4. ENERGY MANAGEMENT AND AUDIT

Definition, Energy audit, Need, Types of energy audit. Energy management (audit) approach, Understanding energy costs, Benchmarking energy performance, Matching energy use to requirement, Maximizing system efficiencies, Optimizing the input energy requirements, Fuel and energy substitution, Energy audit instruments and metering, Manner and intervals of EA regulation.

4.1 Definition and Objectives of Energy Management

The fundamental goal of energy management is to produce goods and provide services with the least cost and least environmental effect. The definition of energy management is:

"The judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions" (or)

"The strategy of adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing total costs of producing the output from these systems"

The objectives of Energy Management include,

- ✓ To achieve and maintain optimum energy procurement and utilisation, throughout the organization
- ✓ To minimise energy costs / waste without affecting production and quality
- ✓ To minimise environmental effects.

Successful energy management must combine an effective strategy with the right practical action. It begins with the key decision makers, and then involves every employee on a day-to-day basis. Many organisations would like to save energy, but to have the most impact and success, they need to give priority to energy management and make it an integral part of company management strategy.

4.2 Energy Audit Definition as per EC Act-2001

Energy Audit is the key to a systematic approach for decision-making in the area of energy management. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions. Industrial Energy Audit is fundamental to a comprehensive energy management programme and is defined in EC Act 2001 as follows:

"Energy Audit" means the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption

4.3 Need for Energy Audit

In any industry, the three top operating costs are often found to be energy (both electrical and thermal), labour and materials. Among the three, energy has the highest potential for cost reduction. Energy audit will help to understand more about the ways energy is used in the industry, and help in identifying the areas where waste can occur and where scope for improvement exists. Such an audit programme will review variations in energy costs, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc. In general, energy audit is the translation of conservation ideas into realities, by evolving technically feasible solutions with economic and other organizational considerations within a specified time.

4.4 Types of Energy Audit and Approach

The type of energy audit to be performed depends on the type of industry, the depth to which final audit is needed, and the potential and magnitude of cost reduction desired. Thus energy audit can be classified into the following types: Preliminary Audit, Targeted Energy Audits and Detailed Audit

Preliminary Energy Audit

Preliminary energy audit, which is also known as Walk-Through Audit and Diagnostic Audit, is a relatively quick exercise and uses existing, or easily obtained data. The scope of preliminary energy audit is to:

- Establish energy consumption in the organization (sources: energy bills and invoices)
- Obtain related data such as production for relating with energy consumption
- Estimate the scope for energy savings
- Identify the most likely and the easiest areas for attention (e.g. unnecessary lighting. higher temperature settings, leakage etc.)
- Identify immediate (especially no-/low-cost) improvements/ savings
- Set up a *baseline* or *reference point* for energy consumption
- Identify areas for more detailed study/measurement

Some example of no-cost energy management measures are:
- Arresting leaks (steam, compressed air)
- Controlling excess air by adjusting fan damper

Some examples of low-cost energy management measures are:
- Shutting equipment when not needed (e.g. idle running of motors)
- Replacement with appropriate lamps and luminaires

Areas for detailed study/measurement are:
- Converting from direct to indirect steam heated equipment and recovery of condensate
- Installing / upgrading insulation on equipment
- Modifying process to reduce steam demand
- Investigating scheduling of process operations to reduce peak steam or water demands
- Evaluating waste heat streams for potential waste heat recovery

Targeted Energy Audits

Targeted energy audits often results from preliminary audits. They provide data and detailed analysis on specified target projects. For example, an organization may target its lighting system or boiler system or steam system or compressed air system with a view of effecting energy savings. Targeted audits therefore involve detailed surveys of the target subjects and analysis of the energy flows and cost associated with the targets. Final outcome is the recommendations regarding actions to be taken.

Detailed Energy Audit

Detailed energy audit is a comprehensive audit and results in a detailed energy project implementation plan for a facility, since it accounts for the energy use of all major equipment. It considers the interactive effects of various projects and offers the most accurate estimate of energy savings and cost. It includes detailed energy cost saving calculations and project implementation costs.

One of the key elements in a detailed energy audit is the energy balance. This is based on an inventory of energy-using systems, assumptions of current operating conditions, measurements and calculations of energy use.

Detailed energy auditing is carried out in three phases: a) Pre Audit Phase b) Audit Phase and c) Post Audit Phase. A comprehensive ten-step methodology for conducting detailed energy audit is suggested as follows. However, methodology is flexible and can be adapted depending upon the industry concerned.

Ten Steps Methodology for Conducting Detailed Energy Audit

Step No	PLAN OF ACTION	PURPOSE / RESULTS
	PHASE I –PRE AUDIT PHASE	
Step 1	• **Plan and Organise** • **Walk through Audit** • **Informal Interview** with Energy Manager, Production / Plant Manager	• Establish/organize a **Energy audit team** • Organize Instruments & time frame • Macro data collection (suitable to type of industry.) • Familiarization with process/plant activities • First hand observation & Assessment of current level of operation and practices
Step 2	• **Introductory Meeting** with all divisional heads and persons concerned with energy management (1-2 hrs.)	• To built up cooperation and rapport • Orientation, awareness creation • Issue questionnaire tailored for each department
	PHASE II –AUDIT PHASE	
Step 3	• **Primary data gathering, Process Flow Diagram and Energy Utility Diagram**	• Historic data collection and analysis for setting up **Baseline energy consumption**

		• All service **utilities system diagram** (e.g. Single line power distribution diagram, water, and compressed air and steam distribution). • Prepare **process flow charts** • Design, operating data and schedule of operation • Annual Energy Bill and **energy consumption pattern** (refer manual, logbook, name plate etc.)
Step 4	• **Conduct survey and monitoring**	• **Measurements** : Motor survey, Insulation, lighting survey etc. with portable instruments for operating data. Confirm and compare operating data with design data.
Step 5	• **Conduct of detailed trials** /tests for selected major energy equipment	• **Trials/ Tests** - 24 hours power monitoring (MD, PF, kWH etc.). - Load variations trends in pumps, fan compressors etc. - Boiler Efficiency trials for (4 – 8 hours) - Furnace Efficiency trials - Equipments Performance tests etc
Step 6	• **Analysis of energy use**	• **Energy and Material balance** • **Energy loss/waste analysis**
Step 7	• **Identification and development of Energy Conservation (ENCON) opportunities**	▪ Conceive, develop and refine ideas ▪ Review ideas suggested by **unit personnel** ▪ Review ideas suggested in previous energy audit report if any ▪ Use brainstorming and value analysis techniques • Contact vendors for new/efficient technology
Step 8	• **Cost benefit analysis**	• Assess technical feasibility, economic viability and prioritization of ENCON options for implementation • Select the most promising projects • Prioritise by low, medium, long term measures
Step 9	• **Reporting and Presentation the Top Management**	• Documentation, draft Report Presentation to the top Management. • Final report preparation on feedback from unit
	PHASE III –POST AUDIT PHASE	
Step 10	• **Implementation and Follow-up**	**Implementation of ENCON recommendation measures** and Monitor the performance ▪ Action plan, schedule for implementation • Monitoring and periodic review

Phase I – Pre Audit Phase

An initial study of the site should always be carried out as proper planning is a pre-requisite for an effective audit. An initial site visit should take only one day and gives the Energy Auditor an opportunity to meet the personnel concerned, to familiarize with the site and to assess the procedures necessary to carry out the energy audit.

During the initial site visit the Energy Auditor/Engineer should carry out the following actions:

- Discuss with the site's senior management about the aims of the energy audit.
- Explain the purpose of the audit and indicate the kind of information needed during the facility tour
- Discuss economic guidelines associated with the recommendations of the audit.
- Analyze the major energy consumption data with the relevant personnel.
- Obtain site drawings where available – plant / building layout, steam distribution, compressed air distribution, electricity distribution etc.
- Tour the site accompanied by site representative.

Typically, Energy Auditor should ask,

1. What function does this system serve?
2. How does this system serve its function?
3. What is the energy consumption of this system?
4. What are the indications that this system is probably working?
5. If this system is not working, how can it be restored to good working conditions?
6. How can the energy cost of this system be reduced?

The outcome of this visit should be:

- To finalise Energy Audit team
- To know the expectation of management from the audit
- To identify the main energy consuming areas/plant items to be surveyed during the audit.
- To identify existing instrumentation and additional metering required prior to audit e.g. for measurement of electricity, steam, oil or gas consumptions
- To plan for audit with time frame
- To collect macro data on plant energy resources, major energy consuming equipments
- To build up awareness and support for detailed energy audit

Phase II – Detailed Energy Audit Phase

Depending on the nature and complexity of the site, a detailed audit can take from several weeks to several months to complete. Detailed studies would involve investigation and establishment of material and energy balances for specific plant departments or process equipment. Whenever possible, checks of plant operations are carried out over extended periods of time, at night and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked.

The information to be collected during the detailed audit includes:

1. Sources of energy supplies (e.g. electricity from the grid or self-generation)
2. Energy cost and tariff data
3. Generation and distribution of site services (e.g. compressed air, steam, water, chilled water).
4. Process and material flow diagrams
5. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.)

6. Energy consumption by type of energy, by department, by major process equipment, by end-use
7. Potential for fuel substitution, process modifications, and the use of co-generation system
8. Review of ongoing energy management procedures and energy awareness training programs.

Energy audit team should ensure that the following baseline data are collected:

- ✓ Quantity and type of raw materials
- ✓ Technology, process used and equipment used
- ✓ Capacity utilization
- ✓ Efficiencies / yield
- ✓ Percentage rejection / reprocessing
- ✓ Quantity and types of wastes
- ✓ Consumption of fuel, water, steam, electricity, compressed air, cooling water, chilled water

Energy auditor must specially interview the supervisors and equipment operators as they have information related to the equipment. Maintenance manager is often the primary person to talk about types of lighting, lamps, sizes of motors, A/c plant and electrical load and related performance problems.

Preparing Process Flow Diagram

An overview of unit operations, important process steps, material and energy use and waste generation is then assembled in the form of process flow diagram. Information from existing drawings, records and shop floor survey will help in preparing the flow chart. Simultaneously the team should identify the various inputs and output streams at each process step. **A typical example of flowchart of Penicillin-G manufacturing** is given in the Figure 4.1.

It may be noted that waste stream (Mycelium) and obvious energy wastes such as condensate drained and steam leakages have been identified in this flow chart. The audit focus will depend upon consumption of input resources, energy efficiency potential, impact of process step on entire process or intensity of waste generation / energy consumption. In case of Penicillin-G manufacturing, the unit operations such as germinator, pre-fermentor, fermentor, and extraction are the major energy conservation potential areas identified.

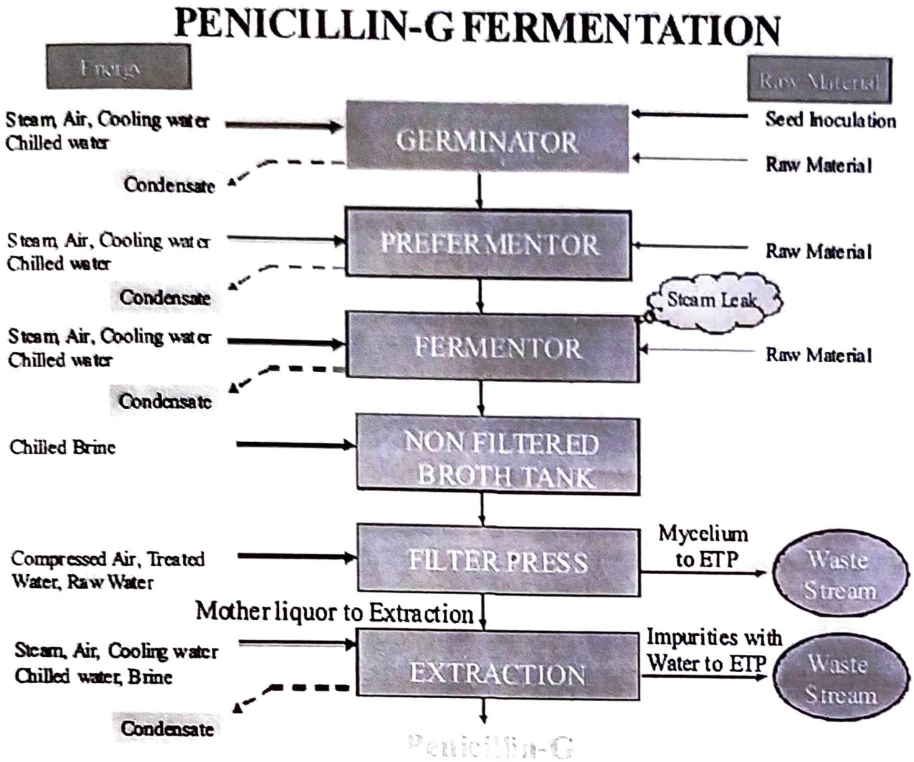

Figure 4.1 Flow Chart for Penicillin-G Manufacture

Identification of ENCON Opportunities

Fuel substitution: Identifying the appropriate fuel for efficient energy conversion

Energy Generation: Identifying efficiency opportunities in energy conversion equipment/utility such as feasibility for high efficient DG sets, optimal loading of DG sets, boiler optimization - minimum excess air combustion with boilers/thermic fluid heating, optimising existing efficiencies, efficient energy conversion equipment, biomass gasifiers, Cogeneration etc.

Energy Distribution: Identifying efficiency opportunities in electrical systems such as transformers, cables, switchgears and power factor improvement in electrical systems and chilled water, cooling water, hot water, compressed air, etc.

Energy Usage by Processes: This is where the major opportunity for improvement lies and many of them are hidden. Process analysis is a useful tool for process integration measures.

Technical and Economic Feasibility

The technical feasibility should address the following issues:

- Technology availability, space, skilled manpower etc
- The impact of energy efficiency measure on safety, quality, production or process
- Reliability, service issues, maintenance requirements and spares availability

The Economic viability often becomes the key parameter for the management acceptance. The economic analysis can be conducted by using Pay back method, Internal Rate of Return method, Net Present Value method etc. For low investment short duration measures, which have attractive economic viability, payback method is sufficient. A sample worksheet for assessing economic feasibility is provided below:

Worksheet for Economic Feasibility

Name of the Energy Efficiency Measure		
1.Investment	2. Annual Operating costs	3. Annual Savings
1. Equipment 2. Civil works 3. Instrumentation 4. Auxiliaries	1. Cost of capital 2. Maintenance 3. Manpower 4. Energy 5. Depreciation	1. Thermal energy 2. Electrical energy 3. Raw materials 4. Waste disposal
Net Savings /year = Annual savings – Annual operating costs **Payback period in months = Investment / Net Savings /year x 12**		

Classification of ENCON Measures

The potential energy saving measures (ENCON) may be classified into three categories:

(a) Low cost – high return

(b) Medium cost – medium return

(c) High cost – high return

Normally the low cost – high return projects receive priority. Other projects have to be analyzed, engineered and budgeted for implementation in a phased manner. Projects relating to equipment and process changes almost always involve high costs coupled with high returns, and required careful scrutiny before funds can be committed. They are complex and need long lead times before they can be implemented. Refer Table 4.1 for project priority guideline.

Table 4.1 Project Priority Guideline

Priority	Economical Feasibility	Technical Feasibility	Risk / Feasibility
A- good	Well defined and attractive	Existing technology adequate	No Risk/ Highly feasible
B-May be	Well defined and only marginally acceptable	Existing technology may be updated, lack of confirmation	Minor operating risk/May be feasible
C-Held	Poorly defined and marginally unacceptable	Existing technology is inadequate	Doubtful
D-No	Clearly not attractive	Need major breakthrough	Not feasible

Energy Audit Report

The length and detail of energy audit report will depend upon the facility audited. The report should begin with an executive summary that provides the management of the audited facility with brief synopsis of the total savings and highlight of each energy saving measure. Executive summary should be tailored to non-technical personnel. The reader who understands the report is more likely to implement the recommended ENCON measures.

The main report should start with general description of the process or facility. Then annual energy consumption and bills should be presented with tables and graphs. This should be followed by description of energy inputs and outputs by major department or by major process and evaluation of efficiency of each step in the process. Then recommended ENCON measures should be presented with calculations for cost and benefits along with expected payback on any capital investment.

The audit report should conclude with specific recommendations for detailed engineering studies and feasibility analyses, which must then be performed to justify the implementation of those conservation measures that require high investments.

Regardless of the audience for the audit report, it should be written in a clear, concise and easy to understand format and style.

Report on

DETAILED ENERGY AUDIT

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ANNEXURE
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A2. List of Vendors and other Technical details

The following worksheets (refer Table 4.2 & Table 4.3) can be used as guidance for energy audit assessment and reporting in Executive Summary. Table 4.4 shows the reporting format for energy conservation recommendations in the main report.

Table 4.2 Summary Of Energy Saving Recommendations

S.No.	Energy Saving Recommendations	Annual Energy (Fuel & Electricity) Savings (kWh/MT or kL/MT)	Annual Cost Savings (Rs. Lakhs)	Capital Investment (Rs. Lakhs)	Simple Payback Period
1					
2					
3					
4					
Total					

Table 4.3 Types and Priority of Energy Saving Measures

	Type of Energy Saving Options	Annual Electricity / Fuel Savings kWh/MT or kJ/MT	Annual Savings (Rs. Lakhs)	Priority
A	No Investment (Immediate) • Operational improvement • Housekeeping			
B	Low Investment (Short to Medium Term) • Controls • Equipment modification • Process change			
C	High Investment (Long Term) • Energy efficient devices • Product modification • Technology change			

Phase III-Post Audit Phase

On completion of energy audit, energy action plan should be prepared. The energy action plan list the ENCONs which should be implemented first, and suggest an overall implementation schedule. Energy audit is incomplete without monitoring and its associated feedback. Monitoring consist of collecting and interpreting data. The data to be collected depends upon goals chosen in the energy action plan. Electrical power consumption and fuel consumption must be evaluated and monitored.

The monitoring data should provide direct feedback to those most able to implement the changes. Often additional instruments should be installed in various departments in addition to main metering.

Monitoring should result in more action. Good practices should be replicated. If the gap between planned objectives and actual achievements is large, reasons should be analyzed and new objectives, new actions should be initiated and results should be monitored. In this way, analysis, action and monitoring are a cyclic process.

Table 4.4 Reporting Format for Energy Conservation Recommendations

A: Title of Recommendation	:	**Combine DG set cooling tower with main cooling tower**
B: Description of Existing System and its Operation	:	Main cooling tower is operating with 30% of its capacity. The rated cooling water flow is 5000 m^3/hr. Two cooling water pumps are in operation continuously with 50% of its rated capacity. A separate cooling tower is also operating for DG set operation continuously.
C: Description of Proposed System and its Operation	:	The DG Set cooling water flow is only 240 m^3/h. By adding this flow into the main cooling tower will eliminate the need for a separate cooling tower operation for DG set, besides improving the %loading of main cooling tower. It is suggested to stop the DG set cooling tower operation.
D: Energy Saving Calculations		
Capacity of main cooling tower	=	5000 m^3/ hr
Temp across cooling tower (design)	=	8 °C
Present capacity	=	3000 m^3/hr
Temperature across cooling tower (operating)	=	4 °C
% loading of main cooling tower	=	(3000 x 4)/(5000 x 8) = 30%
Capacity of DG Set cooling tower	=	240 m^3/hr
Temp across the tower	=	5°C
Heat Load (240x1000 x 1x 5)	=	1200,000 kCal/hr
Power drawn by the DG set cooling tower		
No of pumps and its rating	=	2 Nos x 7.5 kW
No of fans and its rating	=	2 Nos x 22 kW
Power consumption@ 80% load	=	(22 x2 +7.5 x2) x.80 = 47 kW
Additional power required for main cooling tower for additional water flow of 240m^3/h (66.67 l/s) with 6 kg/cm^2	=	(66.67 x 6) / (102 x 0.55) = 7 kW
Net Energy Savings	=	47 – 7 = 40 kW
E: Cost Benefits		
Annual Energy Saving Potential	=	40 kWx 8400 hr = 3,36,000 Units/Year
Annual Cost Savings	=	3,36,000 xRs.4.00 = Rs.13.4 Lakh per year
Investment (Only cost of piping)	=	Rs 1.5 Lakhs
Simple Payback Period	=	**Less than 2 months**

Chapter 5

Performance Evaluation of Electric motors and Variable Speed Drives

Learning Objectives

In this chapter you will learn about

- Methods for determining motor loading
- Method of determining motor efficiency
- Evaluating performance of rewound motors
- Variable speed drive: principles and applications
- Factors for successful implementation of variable speed drive

Energy Auditors

After successfully completin this chapter you will be able t complete the following tasks:

- ✓ **Evaluate the efficiency of induction motor in the field**
- ✓ **Conduct a motor loading survey**
- ✓ **Identify motors for reshuffling/ replacement**
- ✓ **Check performance of rewound motors**
- ✓ **Investigate application potential for variable speed drive**

5. ENERGY PERFORMANCE ASSESSMENT OF MOTORS AND VARIABLE SPEED DRIVES

5.1 Introduction

The two parameters of importance in a motor are efficiency and power factor. The efficiencies of induction motors remain almost constant between 50% to 100% loading (Refer Figure 5.1). With motors designed to perform this function efficiently; the opportunity for savings with motors rests primarily in their selection and use. When a motor has a higher rating than that required by the equipment, motor operates at part load. In this state, the efficiency of the motor is reduced. Replacement of under loaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency. This arrangement is generally most economical for larger motors, and only when they are operating at less than one-third to one-half capacity, depending on their size.

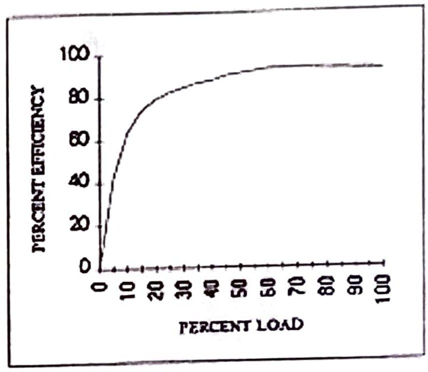


Figure 5.1 Efficiency vs. Loading

5.2 Performance Terms and Definitions

Efficiency :

The efficiency of the motor is given by

$$\eta = \frac{P_{out}}{P_{in}} = 1 - \frac{P_{loss}}{P_{in}}$$

Where P_{out} – Output power of the motor
P_{in} – Input power of the motor
P_{Loss} – Losses occurring in motor

Motor Loading :

$$Motor\ Loading\ \% = \frac{Actual\ operating\ load\ of\ the\ motor}{Rated\ capacity\ of\ the\ motor} \times 100$$

5.3 Efficiency Testing

While input power measurements are fairly simple, measurement of output or losses need a laborious exercise with extensive testing facilities. The following are the testing standards widely used.

Europe: IEC 60034-2, and the new IEC 61972
US: IEEE 112 - Method B
Japan: JEC 37

Even between these standards the difference in efficiency value is up to 3%.

For simplicity nameplate efficiency rating may be used for calculations if the motor load is in the range of 50 –100 %.

Field Tests for Determining Efficiency

(Note: The following section is a repeat of material provided in the chapter-2 on Electrical Motors in Book-3.)

No Load Test :

The motor is run at rated voltage and frequency without any shaft load. Input power, current, frequency and voltage are noted. The no load P.F. is quite low and hence low PF watt meters are required. From the input power, stator I^2R losses under no load are subtracted to give the sum of Friction and Windage (F&W) and core losses. To separate core and F & W losses, test is repeated at variable voltages. It is worthwhile plotting no-load input kW versus Voltage; the intercept is F & W kW loss component.

F&W and core losses = No load power (watts) – (No load current)^2 × Stator resistance

Stator and Rotor I^2R Losses :

The stator winding resistance is directly measured by a bridge or volt amp method. The resistance must be corrected to the operating temperature. For modern motors, the operating temperature is likely to be in the range of 100°C to 120°C and necessary correction should be made. Correction to 75°C may be inaccurate. The correction factor is given as follows :

$\frac{R_2}{R_1} = \frac{235 + t_2}{235 + t_1}$, where, t_1 = ambient temperature, °C & t_2 =- operating temperature, °C.

The rotor resistance can be determined from locked rotor test at reduced frequency, but rotor I^2R losses are measured from measurement of rotor slip.

Rotor I^2R losses = Slip × (Stator Input – Stator I^2R Losses – Core Loss)

Accurate measurement of slip is possible by stroboscope or non-contact type tachometer. Slip also must be corrected to operating temperature.

Stray Load Losses :

These losses are difficult to measure with any accuracy. IEEE Standard 112 gives a complicated method, which is rarely used on shop floor. IS and IEC standards take a fixed value as 0.5 % of output. It must be remarked that actual value of stray losses is likely to be more. IEEE – 112 specifies values from 0.9 % to 1.8 %.

Motor Rating	Stray Losses
1 – 125 HP	1.8 %
125 – 500 HP	1.5 %
501 – 2499 HP	1.2 %
2500 and above	0.9 %

Points for Users :

It must be clear that accurate determination of efficiency is very difficult. The same motor tested by different methods and by same methods by different manufacturers can give a difference of 2 %.

Estimation of efficiency in the field can be summarized as follows:

a) Measure stator resistance and correct to operating temperature. From rated current value, I^2R losses are calculated.

b) From rated speed and output, rotor I^2R losses are calculated

c) From no load test, core and F & W losses are determined for stray loss

The method is illustrated by the following example :

Example :

Motor Specifications

Rated power	=	34 kW/45 HP
Voltage	=	415 Volt
Current	=	57 Amps
Speed	=	1475 rpm
Insulation class	=	F
Frame	=	LD 200 L
Connection	=	Delta

insulation class		operating Temp (°C)
A	→	105
B	→	130
F	→	155
H	→	180

In each insulation class, the operating temperature increases by 25°C

No load test Data

Voltage, V	=	415 Volts
Current, I	=	16.1 Amps
Frequency, F	=	50 Hz
Stator phase resistance at 30^0C	=	0.264 Ohms
No load power, P_{nl}	=	1063.74 Watts

a) Calculate iron plus friction and windage losses

b) Calculate stator resistance at 120^0C

$$R_2 = R_1 \times \frac{235 + t_2}{235 + t_1}$$

c) Calculate stator copper losses at operating temperature of resistance at 120^0C

d) Calculate full load slip(s) and rotor input assuming rotor losses are slip times rotor input.

e) Determine the motor input assuming that stray losses are 0.5 % of the motor rated power

f) Calculate motor full load efficiency and full load power factor

Solution

a) Let Iron plus friction and windage loss, P_i + fw

No load power, Pnl = 1063.74 Watts

Stator Copper loss, P st-30^0C (Pst.cu)

$= 3 \times (16.1 / \sqrt{3})^2 \times 0.264$

= 68.43 Watts

Pi + fw = P_{nl} – Pst.cu

= 1063.74 – 68.43

= 995.3 W

b) Stator Resistance at 120^0C,

120+ t50

$$R_{120^0C} = 0.264 \times \frac{120 + 235}{30 + 235}$$

= 0.354 ohms per phase

c) Stator copper losses at full load, Pst.cu 120^0C

$= 3 \times (57 / \sqrt{3})^2 \times 0.354$

= 1150.1 Watts

d) Full load slip

S = (1500 – 1475) / 1500

= 0.0167

Rotor input, Pr = P_{output}/ (1-S)

= 34000 / (1-0.0167)

= 34577.4 Watts

e) Motor full load input power, P input

$= P_r + Pst\,cu\ 120^0C + (P_i + fw) + P_{stray}$

$= 34577.4 + 1150.1 + 995.3 + (0.005^* \times 34000)$

= 36892.8 Watts

*where, stray losses = 0.5% of rated output (assumed)

f) Motor efficiency at full load

$$\text{Efficiency} = \frac{P_{output}}{P_{input}} \times 100$$

$$= \frac{34000}{36892.8} \times 100$$

$$= 92.2\ \%$$

$$\text{Full Load PF} = \frac{P_{input}}{\sqrt{3} \times V \times I_{fl}}$$

$$= \frac{36892.8}{\sqrt{3} \times 415 \times 57}$$

$$= 0.90$$

Comments :

a) The measurement of stray load losses is very difficult and not practical even on test beds.

b) The actual value of stray loss of motors up to 200 HP is likely to be 1 % to 3 % compared to 0.5 % assumed by standards.

c) The value of full load slip taken from the nameplate data is not accurate. Actual measurement under full load conditions will give better results.

d) The friction and windage losses really are part of the shaft output; however, in the above calculation, it is not added to the rated shaft output, before calculating the rotor input power. The error however is minor.

e) When a motor is rewound, there is a fair chance that the resistance per phase would increase due to winding material quality and the losses would be higher. It would be interesting to assess the effect of a nominal 10 % increase in resistance per phase.

5.4 Determining Motor Loading

1. By Input Power Measurements

- First measure input power $\mathbf{P_i}$ with a hand held or in-line power meter
  P_i = Three-phase power in kW
- Note the rated kW and efficiency from the motor name plate

- The figures of kW mentioned in the name plate is for output conditions. So corresponding input power at full-rated load

$$P_{ir} = \frac{\text{Nameplate full rated kW}}{\eta_{fl}}$$

η_{fl} = Efficiency at full-rated load

P_{ir} = Input power at full-rated load in kW

The percentage loading can now be calculated as follows

$$Load = \frac{P_i}{P_{ir}} x\, 100\%$$

Example

The nameplate details of a motor are given as power = 15 kW, efficiency $\eta = 0.9$. Using a power meter the actual three phase power drawn is found to be 8 kW. Find out the loading of the motor.

Input power at full-rated power in kW, P_{ir} = 15 /0.9
= 16.7 kW

Percentage loading = 8/16.7
= 48 %

2. By Line Current Measurements

The line current load estimation method is used when input power cannot be measured and only amperage measurements are possible. The amperage draw of a motor varies approximately linearly with respect to load, down to about 75% of full load. Below the 75% load point, power factor degrades and the amperage curve becomes increasingly non-linear. **In the low load region, current measurements are not a useful indicator of load.** However, this method may be used only as a preliminary method just for the purpose of identification of oversized motors.

$$\%Load = \frac{Input\ load\ current}{Input\ rated\ current} * 100 \text{ (Valid up to 75\% loading)}$$

3. Slip Method

In the absence of a power meter, the slip method can be used which requires a tachometer. This method also does not give the exact loading on the motors.

$$Load = \frac{Slip}{S_s - S_r} * 100\%$$

Where:
Load = Output power as a % of rated power
Slip = Synchronous speed - Measured speed in rpm
S_s = Synchronous speed in rpm at the operating frequency
S_r = Nameplate full-load speed

Example: Slip Load Calculation

Given: Synchronous speed in rpm = 1500 at 50 HZ operating frequency.
(Synchronous speed = 120f/P) f: frequency, P: Number of poles
Nameplate full load speed = 1450
Measured speed in rpm = 1480
Nameplate rated power = 7.5 kW

Determine actual output power. $$Load = \frac{1500-1480}{1500-1450} * 100\% = 40\%$$

From the above equation, actual output power would be 40% x 7.5 kW = 3 kW
The speed/slip method of determining motor part-load is often favored due to its simplicity and safety advantages. Most motors are constructed such that the shaft is accessible to a tachometer or a strobe light.

The accuracy of the slip method, however, is limited. The largest uncertainty relates to the accuracy with which manufacturers report the nameplate full-load speed. Manufacturers generally round their reported full-load speed values to some multiple of 5 rpm. While 5 rpm is but a small percent of the full-load speed and may be considered as insignificant, the slip method relies on the difference between full-load nameplate and synchronous speeds. Given a 40 rpm "correct" slip, a seemingly minor 5 rpm disparity causes a 12% change in calculated load.

Slip also varies inversely with respect to the motor terminal voltage squared. A voltage correction factor can, also, be inserted into the slip load equation. The voltage compensated load can be calculated as shown

$$Load = \frac{Slip}{(S_s - S_r) \times (V_r / V)^2} \times 100\%$$

Where:

Load = Output power as a % of rated power
Slip = Synchronous speed - Measured speed in rpm
S_s = Synchronous speed in rpm
S_r = Nameplate full-load speed
V = RMS voltage, mean line to line of 3 phases
V_r = Nameplate rated voltage

5.5 Performance Evaluation of Rewound Motors

Ideally, a comparison should be made of the efficiency before and after a rewinding. A relatively simple procedure for evaluating rewind quality is to keep a log of no-load input current for each motor in the population. This figure increases with poor quality rewinds. A review of the rewind shop's procedure should also provide some indication of the quality of work. When rewinding a motor, if smaller diameter wire is used, the resistance and the I^2R losses will increase.

5.6 Format for Data Collection

The motor loading survey can be performed using the format given below:

Motor Field Measurement Format

Company ______________________ Location ______________________

Date ________ Process ______________________

Department ______________________

General Data

Driven Equipment ______________________

Motor Name Plate Data

Manufacturer ______________________
Model ______________________
Serial Number ______________________
Type Squirrel cage/Slip ring ______________________
Size (hp/kW) ______________________
Synchronous Speed (RPM) ______________________
Full-Load Speed (RPM) ______________________
Voltage Rating ______________________
Full Load Amperage ______________________
Full-Load Power Factor (%) ______________________
Full-Load Efficiency (%) ______________________
Temperature Rise ______________________
Insulation Class ______________________

From Test Certificate

Load	100%	75%	25%	No Load
Current				
PF				
Efficiency				

Stator resistance per phase =

Rewound Yes ,if yes How many times rewound ?---

No

Motor Loading % ______________________

Motor Operating Profile:

No of hours of operation

I Shift ____________

II Shift ____________

III Shift ____________

Annual Operating Time ______ hours/year

Type of load

1.Load is quite steady, motor "On" during shift ☐
2.Load starts, stops, but is constant when "On" ☐
3.Load starts, stops, and fluctuates when "On" ☐

Measured Data
Supply Voltage
By Voltmeter
V_{RY} ________
V_{YB} ________ V avg ______
V_{BR} ________
Input Amps
By Ammeter
A a ________
A b ________ A avg ______
A c ________
Power Factor (PF) ______________________
Input Power (kW) ______________________

Motor Operating Speed ____________RPM
At frequency of __________

Driven Equipment Operating Speed

__________RPM

Type of Transmission (Direct/Gear/Fluid coupling)

The monitoring format for rewound motor is given below:

Section	Equipment Code	Motor Code	Motor Type		No Load Current				Starter Resistance/phase		No load loss	
			Sq.Cage	Slip Ring	New Motor		After Rewinding		New	Rewound	New	Rewound
					A	V	A	V			Watts	Watts

5.7 Application of Variable Speed Drives (VSD)

Although there are many methods of varying the speeds of the driven equipment such as hydraulic coupling, gear box, variable pulley etc., the most possible method is one of varying the motor speed itself by varying the frequency and voltage by a variable frequency drive.

5.7.1 Concept of Variable Frequency Drive

The speed of an induction motor is proportional to the frequency of the AC voltage applied to it, as well as the number of poles in the motor stator. This is expressed by the equation:

$$RPM = (f \times 120) / p$$

Where f is the frequency in Hz, and p is the number of poles in any multiple of 2.

Therefore, if the frequency applied to the motor is changed, the motor speed changes in direct proportion to the frequency change. The control of frequency applied to the motor is the job given to the VSD.

The VSD's basic principle of operation is to convert the electrical system frequency and voltage to the frequency and voltage required to drive a motor at a speed other than its rated speed. The two most basic functions of a VSD are to provide power conversion from one frequency to another, and to enable control of the output frequency.

VSD Power Conversion

As illustrated by Figure 5.2, there are two basic components, a rectifier and an inverter, to accomplish power conversion.

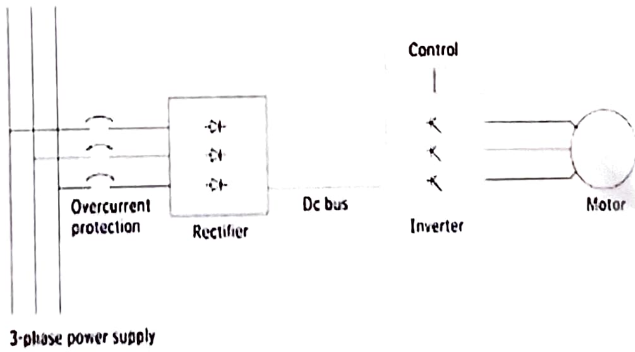


Figure 5.2 Components of a Variable Speed Drive

The rectifier receives the 50-Hz AC voltage and converts it to direct current (DC) voltage. A DC bus inside the VSD functions as a "parking lot" for the DC voltage. The

DC bus energizes the inverter, which converts it back to AC voltage again. The inverter can be controlled to produce an output frequency of the proper value for the desired motor shaft speed.

5.7.2 Factors for Successful Implementation of Variable Speed Drives

a) Load Type for Variable Frequency Drives

The main consideration is whether the variable frequency drive application requires a **variable torque or constant torque** drive. If the equipment being driven is centrifugal, such as a fan or pump, then a variable torque drive will be more appropriate. Energy savings are usually the primary motivation for installing variable torque drives for centrifugal applications. For example, a fan needs less torque when running at 50% speed than it does when running at full speed. Variable torque operation allows the motor to apply only the torque needed, which results in reduced energy consumption.

Conveyors, positive displacement pumps, punch presses, extruders, and other similar type applications require constant level of torque at all speeds. In which case, constant torque variable frequency drives would be more appropriate for the job. A constant torque drive should have an **overload current capacity** of 150% or more for one minute. Variable torque variable frequency drives need only an overload current capacity of 120% for one minute since centrifugal applications rarely exceed the rated current.

If tight process control is needed, then you may need to utilize a sensor less vector, or flux vector variable frequency drive, which allow a high level of accuracy in controlling speed, torque, and positioning.

b) Motor Information

The following motor information will be needed to select the proper variable frequency drive:

Full Load Amperage Rating. Using a motor's horsepower is an inaccurate way to size variable frequency drives.

Speed Range. Generally, a motor should not be run at any speed less than 20% of its specified maximum speed allowed. If it is run at a speed less than this without auxiliary motor cooling, the motor will overheat. Auxiliary motor cooling should be used if the motor must be operated at very slow speeds.

Multiple Motors. To size a variable frequency drive that will control more than one motor, add together the full-load amp ratings of each of the motors. All motors controlled by a single drive must have an equal voltage rating.

c) Efficiency and Power Factor

The variable frequency drive should have an efficiency rating of **95% or better at full load.**

Variable frequency drives should also offer a **true system power factor of 0.95 or better** across the operational speed range, to save on demand charges, and to protect the equipment (especially motors).

d) Protection and Power Quality

Motor overload Protection for instantaneous trip and motor over current.

Additional Protection: Over and under voltage, over temperature, ground fault, control or microprocessor fault. These protective circuits should provide an orderly shutdown of the VFD, provide indication of the fault condition, and require a manual reset (except under voltage) before restart. Under voltage from a power loss shall be set to automatically restart after return to normal. The history of the previous three faults shall remain in memory for future review.

If a built-up system is required, there should also be externally-operated short circuit protection, door-interlocked fused disconnect and circuit breaker or motor circuit protector (MCP)

To determine if the equipment under consideration is the right choice for a variable speed drive:

The load patterns should be thoroughly studied before exercising the option of VSD. In effect the load should be of a varying nature to demand a VSD (refer Figure 5.3 & 5.4).

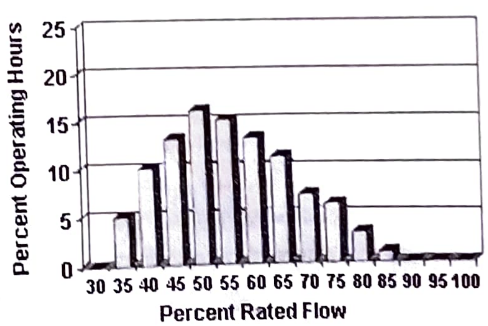


Figure 5.3 Example of an excellent variable speed drive candidate

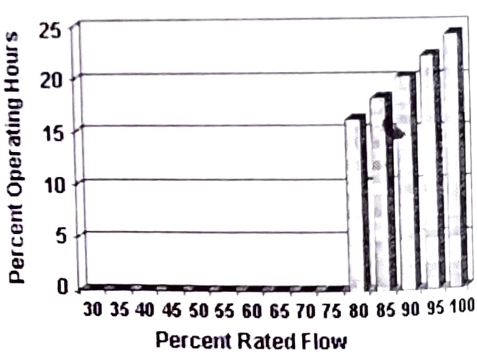


Figure 5.4 Example of a poor variable speed drive candidate

The first step is to identify the number of operating hours of the equipment at various load conditions. This can be done by using a Power analyzer with continuous data storage or by a simple energy meter with periodic reading being taken.

5.7.3 Information needed to Evaluate Energy Savings for Variable Speed Application

1. Method of flow control to which adjustable speed is compared:
    - output throttling (pump) or dampers (fan)
    - recirculation (pump) or unrestrained flow (fan)
    - adjustable-speed coupling (eddy current coupling)
    - inlet guide vanes or inlet dampers (fan only)
    - two-speed motor.
2. Pump or fan data:
    - head v's flow curve for every different type of liquid (pump) or gas (fan) that is handled
    - Pump efficiency curves.
3. Process information:
    - specific gravity (for pumps) or specific density of products (for fans)
    - system resistance head/flow curve
    - equipment duty cycle, i.e. flow levels and time duration.
4. Efficiency information on all relevant electrical system apparatus:
    - motors, constant and variable speed
    - variable speed drives
    - gears
    - transformers.

If we do not have precise information for all of the above, we can make reasonable assumptions for points 2 and 4.

QUESTIONS	
S-1	What parameters are required to be measured to determine motor efficiency?
S-2	The resistance of a motor stator winding at 30°C is 0.264 ohms per phase. What will be the resistance of the stator winding per phase when the motor winding temperature is 100°C?
S-3	Calculate the percentage loading of a motor using the following data: Synchronous speed in rpm = 1500 at 50 HZ operating frequency. Nameplate full load speed = 1440 Measured speed in rpm = 1475 Nameplate rated power = 11 kW
S-4	Calculate the rotor I^2 R losses using the following data: Slip = 4% Stator input = 3000 W Stator I^2R losses = 100 W Core loss = 50 W
S-5	What are the two main advantages of application of a variable frequency drive in an induction motor other than accurate speed regulation?
S-6	What are the two factors influencing the speed of induction motor?
S-7	A 4 pole motor is operating at a frequency of 50 Hz. What is the synchronous speed of the motor?
S-8	If no instrument other than tachometer is available, what method you would suggest for measuring the motor load?
S-9	Which loss is assumed in the efficiency determination of an induction motor?
S-10	Why the line current method used for estimating loading of a motor is not applicable for motor loading less than 75%.
L-1	On the recommendations of energy auditor a company replaced a 15 kW, 4 pole standard motor by a 15 kW, 4 pole energy efficient motor for a centrifugal fan. The power consumption of energy efficient motor actually increased, while the grid frequency and voltage remained same. What could be the reason?
L-2	Determine the actual output power of an induction motor using the following data? No. of poles = 2 Frequency = 50 Hz Rated voltage = 415 V Name plate full speed = 2980 rpm Measured speed at 423 V = 2990 rpm Name plate rated power = 22 kW
N-1	Describe the various methods by which you calculate motor loading.

REFERENCES

1. Motor challenge: Office of Industrial Technologies, Department of Energy, USA
2. Energy audit Reports of National Productivity Council

Chapter 7

Performance Evaluation of Pumps

Learning Objectives

In this chapter you will learn about

- Pump: Performance terms and definitions
- Different methods of assessing the flow
- How to determine the total head?
- How to estimate the efficiency of the pump?
- How to determine the system resistance and duty point?

Energy Auditors

After successfully completing th chapter you will be able complete the following tasks:

- ✓ **Estimate the actual flow rate of th pump using different methods**
- ✓ **Estimate pump efficiency**

7. ENERGY PERFORMANCE ASSESSMENT OF PUMPS

7.1 Introduction

Pumping is the process of addition of kinetic and potential energy to a liquid for the purpose of moving it from one point to another. This energy will cause the liquid to do work such as flow through a pipe or rise to a higher level. A centrifugal pump transforms mechanical energy from a rotating impeller into a kinetic and potential energy required by the system.

The most critical aspect of energy efficiency in a pumping system is matching of pumps to loads. Hence even if an efficient pump is selected, but if it is a mismatch to the system then the pump will operate at very poor efficiencies. In addition efficiency drop can also be expected over time due to deposits in the impellers. Performance assessment of pumps would reveal the existing operating efficiencies in order to take corrective action.

7.2 Purpose of the Performance Test

- Determination of the pump efficiency during the operating condition
- Determination of system resistance and the operating duty point of the pump and compare the same with design.

7.3 Performance Terms and Definitions

Pump Capacity, Q = Volume of liquid delivered by pump per unit time, m^3/hr or m^3/sec
Q is proportional to N, where N- rotational speed of the pump

Total developed head, H = The difference of discharge and suction pressure

The pump head represents the net work done on unit weights of a liquid in passing from inlet of the pump to the discharge of the pump.

There are three heads in common use in pumps namely
(i) Static head
(ii) Velocity head
(iii) Friction head.

The frictional head in a system of pipes, valves and fittings varies as a function (roughly as the square) of the capacity flow through the system.

System resistance: The sum of frictional head in resistance & total static head.

Pump Efficiency: Fluid power and useful work done by the pump divided by the power input in the pump shaft.

$$Pump\ Efficiency = \frac{Hydraulic\ power, P_h}{Power\ input\ to\ the\ pump\ shaft} x\,100$$

Where,

Hydraulic power, P_h (kW) = Q x $(h_d - h_s)$ x ρ x $g / 1000$

Q = Volume flow rate (m^3/s), ρ = density of the fluid (kg/m^3), g = acceleration due to gravity (m/s^2), $(h_d - h_s)$ = Total head in metres

7.4 Field Testing for Determination of Pump Efficiency

To determine the pump efficiency, three key parameters are required: Flow, Head and Power. Of these, flow measurement is the most crucial parameter as normally online flow meters are hardly available, in a majority of pumping system. The following methods outlined below can be adopted to measure the flow depending on the availability and site conditions.

7.4.1 Flow Measurement, Q

The following are the methods for flow measurements:

- Tracer method BS5857
- Ultrasonic flow measurement
- Tank filling method
- Installation of an on-line flowmeter

Tracer Method

The Tracer method is particularly suitable for cooling water flow measurement because of their sensitivity and accuracy.

This method is based on injecting a tracer into the cooling water for a few minutes at an accurately measured constant rate. A series of samples is extracted from the system at a point where the tracer has become completely mixed with the cooling water. The mass flow rate is calculated from:

$$q_{cw} = q_1 \times C_1/C_2$$

Where, q_{cw} = cooling water mass flow rate, kg/s
q_1 = mass flow rate of injected tracer, kg/s
C_1 = concentration of injected tracer, kg/kg
$C2$ = concentration of tracer at downstream position during the 'plateau' period of constant concentration, kg/kg

The tracer normally used is sodium chloride.

Ultrasonic Flow meter

Operating under Doppler effect principle these meters are non-invasive, meaning measurements can be taken without disturbing the system. Scales and rust in the pipes are likely to impact the accuracy.

- Ensure measurements are taken in a sufficiently long length of pipe free from flow disturbance due to bends, tees and other fittings.
- The pipe section where measurement is to be taken should be hammered gently to enable scales and rusts to fall out.
- For better accuracy, a section of the pipe can be replaced with new pipe for flow measurements.

Tank filling method

In open flow systems such as water getting pumped to an overhead tank or a sump, the flow can be measured by noting the difference in tank levels for a specified period during which the outlet flow from the tank is stopped. The internal tank dimensions should be preferable taken from the design drawings, in the absence of which direct measurements may be resorted to.

Installation of an on-line flowmeter

If the application to be measured is going to be critical and periodic then the best option would be to install an on-line flowmeter which can get rid of the major problems encountered with other types.

7.4.2 Determination of total head, H

Suction head (h_s)

This is taken from the pump inlet pressure gauge readings and the value to be converted in to meters ($1 kg/cm^2 = 10. m$). If not the level difference between sump water level to the centerline of the pump is to be measured. This gives the suction head in meters.

Discharge head (h_d)

This is taken from the pump discharge side pressure gauge. Installation of the pressure gauge in the discharge side is a must, if not already available.

7.4.3 Determination of hydraulic power (Liquid horse power),

Hydraulic power, $P_h (kW) = Q \times (h_d - h_s) \times \rho \times g / 1000$

Q = Volume flow rate (m^3/s), ρ = density of the fluid (kg/m^3), g = acceleration due to gravity (m/s^2), ($h_d - h_s$) = Total head in metres

7.4.4 Measurement of motor input power

The motor input power P_m can be measured by using a portable power analyser.

7.4.5 Pump shaft power

The pump shaft power P_s is calculated by multiplying the motor input power by motor efficiency at the existing loading.

$$P_s = P_m \times \eta_{Motor}$$

7.4.6 Pump efficiency

This is arrived at by dividing the hydraulic power by pump shaft power

$$\eta_{Pump} = \frac{P_h}{P_s}$$

Example of pump efficiency calculation

Illustration of calculation method outlined

A chemical plant operates a cooling water pump for process cooling and refrigeration applications. During the performance testing the following operating parameters were measured;

Measured Data

Pump flow, Q	0.40 m^3/s
Power absorbed, P	325 kW
Suction head (Tower basin level), h_1	+1 M
Delivery head, h_2	55 M
Height of cooling tower	5 M
Motor efficiency	88 %
Type of drive	Direct coupled
Density of water	996 kg/ m^3

Pump efficiency

Flow delivered by the pump	0.40 m^3/s
Total head, h2 -(+h1)	54 M
Hydraulic power	0.40 x 54 x 996 x 9.81/1000 = 211 kW
Actual power consumption	325 kW
Overall system efficiency	(211 x 100) / 325 = 65 %
Pump efficiency	**65/0.88 = 74 %**

7.5 Determining the System resistance and Duty point

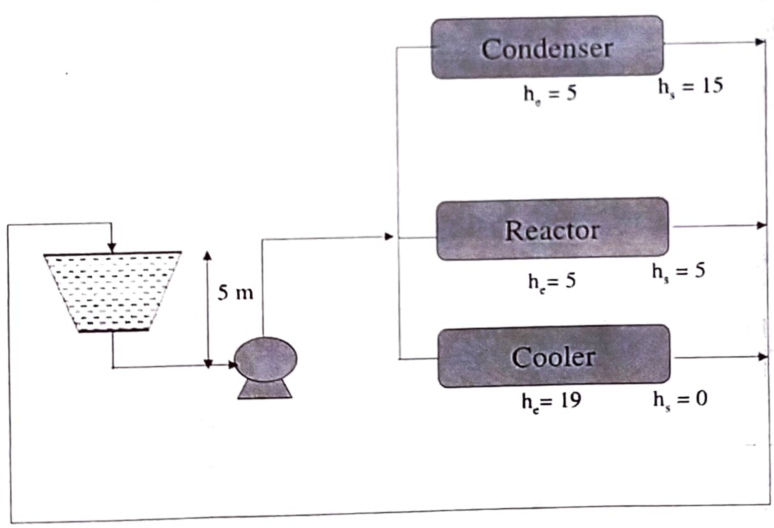
Determination of the system resistance curve and imposing the pump curve over it will give an idea of the operating efficiency of the pump and also the drop in efficiencies when the system curve changes from normal / design. The example following from the earlier example outlines the method of constructing a system curve.

Example:

Location of equipments

The Refrigeration plant is located at +0.00 level and the Process plant condensers are located at +15 m level. One cooler having a design pressure drop of 1.9 kg/cm^2 is located at the 0.00 level (ground level). Other relevant data can be inferred from the earlier section. See schematic in Figure 7.1.

Figure 7.1: Schematic of the System



h_s = Static Head ; h_e = Equipment pressure drop

The step-by-step approach for determining system resistance curve is given below.

Step-1 Divide system resistance into Static and dynamic head

Find static head;

Static head (Condenser floor height) = 15 m

Find dynamic head;

Dynamic Head = Total Head – Static Head

Dynamic head = (54-15) = 39 m

Step-2 Check the maximum resistance circuit

Resistance in the different circuits is as under

S.No.	System	Condenser loop resistance, m	Reactor loop resistance, m	Cooler loop resistance, m
1.	Supply line from pump	15	10	15
2.	Static head	15	5	Nil (cooler at ground level)
3.	Equipment	5	5	19
4.	Return line from equipment to CT	15	10	15
5.	Tower head	-	-	5
6.	Total	50	30	54

It can be noted that at full load the condenser and cooler circuits offer the maximum resistance to flow.

Step-3 Draw system resistance curve

Choose the condenser loop as it offers maximum resistance and is also having a static head component

Static head: 15 m

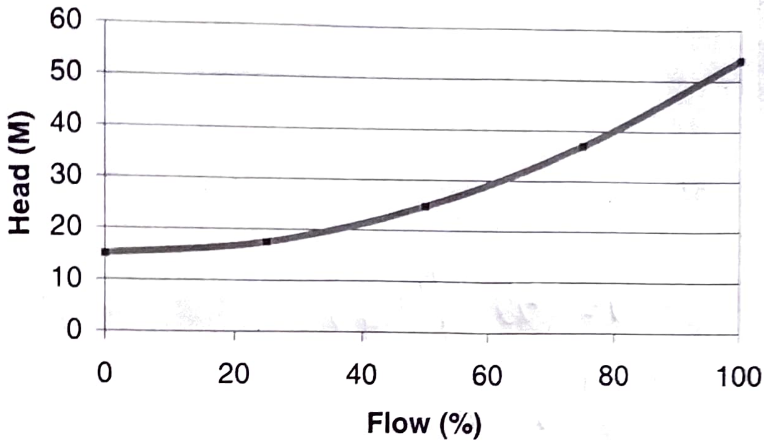
Dynamic head at full load: 39 m

Compute system resistance at different flow rates

S.No.	Flow (%)	Dynamic head = 39x $(\%flow)^2$	Static head, m	Total head, m
1.	100	39	15	54
2.	75	21.9	15	36.9
3.	50	9.75	15	24.75
4.	25	2.44	15	17.44

Step-4 Plot the system resistance against flow in the pump efficiency curves (see Figure 7.2) provided by the vendor and compare actual operating duty point and see whether it operates at maximum efficiency. In the example provided it is found that the pump system efficiency is lower by 4 % due to change in operating conditions.

Figure 7.2 System Resistance Curve



Examples:

1) In a municipality pumping system, water is pumped from the river to an underground circular sump of 8 metre dia in the intermediate booster station. Flow measurements were carried out by level difference in the sump. Pump takes 10 minutes to fill 1 metre level of circular sump. Pressure gauges are not available in the pumping system. The discharge pipe is horizontal, 300mm dia and 8 km long. Friction factor for the pipe is 0.006. The pump has a negative suction of 2 metre.

The details of power measurements at motor are:

3 phase voltage: 415 V, line current: 93 A and power factor: 0.89. The efficiency of the Motor is 0.90.

As an energy auditor, work out the following:

a) Flow rate of the pump in m^3/hr
b) Power drawn by the motor in kW
c) Total head developed by the pump (ignore friction losses in suction piping)
d) Operating efficiency of the pump

Solution:

Flow rate of the pump	$\frac{\Pi \times 8^2}{4} \times \frac{60}{10}$ = $\frac{\pi d^2}{4} \times \frac{60 \text{ min}}{10 \text{ min}}$
	302 m^3/hr
Power drawn by the motor	√3 x v x I x cos Ø
	√3 x 0.415 x 93 x 0.89 → Here V/1000
	59.5 kW
Total head	
Friction head	$4flv^2/2gD$
Velocity (flow/cross sectional area of pipe) metre/ second $V = (Q/3600) / (\pi d^2/4)$	$(302/3600)/(\Pi \times 0.30^2/4)$ = Flow rate in m/sec / cross sectional area of pipe,
	1.19 m/s
Friction head = $4flv^2/2gD$	$\frac{4 \times 0.006 \times 1.19^2 \times 8000}{2 \times 9.81 \times 0.3}$
friction factor – f; v = velocity; L = length in m; g = gravity constant; D = diameter of discharge pipe.	46.2 metres
Total head developed by the pump	46.2 – (-2)
	48.2 m
Operating efficiency of the pump	
Hydraulic power	(302/3600) x 48.2 x 9.81
	39.7 kW
Pump shaft power	59.5 x 0.9
	53.55 kW
Pump efficiency	39.7/53.55
	74.14 %

2) A centrifugal clear water pump rated for 800 m^3/hr was found to be operating at 576 m^3/hr with discharge valve throttled. The pumps speed is 1485 RPM. The discharge pressure of the pump before the throttle valve is 2 kg/cm^2g. The pump draws the water from a sump 4 metres below the centerline of the pump. The input power drawn by the motor is 124 kW at a motor efficiency of 92%.

(i) Find out the efficiency of the pump.

(ii) If the normal required water flow rate is 500 m^3/hr to 700 m^3/hr, what in your opinion should be the most energy efficient option to get the required flow rate variation?

(iii) And what would be the pump shaft power for that most energy efficient option if the pump is delivering the flow rate of 550 m^3/hr.

Solution:

(i) Hydraulic power, P_h (kW) $= Q \times (h_d - h_s) \times r \times g / 1000$

Q = Volume flow rate (m^3/s), r = density of the fluid (kg/m^3), g = acceleration due to gravity (m/s^2), $(h_d - h_s)$ = Total head in metres

$$h_d - h_s = 20 - (-4) = 24 \text{ m}$$

Hydraulic power = (576 x 24 x 1000 x 9.81) / (3600 x 1000)

= 37.67 kw

Input power to pump = 124 kW x 0.92 = 114 kW

Efficiency of the pump = (37.67 /114) x 100 = 33 %

(ii) Since the pump discharge requirement varies from 500 m^3/h to 700 m^3/h, the ideal option would be to operate with a VSD (variable frequency drive, hydraulic coupling)

(iii) For a flow rate 550 m^3/h, the reduced speed of pump would be:

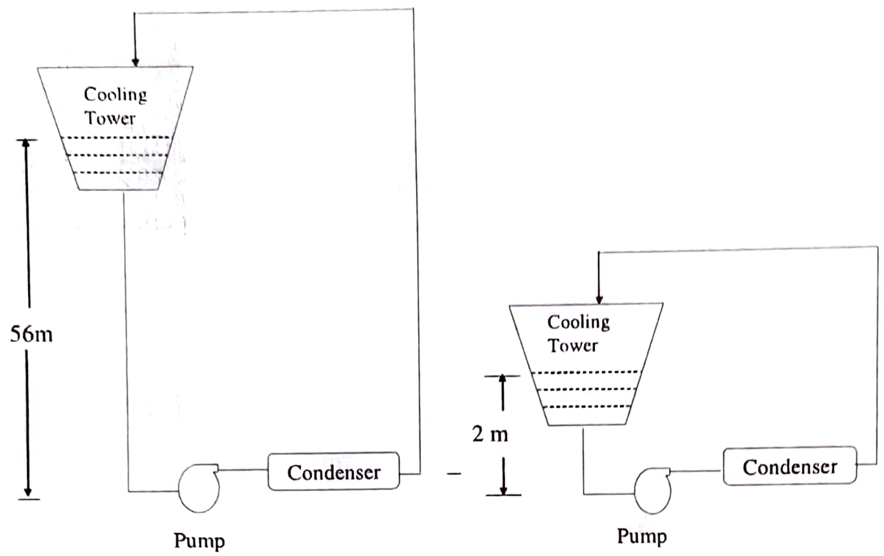
$$(550/800) = (N1/1485)$$

$$N1 = 1021$$

The pump shaft power would be:

$$= \left(\frac{\mathbf{1021}}{\mathbf{1485}}\right)^3 \mathbf{x\ 114} \quad \mathbf{= 37\ kW}$$

3) In a commercial building, an energy auditor recommended to bring down the cooling tower from the terrace to the ground with a view to save energy in the pump. Details are given in the sketch below. Ignoring the friction losses, will this measure save energy? Explain with reason



Answer:

No, because the pressure differential across the pump will be same as friction losses are ignored

QUESTIONS	
S-1	How would you measure the flow by using tracer method?
S-2	Why does the friction head increase with increasing flow in a pumping system?
S-3	What is system resistance?
S-4	When should one consider impeller trimming option for a pump?
S-5	What parameters influence the hydraulic power in a pumping system?
S-6	A centrifugal pump raises water to a height of 12 metre. If the same pump handles brine with specific gravity of 1.2, to what height the brine will be raised?
S-7	Briefly explain static head and how it varies with flow rate?
S-8	State two methods of non-intrusive water flow measurements in a pipe.
S-9	The level in an overhead tank of 2m x 2m rises by 1m in 2 min. what is the flow rate of the pump?
S-10	By what percent the head will reduce if the pump's impeller is trimmed by 10%?
L-1	The suction head is 1m below the pump centerline. The discharge pressure shows 3 kg/cm^2. The flow is calculated to be 100 m^3/hr. Find out the pump efficiency.
L-2	The pump efficiency is 70%. The hydraulic power is calculated to be 22 kW. Find out the motor power required to drive the pump.
N-1	A centrifugal clear water pump rated for 800 m^3/hr was found to be operating at 576 m^3/hr with discharge valve throttled. The pumps speed is 1485 RPM. The discharge pressure of the pump before the throttle valve is 2 kg/cm^{2}g. The pump draws the water from a sump 4 metres below the centerline of the pump. The input power drawn by the motor is 124 kW at a motor efficiency of 92%. (i) Find out the efficiency of the pump. (ii) If the normal required water flow rate is 500 m^3/hr to 700 m^3/hr, what in your opinion should be the most energy efficient option to get the required flow rate variation? (iii) And what would be the pump shaft power for that most energy efficient option if the pump is delivering the flow rate of 550 m^3/hr.

REFERENCES

1. Pump handbook by Karassik
2. Energy Audit Reports of National Productivity Council