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Computer program for the prediction of air-lift pump performance

Associated software: ESDUpac A8814

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the following Working Party on behalf of the Internal Flow Panel:

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The ESDU Fluid Mechanics, Internal Flow Series is recognised as a valuable source of validated data and methods by the Institution of Mechanical Engineers and its Thermofluids Group is involved in continually reassessing the scope and focus of the content of this Series.

COMPUTER PROGRAM FOR THE PREDICTION OF AIR-LIFT PUMP PERFORMANCE

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	4
2.1 Scope and Applicability of the Computer Program	4
2.2 Principles of Operation of Air-lift Pumps	4
2.3 Operating Characteristics of Air-lift Pumps	5
2.4 Methods of Air Injection	5
3. RUNNING THE PROGRAM	7
3.1 Program Input	7
3.2 Program Output	7
3.3 Worked Examples	12
3.3.1 Specification of Example 1	12
3.3.2 Program output for design 1a	15
3.3.3 Specification of Example 2	17
3.3.4 Program output for Example 2	18
3.4 Program Performance	20
4. REFERENCES AND DERIVATION	23
4.1 References	23
4.2 Derivation	23
APPENDIX A – AIR-LIFT PUMP MODEL	24
A.1 INTRODUCTION	24
A.2 GRAVITY COMPONENT OF PRESSURE GRADIENT	25
A.3 FRICTION COMPONENT OF PRESSURE GRADIENT	26
A.5 MIXER LOSSES	28
A.6 RISER INLET PRESSURE	28
A.7 ANNULAR FLOW TRANSITION	28
A.8 POWER CONSUMPTION	28

COMPUTER PROGRAM FOR THE PREDICTION OF AIR-LIFT PUMP PERFORMANCE

1. NOTATION AND UNITS

		Units	
		<i>SI</i>	<i>British</i>
A	cross-sectional area of flow	m^2	ft^2
D	pipe internal diameter	m	ft
E	parameter defined by Equation (A.19)	—	—
F	parameter defined by Equation (A.20)	—	—
Fr	Froude number, $G^2/(Dg\rho_H^2)$	—	—
f	Fanning friction factor, Equation (A.25)	—	—
G	mass velocity of whole mixture, $4(\dot{m}_G + \dot{m}_L)/(\pi D^2)$	kg/s m^2	lb/s ft^2
g	acceleration due to gravity	m/s^2 (9.81)	ft/s^2 (32.18)
g_c	constant of proportionality in Newton's second law	— (1.0)	lb ft/lbf s^2 (32.18)
H	parameter defined by Equation (A.21)	—	—
K_f	single-phase flow pressure loss coefficient	—	—
L	pump height, see Sketch 2.1	m	ft
L_d	total length of straight sections in downcomer	m	ft
M	gas molar mass	kg/kmol	lb/lbmol
$\dot{m}_G$	mass flow rate of gas component of mixture	kg/s	lb/s
$\dot{m}_L$	mass flow rate of liquid component of mixture	kg/s	lb/s
N	dimensionless inverse viscosity, Equation (A.10)	—	—
$N_{Eö}$	Eötvös number, Equation (A.11)	—	—
n	parameter defined by Equations (A.12) to (A.14)	—	—
P	power	W	ft lbf/s
p	absolute static pressure	$\text{Pa (N/m}^2\text{)}$	lbf/ft^2

Issued September 1988
Reprinted at Amendment B – 28 pages
This page Amendment A

dp/dz	local pressure gradient	Pa/m (N/m ³)	lbf/ft ³
dp_a/dz	component of local pressure gradient due to momentum change	Pa/m (N/m ³)	lbf/ft ³
dp_f/dz	component of local pressure gradient due to friction	Pa/m (N/m ³)	lbf/ft ³
dp_g/dz	component of local pressure gradient due to gravity	Pa/m (N/m ³)	lbf/ft ³
R	radius of bend centre-line	m	ft
R_g	gas constant	J/kg K	ft lbf/lb°R
R_M	universal gas constant	J/kmol K (8314.4)	ft lbf/lbmol°R (1545)
Re_d	downcomer Reynolds number, $4\dot{m}_L/\pi D\mu_L$	—	—
Re_{GO}	Reynolds number, GD/μ_G	—	—
Re_{LO}	Reynolds number, GD/μ_L	—	—
S	submergence, see Sketch 2.1	m	ft
T	temperature	°C	°F
U	actual phase velocity	m/s	ft/s
U_b	bubble rise velocity in slug flow	m/s	ft/s
U_{GV}	gas drift velocity, $U_G - (V_G + V_L)$	m/s	ft/s
U_∞	single bubble rise velocity in a stagnant liquid	m/s	ft/s
V	total two-phase superficial velocity, $(V_G + V_L)$	m/s	ft/s
V_G	gas superficial velocity, $\dot{m}_G/\rho_G A$	m/s	ft/s
V_L	liquid superficial velocity, $\dot{m}_L/\rho_L A$	m/s	ft/s
We	Weber number, $G^2(D/(\sigma\rho_H g_c))$	—	—
x	mass quality of mixture, $\dot{m}_G/(\dot{m}_G + \dot{m}_L)$	—	—
z	pipe axial length, positive in direction of flow	m	ft
α	void fraction, fraction of flow cross section occupied by gas phase	—	—
γ	ratio of specific heat capacities	—	—
ε	effective roughness height	m	ft

This page Amendment A

μ_G	dynamic viscosity of gas phase	N s/m ²	lbf s/ft ²
μ_L	dynamic viscosity of liquid phase	N s/m ²	lbf s/ft ²
ρ_G	density of gas phase	kg/m ³	lb/ft ³
ρ_H	homogeneous density of mixture, $[x/\rho_G + (1-x)/\rho_L]^{-1}$	kg/m ³	lb/ft ³
ρ_L	density of liquid phase	kg/m ³	lb/ft ³
σ	surface tension	N/m	lbf/ft
Φ_{LO}^2	two-phase multiplier, see Section A.3	—	—

Subscripts

<i>atm</i>	atmospheric conditions
<i>d</i>	downcomer
<i>G</i>	gas flowing alone at same mass flow rate as gas component of two-phase mixture
<i>GO</i>	gas flowing alone at same mass flow rate as complete two-phase mixture
<i>L</i>	liquid flowing alone at same mass flow rate as liquid component of two-phase mixture
<i>LO</i>	liquid flowing alone at same mass flow rate as complete two-phase mixture
0	conditions at supply liquid surface, see Sketch 2.1
1	conditions at entry to riser, defined as location of gas injection, see Sketch 2.1
2	conditions at exit from riser, see Sketch 2.1

2. INTRODUCTION

Air-lift pumps provide a reliable means of raising corrosive, hazardous or abrasive liquids and slurries because they incorporate no moving parts and require virtually no maintenance. They have applications in the chemical industry, the nuclear industry for handling highly radioactive liquids, and also for lifting slurries from deep wells.

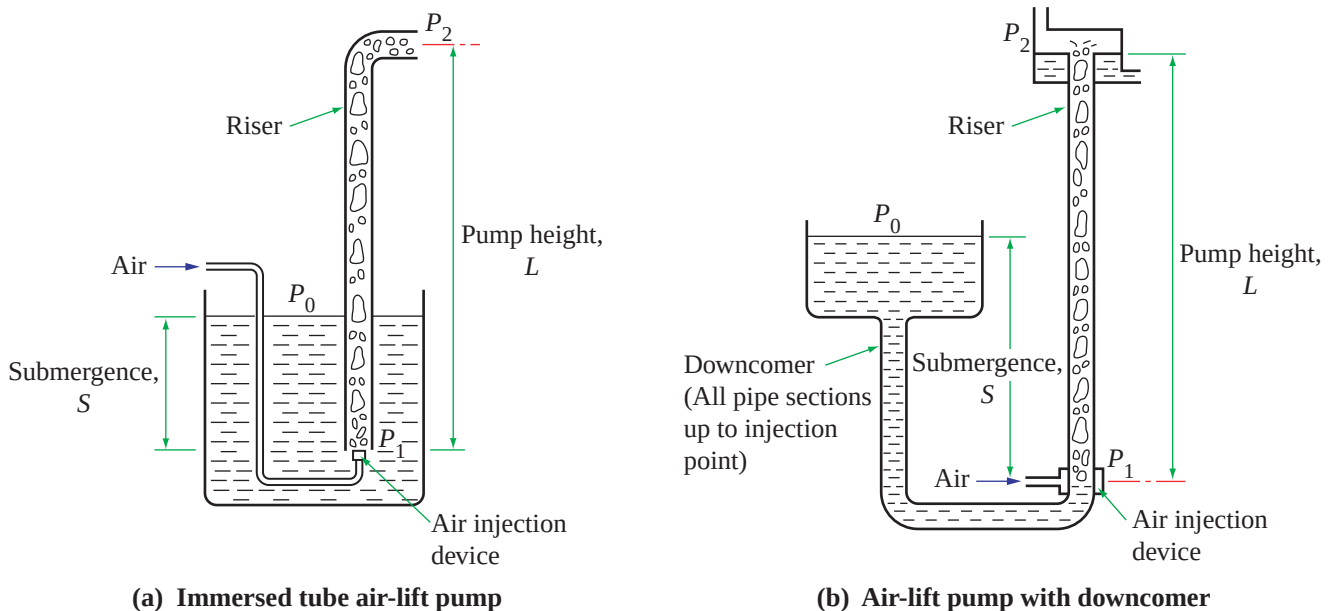
2.1 Scope and Applicability of the Computer Program

This Item provides a computer program for predicting the operating characteristics of air-lift pumps. The program covers pumps operating in isothermal, vertical two-phase flow with Newtonian liquids.

The accuracy of any prediction method in two-phase flow is constrained by the accuracies of the underlying correlations. Typically, the most accurate generalised two-phase friction and void fraction correlations display rms errors of about 40% (see Reference 2). Because of these errors the program incorporates the option of applying a correction factor to the void fraction. It is recommended that the program output be matched to existing data, where available, before being used to predict the effect of modifications on pump performance. Alternatively, the program can be used to carry out a sensitivity analysis on a basic pump design to ascertain the influence on the performance of the input parameters. Examples illustrating these two aspects of the use of the program are given in Section 3.3.

2.2 Principles of Operation of Air-lift Pumps

Two possible configurations of an air-lift pump are shown in Sketch 2.1.

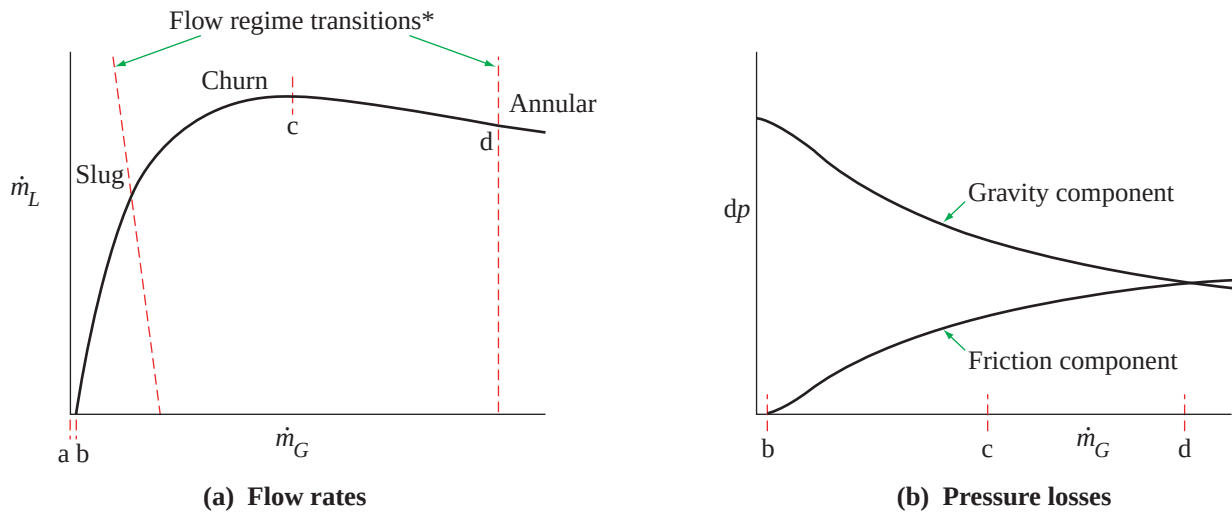


Sketch 2.1 Air-lift pump configurations

Pumping is achieved by injecting air at or near the bottom of the riser to create a two-phase mixture. The driving force is generated by the density difference between the density of this mixture in the riser and the density of the surrounding liquid (or the liquid in the downcomer).

2.3 Operating Characteristics of Air-lift Pumps

A typical relationship between the amount of air injected and the amount of liquid pumped is shown in Sketch 2.2a. Sketch 2.2b shows the relative contributions of frictional and gravitational pressure drops to the total pressure drop in an air-lift pump.



Sketch 2.2 Operating characteristics of an air-lift pump

For a description of the flow regimes indicated in Sketch 2.2a, see, for example, Taitel and Dukler¹³.

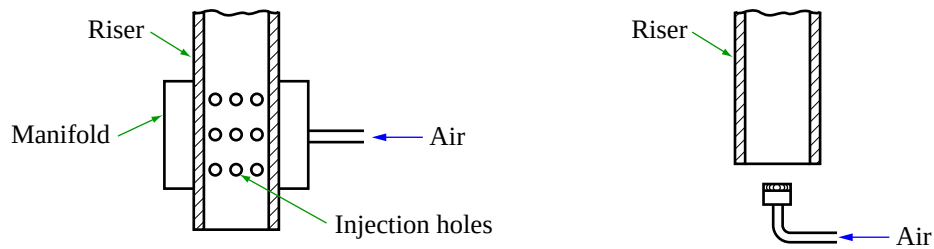
Sketch 2.2a shows three distinct regions that occur as the air mass flow rate is increased from zero.

- (i) Region a – b. At very low air injection rates no liquid is pumped. A homogeneous bubbly mixture with a low void fraction is formed and pumping does not commence until the density of this mixture is reduced sufficiently to allow it to rise above the exit of the riser.
- (ii) Region b – c. Increasing the air injection rate produces an increase in liquid pumping rate. This is a result of the increase in void fraction (decrease in mixing density) with increasing air mass flow rates. The total pressure drop through the pump is fixed by the external pressure conditions at the inlet and outlet; decreasing the gravitational pressure drop allows a larger frictional pressure drop. As point c is approached, the slugs break up to form a churn-turbulent flow pattern and the frictional pressure drop increases more rapidly with increasing air mass flow rates. The operating curve reaches a maximum liquid mass flow rate at point c.
- (iii) Region c – d. Once point c is reached any additional air injection rate causes a decrease in the liquid flow rate pumped, and unnecessary compression costs will be incurred.

2.4 Methods of Air Injection

Two possible methods of air injection are shown in Sketch 2.3.

* These transition lines should be treated as bands.



Sketch 2.3 Air injection methods

Derivation 10 compares the two designs with various sizes and numbers of orifices for a 24 mm diameter riser. No significant differences between the two methods were reported. The injection method may therefore be chosen from practical considerations.

3. RUNNING THE PROGRAM

ESDUpac A8814 is provided on disk in two versions, as described below. Example input and output files are included with both versions.

The interactive version is contained within ESDUview, a user-friendly 'windowing' environment for running ESDUpacs on personal computers. ESDUview manages all operations such as setting up input files, running the Fortran code and viewing the output files. On selecting ESDUpac A8814 from the menu of available programs, the user is prompted for all the input data. Guidance is provided on the features of ESDUview and all the program variables in the context-sensitive HELP facility. At various points throughout operation a number of checks are carried out on the entered data. Error messages alert the user to incorrect numerical values and guide in their correction; other potential problems are highlighted by warning messages.

An executable version of this program is available. In order to run this version the user creates a data file, which contains the input data required by the program, by following exactly the data input sequence of Section 3.1. To run the executable version of the program from the keyboard the name of the data input file must be specified on the command line using the operating system redirection symbols, *e.g.* for MS-DOS:

```
A8814 < IN8814 > RS8814
```

The ESDUview version of the program is recommended for its ease of operation. Instructions for creating the data input file are given in Section 3.1. Although the ESDUview version can be operated without reference to this Data Item, the user may find useful the guidance (complementary to that in the ESDUview HELP facility) on the program variables and model details given throughout this Item.

The computer program calculates the gas mass flow rate, the individual components of pressure drop and the power required to compress the gas isentropically for a given liquid mass flow rate. The program may also be used to calculate the pump operating curve for a range of liquid mass flow rates between zero and the transition to annular flow (see Section A.7).

3.1 Program Input

The program reads the required input data from a data file. This allows the input data to be checked for mistakes prior to each run and edited if necessary.

The data file is assembled following the input sequence given in Table 3.1.

3.2 Program Output

The program output file comprises the input data together with *either*

- gas mass flow rate,
- power requirement,
- gravitational pressure drop,
- frictional pressure drop,
- momentum-change pressure drop,
- mixer pressure drop, and
- downcomer pressure drop (if applicable),