent heat. The condensate is often just sent down the drain. The condensate, due to its high temperature and pressure, has a high heat content which can be used profitably. Thus, we find that though the efficiency of the boiler is 88%, the efficiency of the system is only 66% (Table 1).

Many well-managed plants reuse the condensate. The simplest method to recover this energy is to recycle the condensate back to the boiler, commonly called a condensate recovery system (Fig. 1). However, heat is lost in low-pressure flash steam if there is no requirement. This increases the system efficiency to 71% (Table 1) assuming condensate return at 75°C.

Some progressive plants have a very elegant steam distribution system capable of using all the flashed steam for lower pressure applications (Fig. 2).

Consider a typical plant having steam requirements of 15 kg/cm^{2}g (process A), 10 kg/cm^{2}g (process B) and 3 kg/cm^{2}g (process C). Condensate at 15 kg/cm^{2}g is flashed to give steam at

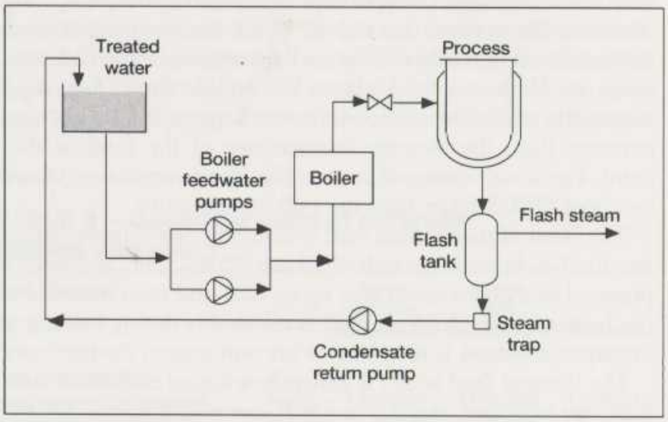

Fig. 1—Steam system with condensate recovery.

TABLE 1—Efficiencies of different heating systems

Fuel: Heavy oil	Steam without condensate recovery	Steam with condensate recovery	Thermal fluid
Fuel consumption			
Heat required by process, kcal/h	1,000,000	1,000,000	1,000,000
Latent heat of steam at 10.54 kg/cm^{2}g, kcal/kg	476.65	476.65	
Steam required by the process assuming no piping losses, kg/h	2,097.98	2,097.98	
Enthalpy of steam generated at 10.54 kg/cm^{2}g, kcal/kg	664.30	664.30	
Temperature of feed water, °C	30	75	
Enthalpy of feed water, kcal/kg	30	75	
Heat to be generated by boiler, kcal/h	1,330,746	1,236,337	1,000,000
Efficiency of boiler/heater, %	88	88	88
Net calorific value of fuel, kcal/kg	9,650	9,650	9,650
Fuel consumption, kg/h	156.71	145.59	117.76
Heat input to the boiler/heater, kcal/h	1,512,211	1,404,928	1,136,364
Boiler efficiency, %	88	88	88
Overall system efficiency, %	66.13	71.18	88.00

10 kg/cm^2g. This steam supplements the steam from the main steam line. This condensate at 10 kg/cm^2g is sent to the flash tank for further flashing to 3 kg/cm^2g (Fig. 2).

Thus, all condensate is recovered and sent back to the boiler at as high temperature as possible. Excess low-pressure steam, instead of being flashed to atmosphere or condensed, can be used in absorption chillers to generate chilled water for cooling.

Such elaborate systems can give quite high system efficiencies, but require considerable planning, preferably during plant design or for a revamp. It should be remembered that hot condensate is quite tricky to handle. Not only does it tend to be corrosive, but being very close to boiling point it is very difficult to pump great heights or distances.

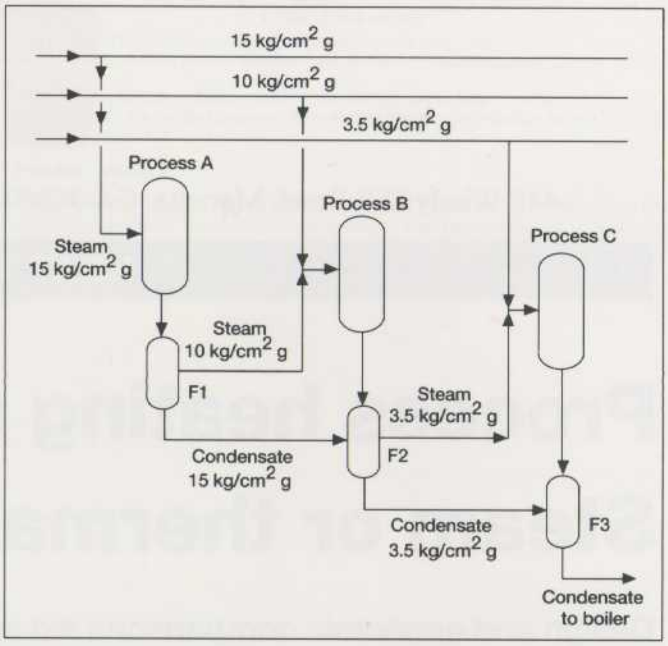

Fig. 2—Multistage condensate recovery system.

Thermal fluid heating system. For process temperatures of about 200°C and above, thermal fluid heating is superior to steam heating in almost all respects.

Thermal fluids are heat transfer fluids which have relatively high boiling points, depending upon their application. These may be petroleum based or synthetic. The operating pressures of thermal fluid systems are from 5 to 15 kg/cm^2g.

The selection of thermal fluids is essentially dependent on the maximum temperature required by the process. Each thermal fluid has a maximum temperature recommended by the manufacturer. Remember that the life of the fluid is dependent on the maximum film temperature and not necessarily the bulk temperatures. When the fluid is being heated, the film of fluid adjacent to the tubewall and exposed to the flame is at a higher temperature than the average temperature of the fluid at that point. For a well-designed heater, the film temperature would be about 30°C higher than the bulk temperature.

The heart of the thermal fluid system (Fig. 3) is a heater where the fluid is heated through to about 25°C. The hot fluid is pumped to the process to give up its heat and then returned to the heater. These fluids expand considerably during heating so an expansion tank is provided to prevent system overpressure.

The thermal fluid heater is generally a forced circulation unit. Sufficient velocities, about 3 to 5 m/s, are maintained in the coil to prevent overheating of the fluid. To avoid large pressure drops in the heater, multiple start coils are used.

Thermal fluid heaters are essentially of two types. For smaller and packaged type units we have tightly wound, twin concentric helical coils with very little refractory. This is designed as per DIN 4754[1]. In refineries and petrochemical plants the heaters are very similar to the process heaters,[2] which are designed as per API 560[3] and API 530.[4]

Thermal fluid heating uses only sensible heat since it is in a liquid state. Hence, there are no "condensate losses." This is why the thermal fluid heating system has better efficiency than steam (Table 1). Also, the system works in a closed loop, barring thermal fluid losses through degradation or through valves, pumps, etc.

Vapor phase thermal fluid systems are also used, especially in chemical and polyester fiber plants. There are two different types of systems. There may be a heater, vaporizer, where the liquid is directly vaporized, similar to a steam boiler. In another system, the liquid under pressure is flashed to a lower pressure to generate vapor (Fig. 4).

The major advantage of the vapor phase system over the liquid phase system is that better temperature control is possible in a condensing system than in a liquid phase system. Also, the condensing heat transfer coefficients are better than convection coefficients for the same fluid.

The thermal fluid system does have disadvantages:

- It cannot be used where direct injection of steam is required by the process.

TABLE 2—Heat transfer area for steam and thermal fluid (T. F.) heating

		Case 1		Case 2		Case 3	
Heating medium		T.F.	Steam	T.F.	Steam	T.F.	Steam
Temp. in.	°C	250	187	250	187	250	187
Temp. out	°C	225	187	225	187	225	187
Heat trans. coeff.	kcal/h m² °C	1,000	5,000	1,000	5,000	1,000	5,000
Fouling factor	h m² °C/kcal	0.0005	0.0001	0.0005	0.0001	0.0005	0.0001
Process fluid							
Heat required	kcal/h	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Temp. in	°C	130	130	130	130	130	130
Temp. out	°C	150	150	150	150	150	150
Heat trans. coeff.	kcal/h m² °C	1,000	1,000	500	500	1,000	1,000
Fouling factor	h m² °C/kcal	0.0005	0.0005	0.0005	0.0005	0.001	0.001
Overall HTC	kcal/h m² °C	333.33	555.56	250.00	357.14	285.71	434.78
LMTD	°C	97.48	46.28	97.48	46.28	97.48	46.28
Heating area reqd.	m²	30.78	38.89	41.03	60.50	35.91	49.70

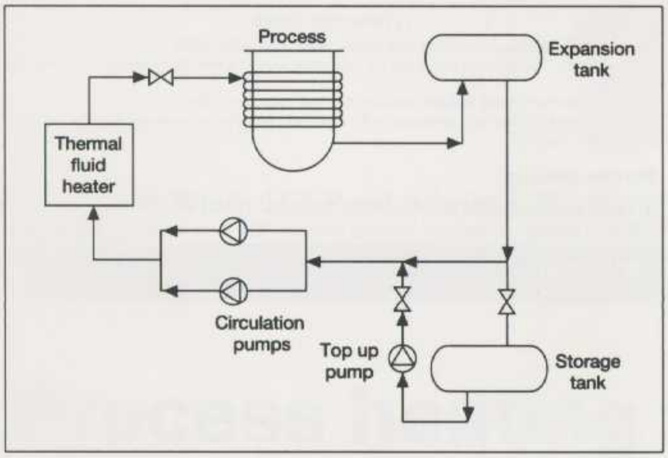

Fig. 3—Liquid phase thermal fluid system.

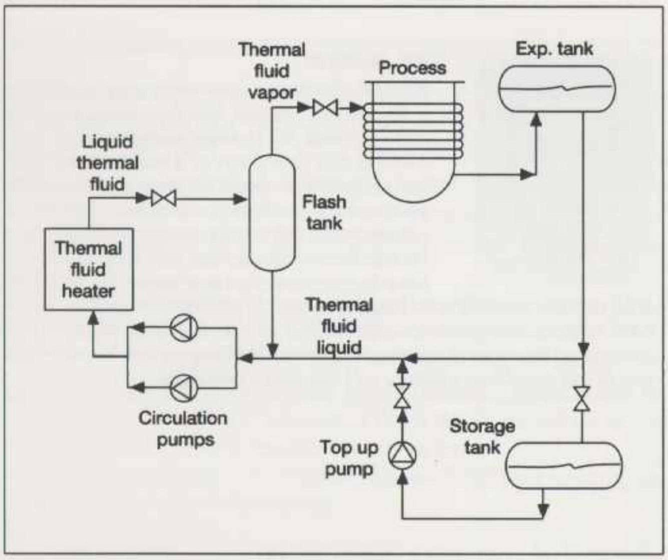

Fig. 4—Vapor phase thermal fluid system.

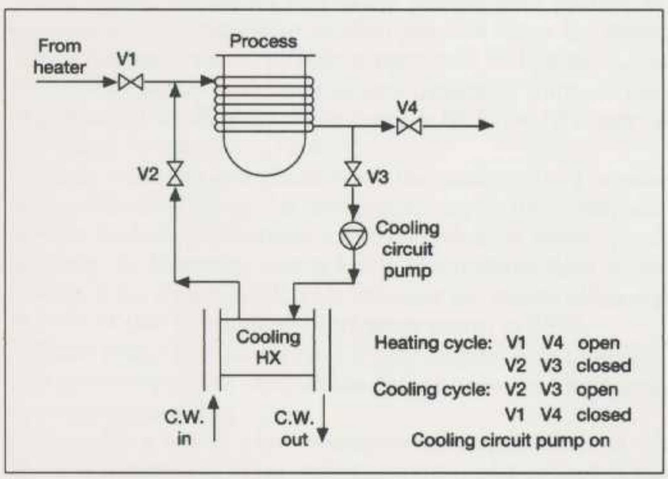

Fig. 5—Thermal fluid cooling system.

• When the process needs a cooling cycle, design of the heat exchanger for cooling the thermal fluid is quite complex. This is because unsteady state heat transfer with the properties of the thermal fluid and of the process varies with temperature (Fig. 5).

• Petroleum-based thermal fluids are flammable so precautions have to be taken. Many accidents have happened but very few in chemical plants because of good maintenance. Great care must be taken in using thermal fluid systems in food and pharmaceutical plants because any leakage may have grave consequences.

• Being a single phase heat transfer, temperature control is a little more complex than in a condensing system (like steam), though temperature control of 2 to 4°C can be achieved.

• The heat transfer coefficients on the thermal fluid side are definitely lower than steam condensing coefficients. But the higher temperature of thermal fluid increases the overall heat transfer rate. However, it is better to check the overall rate of overall heat transfer for each individual case.

In practice, the heat transfer rate is always equal to or more than that of steam. Often a plant has been able to increase production by shifting to thermal fluid heating.

We shall study the overall heat transfer rates for steam and thermal fluid heating (Table 2). Assume the heat transfer coefficients for condensing steam as 5,000 kcal/hm^2 °C, of thermal fluid as 1,000 kcal/hm^2 °C and the process fluid as 1,000 kcal/hm^2 °C. Though the overall coefficient is 66% greater for

TABLE 3 —Operating costs of different heating systems

Fuel: Heavy oil		Steam without condensate recovery	Steam with condensate recovery	Thermal fluid
Fuel consumption				
Heat required by process	kcal/h	1,000,000	1,000,000	1,000,000
Latent heat of steam at 10.54 kg/cm^{2}g	kcal/kg	476.65	476.65	
(Steam required by the process assuming no piping losses)	kg/h	2,097.98	2,097.98	
Enthalpy of steam generated at 10.54 kg/cm^{2}g	kcal/kg	664.30	664.30	
Temperature of feed water	°C	30	75	
Enthalpy of feed water	kcal/kg	30	75	
Heat to be generated by boiler	kcal/h	1,330,746	1,236,337	1,000,000
Efficiency of boiler/heater	%	88	88	88
Net calorific value of fuel	kcal/kg	9,650	9,650	9,650
Fuel consumption	kg/h	156.71	145.59	117.76
Annual operation	h	8,000	8,000	8,000
Annual fuel consumption	mt	1,254	1,165	942
Cost of fuel	Rs/mt	3,300	3,300	3,300
Annual fuel cost (relative)	Rs	4,137,034	3,843,535	3,108,808
Power consumption				
Fuel pump/blower	kW	0.75	0.75	1
Circulating/feed pump	kW	5.5	5.5	7.5
Condensate return pump	kW	0	1.5	0
Total hourly average	kW	4.42	5.42	8.5

The fuel pump/blower motor of all the equipment will operate continuously. The circulating pumps of the thermal fluid heater and hot water heater will also run continuously.

It is assumed that the boiler feed pump and condensate return pump will be operating only ⅔ of the time.

Annual power consumption	kW	35,333	43,360	68,000
Cost of power	Rs/kW	1.20	1.20	1.20
Annual power cost (relative)	Rs	42,400	52,032	81,600
Total operating costs (relative)	Rs	4,179,434	3,895,567	3,190,408

steam, the much higher LMTD (log mean temperature difference) gives the area required by thermal fluid heating as only 80% of that for steam. Considering a lower process side coefficient of 500 kcal/hm^2 °C, gives an even lower figure of 69% of the area. A larger fouling factor also favors the thermal fluid heating system.

Pressurized hot water system. This system is similar to the liquid phase thermal fluid heating system. The heat transfer media is water under pressure. It can be used only for lower temperatures as it has the same pressure/temperature constraints as steam systems.

The major advantage of this system is that water, unlike thermal fluid, is nonflammable and hence, the fire risks are lower. Also, as the specific heat of water (cp=1 kcal/kg °C) is much higher than that of thermal fluid (cp=0.5 to 0.7 kcal/kg °C), the heat transfer medium flowrates and hence, pump power consumption is much lower. Efficiencies are the same as thermal fluid heating systems.

Operating costs analysis. The efficiencies and operating costs of a steam system versus a thermal fluid system are analyzed in Tables 1 and 3.

Consider a process which requires one million kcal/h of heat. Temperatures required are such that steam at 10.54 kg/cm^{2}g (150 psi) can be used.

Steam required will be about 2,100 kg/h to give sufficient heat. Assuming no condensate is recovered and the boiler feed water is at 30°C, the boiler will have to generate 1,330,746 kcal/h. Considering the boiler efficiency to be 88%, the overall system efficiency is just 66%.

The situation is slightly better when a condensate recovery system is used. The boiler will have to generate only 1,236,337 kcal/h, giving an overall system efficiency at 71%.

In comparison, the overall efficiency of a thermal fluid system is 88%.

LITERATURE CITED

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[3] Fired Heaters for General Refinery Services. API 560, 1st edition, 1986.
[4] Recommended Practice for Calculation of Heater Tub Thickness in Petroleum Refinery. API 530, 2nd edition May 1978.

Further reading

Very little information is available in technical books and journals about the different aspects of thermal heating systems. The best source of information is the product literature of the manufacturers of thermal fluids and thermal fluid heaters.

The author

***Kersi K. Dotiwalla** is working with M/s Larsen & Toubro Ltd., Powai, Bombay, India, as a project engineer. His present assignment is engineering and execution of a food project. Earlier he did the proposal engineering for an NGL fractionation plant and project management of a membrane cell based caustic chlorine plant. He was previously working with a reputed company in system design and sales of oil/coal/gas fired boilers, thermal fluid heating systems, absorption chillers, waste heat boilers and other energy saving systems. He is an associate member of the Indian Institute of Chemical Engineers and a former member of the American Institute of Chemical Engineers.*