5. THERMAL EFFICIENCY

5.1 General

The thermal efficiency of a process is a qualitative indication of certain aspects of the process' effect on the environment. (The thermal efficiency is the percentage of the coal heating value that is retained in useful products.) For example, it is an indication of the disturbances associated with the mining of the raw fuel. It is also a measure of the heat released to the environment and, in this respect, is some indication of the possible water requirements.

Perhaps the greatest benefits from the consideration of thermal efficiency, especially when a detailed examination of it is made, are the ideas for process improvements that may emerge. The reaction,

$$\text{Coal} + H_2O \longrightarrow CH_4 + CO_2 + \text{By-products},$$

representating overall coal gasification to high Btu gas, is endothermic. When the theoretical amount of coal is burned to supply the heat for this reaction, the theoretical thermal efficiency is 100%. Since the heating value of the useful products from coal gasification is less than that of the coal to the plant, part of the heat must be degraded to the point where it is no longer useful and is rejected to the environment. A consideration of the reasons for conversion of the energy of the coal to sensible heat, reasons for the degradation of the heat and ways of conserving the heat can lead to ideas for improvements in the processes to reduce their environmental impact.

Perhaps no other parameter of fuel conversion processes is as difficult to quantify, in such a way that the results can be compared for different processes, as the thermal efficiency. On the other hand, except for "cost per million Btu," probably no other number can generate as much interest. The difficulties associated with comparing the thermal efficiencies of two processes arise from sources other than from the process itself. These are discussed below in an attempt to prevent erroneous conclusions from being drawn in making such comparisons.

5.2 Non-Process Related Factors Affecting Thermal Efficiency

One of the first major differences in thermal efficiencies of two processes can be caused by differences in the coal feeds to the processes. A high moisture content in the coal throws a heavier heat load on the coal drier; a lower hydrogen to carbon ratio means that more hydrogen must be produced from water within the process and this leads to a heat loss; a high ash content requires more energy for handling and grinding and more heat is lost as sensible heat in the rejected solids; a high sulfur content in the feed coal can cause a heavier load on acid gas removal facilities and can require flue gas scrubbing or the use of clean product as fuel for heat sources. All of these properties of the feed coal can have a significant bearing on the ultimate overall thermal efficiency of the process.

The nature of the final products plays an important role in determining the thermal efficiency of a process. Of major importance is the type of fuel products desired. If a large fraction of the fuel products consists of solid, high Btu char then the thermal efficiency tends to be high because the char can be thought of as a stream of coal that has by-passed the process and retains its original heating value. Liquid products require less hydrogen than synthetic natural gas (SNG) and this leads to a higher thermal efficiency for liquids production than for SNG. This fact tends to increase the thermal efficiency of a gasification process if a significant fraction of the products is liquid. The question then naturally arises as to whether or not the heating value of the liquids should be included in the thermal efficiency, especially if only gaseous products are desired and the liquids are a nuisance. Another major difference in thermal efficiencies results from the type of gaseous products desired. If a low Btu gas is suitable then air can be used for gasification and the high energy losses associated with oxygen production and methanation are avoided. If a medium Btu gas is required (for example, as synthesis gas) then an oxygen plant is usually necessary but methanation is avoided. SNG production, of course, requires a methanation plant and usually an oxygen plant. The desired pressure of the gaseous product can also have a large affect on the thermal efficiency.

Another large effect on the thermal efficiency is caused by environmental considerations. For example, the type of fuel used for steam generation is significant. The use of feed coal tends to give the highest and the use of clean product the lowest thermal efficiencies. Quite often however, the use of coal requires flue gas clean up, and this leads to other environmental problems such as, for example, disposal of solid wastes from the scrubbing operation. Another environmental consideration that affects thermal efficiency is water availability and use. Air fin cooling can replace cooling water to a large extent, but decreases thermal efficiency. Cooling tower blowdown can be cleaned for reuse, but again, thermal efficiency is decreased. Any unit added to decrease pollutant discharge will, of course, decrease thermal efficiency.

Another area that can have a major effect on thermal efficiency is related to the conservatism of the designer and to the degree of engineering optimization. Obviously, more heat can be recovered by the use of more heat exchangers, heat pumps, power recovery from high pressure liquids, etc., but cost or other considerations might limit such use. In some cases, heat conservation can be increased with the use of equipment whose reliability is uncertain. The limits of cost and reliability used by the designer can significantly affect the thermal efficiency of the plant. Such effects are difficult to point out in comparisons of the thermal efficiency of two processes.

5.3 Thermal Efficiencies of Processes Investigated

The thermal efficiencies of the processes investigated and described in sections 2 to 4 were estimated. These were overall estimates based on products produced and coal fed. In most cases, variations in the thermal efficiencies were estimated for different assumptions concerning boiler fuel and other alternatives of the processes.

The results for gasification are given in table 54. Several values are presentd which correspond to various assumptions: when only the gaseous product is considered, when total combustible products (including sulfur and ammonia) are used in the calculations, and for the range of thermal efficiencies for the alternatives considered.

Thermal efficiencies for liquefaction are tabulated in table 55 The efficiencies for liquefaction are confused by the presence of non-liquid products. Thus, in the COED process, the solid char represents a larger portion of the product than the liquid. Since the char still contains considerable sulfur, it cannot be considered a clean fuel, and this clouds the picture as to how to include it in the thermal efficiency. Similarly, the H-coal process produces excess gas. This gas is, however, clean and could be used directly if a need were present.

The Meyers process was the only coal treating process investigated in depth. The thermal efficiency was 92.5% including the sulfur product and utilizing cleaned coal for fuel.

5.4 Detailed Losses in Thermal Efficiency

As indicated previously, losses of thermal efficiency represent heat that is rejected to the environment. It is of interest to know where this heat leaves the process and how. Obviously, the heat leaves as sensible heat or is rejected to cooling water or to air, but what process units are responsible for the losses is of much more interest.

The point at which heat leaves the overall complex can be pinpointed but the unit responsible for the loss is not so easy to ascertain. For example, sensible heat in the raw product stream is usually recovered down to the level where the cost of recovery becomes too great (or to the level where there is no use for the heat). The plant unit where this final low level heat is rejected to the atmosphere is not responsible for the total loss. This loss should, in some way, be prorated over the entire plant, but how this should be done is not evident. Similarly, losses from steam generation should be prorated over those units requiring steam. This can be done.

As an example, to give some indication of the units responsible for the energy losses, the Lurgi process was examined in more depth. This process was chosen because it was representative of the most complicated gasification sequence, that of producing high Btu SNG, and because considerable information was available. In carrying out this study the total heating value of materials

Table 54

Thermal Efficiency in Gasification

Process	Basic Efficiency, % (1) (2)	Efficiency Including By-products, %(1)	Efficiency Range of Alternatives Considered, %
Koppers-Totzek	62.3 (3)	62.5 (3)	53.0 - 69.0 (3)
Synthane	59.3 (4)	64.3 (4)	59.3 - 66.0
Lurgi	55.1 (5)	67.3	52.9 - 67.3
CO_2 Acceptor	62.4	67.7 (9) (10)	60.2 - 67.7 (10) (11)
BI-GAS	65.9	66.8	61.8 - 66.8 (12)
HYGAS	64.2 (6)	70.5	60.3 - 70.5
U-Gas	69.6 (7) (8)	70.8 (8)	68.1 - 70.8 (8)
Winkler	67.6 (3) (9)	68.9 (3)	66.8 - 68.9 (3)

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(1) Coal as fuel.
(2) No by-products included, no debit for flue gas scrubbing.
(3) Medium Btu gas.
(4) Char to boiler, no drying required.
(5) Base case is 52.9% with clean fuel gas to boiler; no drying required.
(6) Base case is 60.3% with clean fuel gas to boiler and drying.
(7) Base case is 68.1% with clean product gas as fuel.
(8) Low Btu gas.
(9) Base case is 66.8% with clean product gas as fuel.
(10) Includes by-product steam and electricity.
(11) Efficiency is 76% if only medium Btu gas is produced.
(12) Efficiency is 77% if only medium Btu gas is produced.

Values shown in this table depend on the original bases chosen; plant sizes as well as other factors differ and direct comparison of the values is difficult. The process reports in references 3-10 should be consulted to determine each design basis, information sources, and qualifications (see Section 1.5) if individual numbers are to be utilized.

Table 55

Thermal Efficiency in Liquefaction

Process	Base Thermal Efficiency, %[1]	Range of Thermal Efficiency, %
COED	72.2[2]	57.6 - 72.2
SRC	64.0	60.3 - >70
H-Coal	77.0[3]	67.7 - 77.0

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(1) Includes all net products
(2) Char accounts for 46.3% out of 72.2%.
(3) Includes 7.5% for clean by-product gas.

Values shown in this table depend on the original bases chosen; plant sizes as well as other factors differ and direct comparison of the values is difficult. The process reports in references 3-10 should be consulted to determine each design basis, information sources, and qualifications (see Section 1.5) if individual numbers are to be utilized.

out of each unit plus the sensible heat of useful products out of the unit were subtracted from the heating value and sensible heat of materials entering the unit (including electricity). It was impossible to take into account a number of minor streams and vents but these were indicated to be small enough to cause no major change in the results. The difference in the total heat to the unit and total heat in useful materials out of the unit represents the thermal loss from that unit. This loss occurs to cooling water, air cooling or as sensible heat in waste materials such as ash and carbon dioxide.

Table 56 shows the percentage loss for the major areas in the gasification plant. The first column includes the utilities area and the fuel gas production area. Since these areas exist only to supply energy to the other areas, their losses should be prorated to those areas utilizing this energy. This has been done and the results are shown in the second column of table 56. The second column gives a better perspective of the energy debits incurred by each process unit.

There are numerous qualifications of table 56, all of which are not quantified. These latter include the miscellaneous minor streams not taken into account, rather insignificant sensible heats of streams not included and miscellaneous vents. One item noted in the table involves losses in methanation and pipeline compression. In the design, extraction turbines were used for the compressors in these two areas whereas in most other areas condensing turbines were used. Since the use of extraction turbines in these two areas is due to process optimization and since the latent heat losses do not appear in these areas, an estimate was made of the losses from these areas when steam losses were evenly distributed to steam drives according to horsepower. The losses in methanation and pipeline compression are then approximately 11.9% and 6.9% respectively. The other areas losses would all be reduced sufficiently to match this increase. Part of the steam drive for electricity generation is also furnished by an extraction turbine. This was not corrected because electric power is spread rather evenly over all units.

Another type of qualification that must be made to table 56 involves those losses which have been subjectively assigned to a specific unit. Especially significant are losses associated with the shift and cooling area. The majority of the losses in this area is due to final cooling of the main gas stream before purification and not to any large electrical or compression debits. Ideally, these cooling losses should be distributed over other areas but no locigal way of doing this is evident.

Table 56

Thermal Losses by Unit in Lurgi Gasification

Plant Section	Percent of Total Energy Loss	
	Before Proration of Utility and Fuel Gas Losses	After Proration of Utility and Fuel Gas Losses
Coal Preparation	0.4	2.2
Oxygen Production	13.4	22.6
Gasification and Quench	5.7	22.8
Shift and Cooling	14.3 (1)	14.5 (1)
Purification	15.1	18.7
Methanation	6.7	7.7 (3)
Pipeline Compression	1.1	1.7 (3)
Sulfur Recovery	1.3	2.4
Gas Liquor Treating	6.4	7.4
Utilities	17.5 (2)	---
Fuel Gas Production	18.1	---

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(1) Major losses due to cooling--see text.
(2) Includes miscellaneous areas totaling 0.4%.
(3) Extraction turbines used; if total losses in condensing steam to steam drives is distributed evenly, these numbers become 11.9% for methanation and 6.9% for pipeline compression with equivalent reductions in all other areas.