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STEAM PLANT CALCULATIONS MANUAL

V. GANAPATHY

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OTHER VOLUMES IN PREPARATION

To my mother, RaJammal Viswanathan

Preface

Engineers connected with the performance, operation, and maintenance of steam power and process plants often have to perform simple and sometimes involved calculations related to boilers, pumps, fans, fuels, combustion, fluid flow, valve selection, heat transfer, and energy utilization. These are not the routine lengthy, design calculations a design office would perform, but rather simple calculations done to realize the following objectives:

- To understand the performance characteristics of the equipment
- To check if the equipment is performing within predicted range of parameters
- To evaluate cost effectiveness of proposals
- To utilize energy in an optimum manner
- To specify equipment for different service conditions

Plant engineers of today have to be more energy and cost conscious than they were a few years ago, when knowledge of equipment and its performance alone was adequate. With the increasing cost of energy, all aspects of energy utilization and economics of operation must be considered by plant engineers in their day-to-day work. Examples have been dispersed throughout this text to illustrate the above-mentioned subjects.

The book is divided into five chapters and is written in a question and answer style. This approach, it is felt, would be appealing to plant engineers, who have little time to go into theory.

Chapter 1 deals with the general category of calculations such as conversion of mass-to-volume flow rates, energy utilization from boiler blowdown and exhaust gases, ASME code calculations to figure pipe sizes for external and internal pressure applications, life cycle costing methods, and estimation of noise levels. A few examples illustrate how gas leakage across dampers, its cost, and leakage rates of steam through openings can be found. Importance of moisture in air and water dew point is also explained. Application of life cycle costing to equipment selection is explained. Purchase of equipment based on initial cost may not be generally a good proposition.

Chapter 2 deals with fuels, combustion, and boiler or heater efficiency. Often, fuel analysis will not be available and plant engineers may be required to estimate the combustion air requirements, the excess air, or the boiler efficiency. A few examples illustrate how these can be done. The dollar savings that can be realized by reducing the oxygen levels in the flue gas can also be estimated. Engineers are often confused between the efficiencies based on higher and lower heating value of the fuel. Often furnaces are designed to burn a particular fuel and may be required to burn a different one later. The factors that are to be considered in burner are also discussed.

Chapter 3 deals with fluid flow, sizing of flow meters, and selection of control and safety valves. Importance of permanent pressure drop in flow meters and its cost is discussed, followed by examples on selection of safety and control valves. Relieving capacity of a given safety valve when used on a different fluid and different pressure conditions is also discussed. Correction of orifice meter readings for different steam parameters is discussed, followed by pressure drop calculations for fluids inside pipes, and flow over plain and finned tube bundles. Knowledge of pressure drop also helps the plant engineer to check whether or not fouling has occurred. A large increase in gas pressure drop across an economizer tube bundle, for example, means that fouling could have taken place and cleaning cycles may have to be initiated.

In Chapter 4 on heat transfer, several problems covering estimation of heat transfer coefficients for flow over plain and finned tubes, flow inside tubes, nonluminous radiation and prediction of the performance of heat transfer devices are illustrated. A simple approach has been used, and lengthy, routine methods are avoided. Estimation of performance of a given thickness of insulation and determining the optimum thickness of insulation using life cycle costing are also discussed.

The last chapter deals with pumps, fans, and turbines. Often plant engineers switch fans from one site to another without considering aspects such as the ambient temperature or elevation on the fan performance. Based on motor current readings, one can double-check whether a fan or a pump is working well. Examples have been provided to illustrate these points.

Net positive suction head (NPSH) and power requirements for centrifugal and reciprocating pumps are also covered. Cogeneration is an important topic and several plants are using steam turbines for power generation and process steam applications. A few examples illustrate how the steam requirements and power generation can be evaluated.

In all, over 125 examples covering practical aspects of equipment utilization and energy management are worked out, which should make this book a good companion for plant engineers, operators, managers, and design engineers. It would also be of interest to engineers preparing for professional license examinations.

During the past several years, I have had the privilege of authoring several articles in various magazines such as Plant Engineering, Power Engineering, Chemical Engineering, Hydrocarbon Processing, and Oil and Gas Journal. Based on the interaction I have had with several readers, I felt that a book of this nature would be helpful to a large cross section of steam plant engineers and managers.

Being the first edition, there are likely to be a few errors and topics that have been missed. I shall be glad if the readers could bring these to my attention.

Finally I would like to thank the various journals and organizations which gave me permission to reproduce material from their publications.

V. Ganapathy

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Basic Steam Plant Calculations

1.01

Q: Convert 50,000 lb/hr of hot water at a pressure of 1000 psia and 390°F to gpm.

A: To convert from lb/hr to gpm, or vice versa, for any liquid, we may use the following expressions:

$$W = 8 \frac{q}{v} \quad (1)$$

$$\rho = 62.4s = \frac{1}{v} \quad (2)$$

where

W = flow, lb/hr

q = flow, gpm (gallons per minute)

ρ = density of liquid, lb/cu ft

s = specific gravity of liquid

v = specific volume of liquid, cu ft/lb

For hot water we may obtain the specific volume from the steam tables (see the Appendix). v at 1000 psia and 390°F is 0.0185 cu ft/lb. Then, from Eq. (1),

$$q = 50,000 \times \frac{0.0185}{8} = 115.6 \text{ gpm}$$

For water at temperatures 40 to 100°F, for quick estimates we may divide lb/hr by 500 to obtain gpm. For example, 50,000 lb/hr of water at 70°F would be 100 gpm.

1.02a

Q: Estimate the head developed by a pump in feet when it is pumping oil with a specific gravity of 0.8 through a differential pressure of 150 psi.

A: Conversion from feet of liquid to psi, or vice versa, is needed in pump calculations. The expression relating the variables is

$$H_l = 144\ \Delta P\ v = 2.3\ \frac{\Delta P}{s} \tag{3}$$

where

ΔP = differential pressure, psi

H_l = head, feet of liquid

Substituting for ΔP and s, we have

$$H_l = 2.3 \times \frac{150}{0.8} = 431.2 \text{ ft}$$

1.02b

Q: If a fan develops 8 in. WC (inches of water column) with a flue gas density 0.05 lb/cu ft, what is the head in feet of gas and in psi:

A: Use the expressions

$$H_g = 144\ \frac{\Delta P}{\rho_g} \tag{4}$$

$$H_w = 27.7\ \Delta P \tag{5}$$

where

H_g = head, feet of gas

H_w = head, in. WC

ρ_g = gas density, lb/cu ft

Combining Eqs. (4) and (5), we have

$$H_g = 144 \times \frac{8}{27.7 \times 0.05} = 835 \text{ ft}$$

$$\Delta P = \frac{8}{27.7} = 0.29 \text{ psi}$$

1.03

Q: Estimate the density of air at 5000 ft elevation and at 200°F.

A: The density of any gas may be estimated from

$$\rho_g = 492 \times MW \times \frac{P}{359 \times (460 + t) \times 14.7} \qquad (6)$$

where

P = gas pressure, psia

MW = gas molecular weight (Table 1.1)

t = gas temperature, °F

ρ_g = gas density, lb/cu ft

The pressure of air decreases as the elevation increases, as shown in Table 1.2, which gives the term (P/14.7) · MW of air = 29. Substituting the various terms, we have

TABLE 1.1 Gas Molecular Weights

Gas	MW
Hydrogen	2.016
Oxygen	32.0
Nitrogen	28.016
Air	29.2
Methane	16.04
Ethane	30.07
Propane	44.09
n-Butane	58.12
Ammonia	17.03
Carbon dioxide	44.01
Carbon monoxide	28.01
Nitrous oxide	44.02
Nitric oxide	30.01
Nitrogen dioxide	46.01
Sulfur dioxide	64.06
Sulfur trioxide	80.06
Water	18.02

TABLE 1.2 Density Correction for Altitude

Altitude (ft)	Factor
0	1.0
1000	0.964
2000	0.930
3000	0.896
4000	0.864
5000	0.832
6000	0.801
7000	0.772
8000	0.743

$$\rho_g = 29 \times 492 \times \frac{0.832}{359 \times 660} = 0.05 \text{ lb/cu ft}$$

A simplified expression for air at atmospheric pressure and at temperature t at sea level is

$$\rho_g = \frac{40}{460 + t} \qquad (7)$$

For a gas mixture such as flue gas, the molecular weight MW may be obtained as discussed in Q1.05. In the absence of data on flue gas analysis, Eq. (7) also gives a good estimate of density.

When sizing fans, it is the usual practice to refer to 70°F and sea level as standard conditions for air or flue gas density calculations.

1.04a

Q: What is acfm (actual cubic feet per minute), and how does it differ from scfm (standard cubic feet per minute)?

A: acfm is computed using the density of the gas at given conditions of pressure and temperature, and scfm is computed using the gas density at 70°F and at sea level (standard conditions).