

泡状流中含气率和气泡尺寸分布的超声非接触测量方法

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摘要: 搭建了一套超声法非接触测量装置,用于循环系统中气液两相泡状流含气率和气泡尺寸在线测量。针对截面为 20 mm × 3 mm 垂直矩形窄通道出口,在常压、入口温度 313 K 的过冷条件,利用 UAS(超声衰减谱法)对水流动沸腾引起的垂直上升气液两相泡状流含气率和气泡尺寸分布进行测量,分析了加热功率和质量流量对泡状流含气率和气泡尺寸及其分布的影响。实验结果表明:质量流量一定时,随着加热功率升高,气泡中位径 D_{50} 增大,尺寸分布增宽,气液两相流含气率增大;在工况大致相当(可通过出口温度 T_2 和出口绝对压力 p_2 判断)的条件下,随着质量流量的增大,气泡中位径 D_{50} 减小,尺寸分布变窄,含气率减小。将超声法所测含气率与气液分离法所测含气率比较,最大相对偏差为 4.5%,说明实验测量结果基本可靠。

关键词: 含气率; 气泡尺寸分布; 气液两相流; 超声衰减谱; 矩形窄缝通道

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引言

气液两相流广泛存在于自然界、工程设备乃至日常生活中。随着工业技术的飞速发展,在动力、化工、石油、制冷、核能等领域中两相流传热问题受到高度关注。

对于竖直管流,当循环流量、加热功率和进口温度改变时,在流动方向上的含气率、气泡尺寸、界面浓度必会发生变化。Chapelon 等人利用双频率多普勒测量系统对气泡的大小进行了检测^[1],Zeitoun 采用高速摄像技术实验测量了冷凝流动系统里的气泡尺寸及相界面浓度等流动参数^[2],张志斌采用光电毛细管探头测量了搅拌槽中较宽操作范围内的气泡大小分布^[3],高永慧等人用声透射损失方法测量在

气泡大小、分布一定的情况下时气液混相物质中的含气量^[4]。

泡状流是连续的液体中存在大量弥散状的微气泡的两相体系,本研究采用一种非接触式测量方法—UAS(超声衰减谱法)研究泡状流中气泡含气率及气泡尺寸分布,对工程中如各式凝结器,各种热交换器,核电站和火力发电站在生产过程控制、管理和运行提供重要参考价值^[5-6]。

超声法颗粒测量通过声学特征信号分析尺寸大小和浓度信息,其具有非侵入式、快速、无需对样品进行稀释等特点^[7]。超声衰减谱法是基于超声波在通过含有气相的连续介质时所引起的依赖频率变化的衰减谱来表征气泡尺寸大小的测量技术^[8]。其中的主要的理论基础为 McClements 和 BLBL 先后发展的声学理论模型^[9-11],同时,一种结合改进的 Chahine 算法可以用于气泡尺寸分布的反演^[12]。

1 理论模型和反演算法

1.1 McClements & BLBL 模型

McClements D J 对于一些两相介质中的声波动情况进行讨论,认为热传导和黏性机制对于很多实际情况非常重要,同时在经典的 ECAH 模型系数 A_n 的序列中^[13-14],前两项 A_0 、 A_1 起主导作用,即获得如下简化的复波数计算公式:

$$\left(\frac{\beta}{k}\right)^2 = 1 + \frac{3\varphi}{jk^3 R^3}(A_0 + A_1) \quad (1)$$

式中: β —气液两相流中的复波数且有 $\beta = \omega/c_s(\omega) + i\alpha_s(\omega)$, m^{-1} ; k —连续介质中的声波数, m^{-1} ; $i = \sqrt{-1}$; ω —角频率, rad/s ; $a_s(Np \cdot m^{-1})$ 、 $c_s(m/s)$ —

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声衰减系数和声速; φ —气泡的体积浓度即含气率; R —气泡的尺寸大小 μm 。

散射系数 A_0 、 A_1 表达式为:

$$A_0 = \frac{i(kR)^3 \cdot [(\rho k^2 / \rho' k^2) - 11 - k^2 R C T \rho \tau H \times (\beta_0 / \rho c_p - \beta'_0 / \rho' c'_p)]}{3} \quad (2)$$

$$A_1 = -i(kR)^3 (\rho - \rho') / \left[\frac{3[3\rho + 2(\rho' - \rho)]}{1 + 3(1+i)\delta_v / 2R + 3i\delta_v^2 / 2R^2} \right] \quad (3)$$

式中: 上撇号代表气相参数; T —绝对温度, K ; β_0 —热膨胀系数 m/K ; c —连续相声速, m/s ; c_p —定压比热容 J/K ; τ —导热系数, $\text{W}/(\text{m} \cdot \text{K})$ 。

$$H = \left\{ \begin{array}{l} 1/(1-iz) \\ -\tau/\tau' \cdot \tan(z') / [\tan(z') - z'] \end{array} \right\}^{-1} \quad (4)$$

式中: $z = (1+i) \cdot R/\delta_i$; $\delta_v = \sqrt{2\eta/\omega\rho}$; $\delta_i = \sqrt{2\tau/\omega\rho c_p}$; η —黏度, $\text{Pa} \cdot \text{s}$; δ_v [$\text{m}/(\text{Pa} \cdot \text{s})$], δ_i (m/J)—黏性和热集肤深度; 表征气液界面处产生的黏性波和热波在介质中的传递能力。

BLBL(声散射)模型通过纯散射效应来描述不同含气率的气液两相流中的消声效应,形式上类似光全散射法。从气液两相流中无限薄层的声强度平衡出发,

$$dI = -I\alpha_s dz \quad (5)$$

对式(5)积分,根据散射衰减系数 α_s 的定义,并引入消声效率概念,得到衰减系数的表达式为:

$$\alpha_s = \frac{3\varphi K_{\text{ext}}}{8R} \quad (6)$$

K_{ext} 即为消声效率,由式(7)给出:

$$K_{\text{ext}} = -\frac{4}{\sigma^2} \sum_{n=0}^{\infty} (2n+1) R_e \{A_n\} \quad (7)$$

式中: σ —通常称颗粒尺寸系数, $\sigma = \omega R/c$; c —连续相声速, m/s 。

无限序列 A_n 可以根据 Hay&Mercer^[15] 理论,带入 σ 以及其第一、二类球 Bessel 函数求出。

上述理论模型从物理上反映了超声波与含气泡两相流中的声波动特征,并可从数值上预测其声衰减系数,再将声衰减系数带入公式(6)中即可求得含气率。

1.2 反演算法

在气液两相流气泡尺寸检测中的反演过程通常是指通过已有模型预测和实验测试获得的频谱进行反计算,进而重建气泡尺寸分布信息。一般情况下,

可以通过理论模型构建核矩阵 W ,再代入实测衰减谱信息 B 构造一个线性方程组 $W \cdot X = B$,通常的求解是采用非负最小二乘或正则化方法求解气泡尺寸分布 X 。

文献[16]利用文献[17]提出的迭代算法修正式,提出了一种改进的 Chahine 算法,具有如下的迭代形式:

$$X_i^{(p+1)} = X_i^p \cdot \sum_{j=1}^{N_F} W_{ij} \frac{B_j^{(m)}}{B_j^{(p)}} \quad (8)$$

其中 $W_{ij} = A_{ij} / \sum_{k=1}^{N_F} A_{ik}$, W_{ij} 为归一化的权重因子。

2 测量装置和方法

2.1 测量装置

搭建了如图 1 所示气液两相流含气率的超声检测实验系统,分为气液两相流循环和超声测量两个部分。循环系统由水箱、蠕动泵、18 L/h 的玻璃转子流量计、预热器、矩形窄通道、气液分离器、冷凝器组成,测量区布置在窄通道出口处。超声测量装置包括超声脉冲发射接收仪 (Olympus, Model 5073PR)、一对中心频率 5 MHz 水浸式宽频直探头 (Panametrics NDT, V324)、非侵入式测量隔离缓冲块、双通道高速信号采集卡 (NI, USB 5133, 最高采样率为 100 MS/s) 及其它附件。

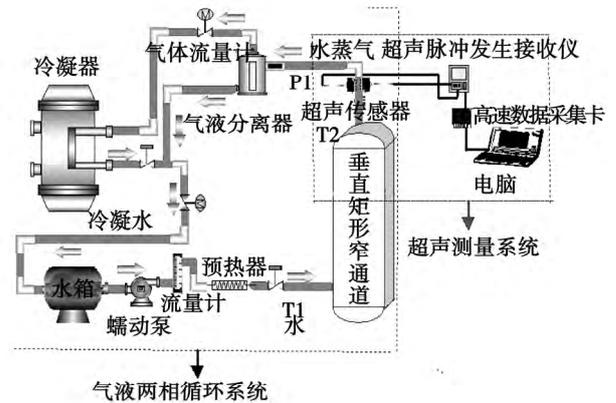


图 1 实验系统示意图

Fig. 1 Schematic diagram of the test system

2.2 测量方法

传感器和样品之间通过钢化玻璃材料隔离,既确保测量的非接触特征,同时避免了样品对传感器

的污染。超声测量采用一发一收形式,利用高速采集卡进行信号采集,并同步送入计算机,由自行开发 LabVIEW 程序进行处理,分析超声波信号。实验中先后对流动纯水介质(背景)和气液两相流的脉冲波信号进行测量,通过快速傅里叶变换(FFT)获取频谱,依据式(9)计算不同频率分量的超声衰减系数。

$$\alpha = \frac{\ln(A_0/A_1)}{L} \quad (9)$$

式中: A_0 、 A_1 —相同流量下纯水和气液两相流测得超声波幅值 μV ; L —窄通道出口测量段的厚度 m 。

这一方法测量简便,测量过程中也无须考虑反射损失的影响。

2.3 实验参数

实验前需获取窄通道出口温度 T_2 和出口压力 p_1 及气相和液相密度、声速、膨胀系数、比热容、导热系数和弹性系数,对液相还需知道黏性系数。对于不同温度、压强下的气泡参数可通过声学手册和美国国家标准与技术研究院网页查得。

表 1 列出由不同加热功率 P ,窄通道出口温度 T_2 ,出口绝对压力 p_2 和气液两相流质量流量 Q_m 构成的实验工况。

表 1 各工况的参数

Tab.1 Parameters under various operating conditions

工况	加热功率 P/W	出口温度 T_2/K	出口压强 p_2/MPa	质量流量 $Q_m/\text{kg} \cdot (\text{m}^2 \cdot \text{s})^{-1}$
1-1	718	374.05	0.103	2.22
1-2	787	374.18	0.102	2.86
1-3	933	374.28	0.104	3.49
2-1	782	378.55	0.123	2.22
2-2	1 024	378.45	0.122	2.86
2-3	1 109	378.78	0.125	3.49
3-1	858	381.07	0.130	2.22
3-2	1 103	379.13	0.127	2.86
3-3	1 196	381.07	0.132	3.49
4-1	938	383.95	0.143	2.22
4-2	1 199	382.36	0.140	2.86
4-3	1 292	384.70	0.147	3.49
5-1	1 024	387.85	0.159	2.22
5-2	1 294	387.68	0.157	2.86
5-3	1 498	388.93	0.164	3.49

3 实验结果与讨论

3.1 超声幅度谱

图 2-图 4 分别是流量为 2.22、2.86、3.49 $\text{kg}/(\text{m}^2 \cdot \text{s})$ 时,不同功率下对气液两相流的超声幅度谱进行高斯函数拟合后的曲线。从图中可知,在某一流量下,纯水的超声幅度和有效带宽均最大,随着加热功率的增大,超声幅度减小,有效带宽变窄。这是因为,气泡尺寸逐渐增大,受气泡吸收、反射、衍射等因素影响,造成接收探头接收的声能减少,幅值逐渐下降,有效带宽亦变窄。

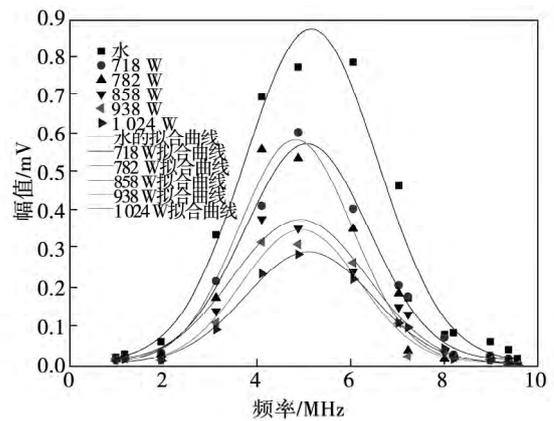


图 2 超声幅度谱 ($Q_m = 2.22 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

Fig.2 Ultrasonic amplitude spectrum ($Q_m = 2.22 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

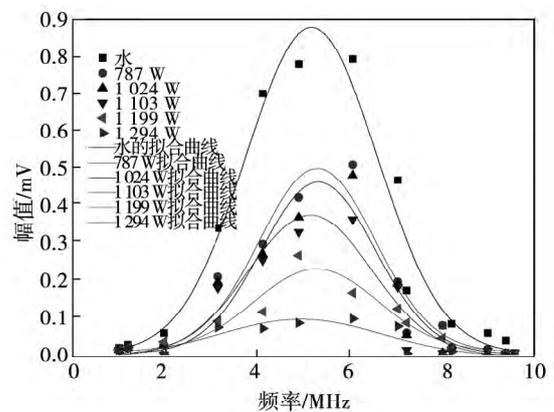


图 3 超声幅度谱 ($Q_m = 2.86 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

Fig.3 Ultrasonic amplitude spectrum ($Q_m = 2.86 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

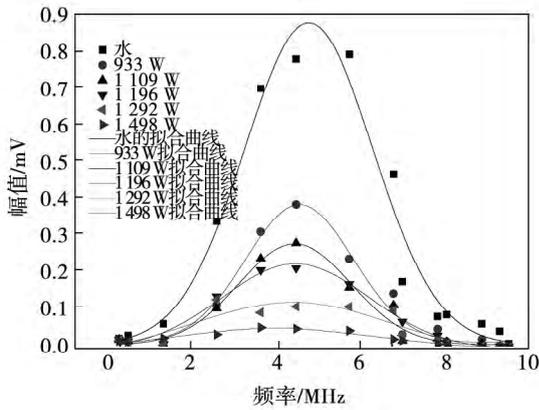


图 4 超声幅度谱 ($Q_m = 3.49 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

Fig. 4 Ultrasonic amplitude spectrum
($Q_m = 3.49 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

3.2 超声衰减谱

利用式(9)计算各个分频率下超声衰减系数,得到不同质量流量、不同加热功率下的超声衰减谱,对衰减曲线做一阶指数衰减拟合得到超声衰减谱,如图5-图7所示。从图中可知,在某一质量流量下,同一超声频率随着加热功率增大,超声衰减系数也增大,高频部分的声衰减更明显。

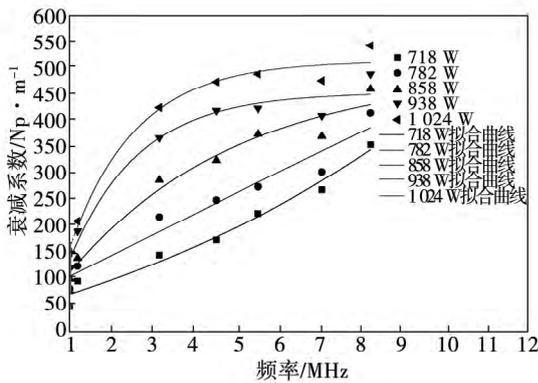


图 5 超声衰减谱 ($Q_m = 2.22 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

Fig. 5 Ultrasonic attenuation spectrum
($Q_m = 2.22 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

这是因为,功率较低时流体有可能发生过冷沸腾,一方面由于主流流体是过冷的,气泡的产生会随着主流流体而冷凝,最后消失,因而声波的耗散减少,声衰减小;而随着加热功率的增大,流体达到饱和状态,气泡的产生、聚合也更加容易,因而气泡数目的增加和部分小气泡聚合为体积较大的气泡,使整个气相所占的比例增大,对声波耗散亦会增强,

造成声衰减增大;另一方面气泡在形变过程中发生热传导损耗及液体对气泡面振动产生粘滞阻力,即气泡在振动过程中把部分入射波的能量变成液体分子的无规则热运动,当超声波频率等于气泡的共振频率时,气泡处于共振状态,气泡对声波衰减最强,超声波穿过气泡群时,衰减系数取决于气泡半径的概率分布。当最大概率半径所对应的气泡固有频率与入射波的频率相近时,大部分气泡处于共振状态,声波在其中传播时,衰减也最强。除了气泡对超声波的散射和吸收外,液相物质本身也会对超声波产生与声波频率平方成正比的热传导吸收和粘滞吸收,但不占主导。

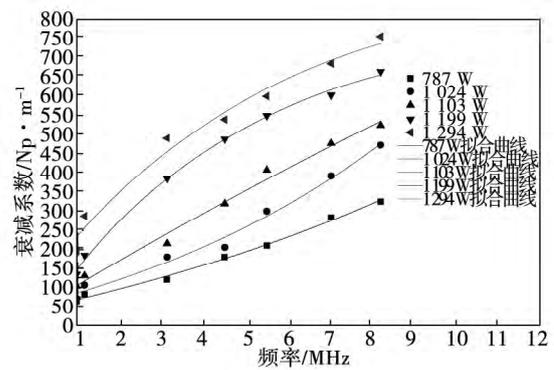


图 6 超声衰减谱 ($Q_m = 2.86 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

Fig. 6 Ultrasonic attenuation spectrum
($Q_m = 2.86 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

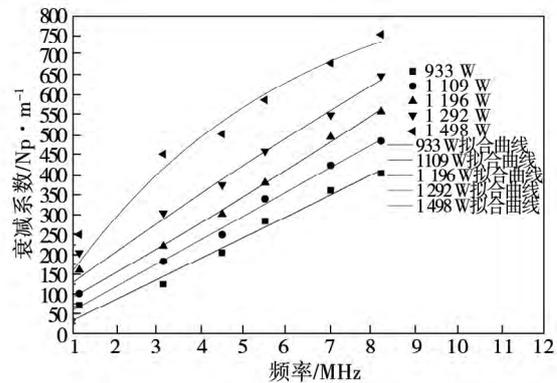


图 7 超声衰减谱 ($Q_m = 3.49 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

Fig. 7 Ultrasonic attenuation spectrum
($Q_m = 3.49 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

3.3 气泡尺寸分布及含气率

将超声衰减谱带入理论模型和反演算法求解出气泡的尺寸分布。图8-图10分别为不同质量流量

时气泡尺寸分布。由图可知: 在某一质量流量下, 随着加热功率的增大, 气泡的尺寸分布向较大尺寸方向偏移。从图 8 中看出, 在较低的流量 $2.22 \text{ kg}/(\text{m}^2 \cdot \text{s})$ 随着加热功率的增加, 气泡尺寸分布的趋势基本不变, 在加热功率达到 1024 W 时, 气泡尺寸分布变得非常宽, 说明当加热功率增大一定值后, 气液两相流气泡整体大小改变, 且各个尺寸气泡所占比例也会改变, 此时由于较小的气泡会合并为大气泡, 所以大气泡所占比例增大, 小气泡数目则减小。

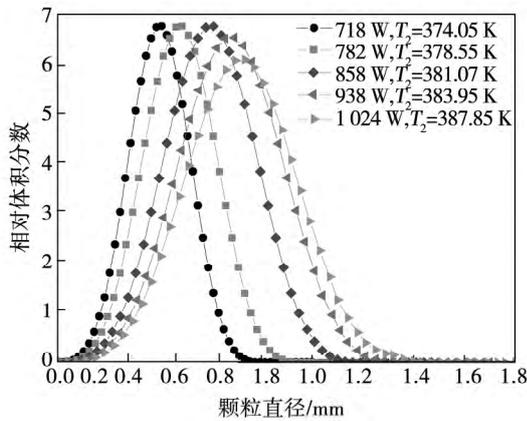


图 8 气泡尺寸分布 ($Q_m = 2.22 \text{ kg}/(\text{m}^2 \cdot \text{s})$)
Fig. 8 Distribution of the dimensions of air bubbles ($Q_m = 2.22 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

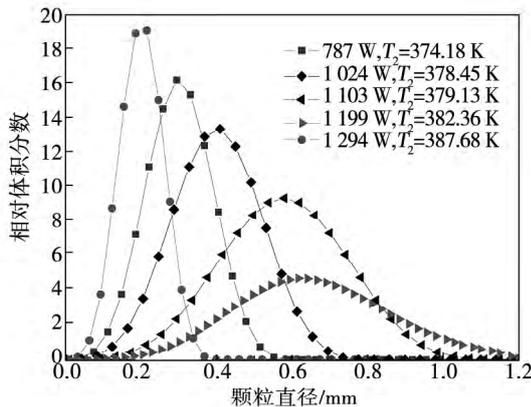


图 9 气泡尺寸分布 ($Q_m = 2.86 \text{ kg}/(\text{m}^2 \cdot \text{s})$)
Fig. 9 Distribution of the dimensions of air bubbles ($Q_m = 2.86 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

图 11 - 图 13 分别对应工况 1、3、5 不同质量流量时的气泡尺寸分布。由图可知, 在同工况下, 随质量流量的增大, 气泡尺寸分布峰值增大, 分布变窄, 尺寸分布向较小尺寸方向偏移。

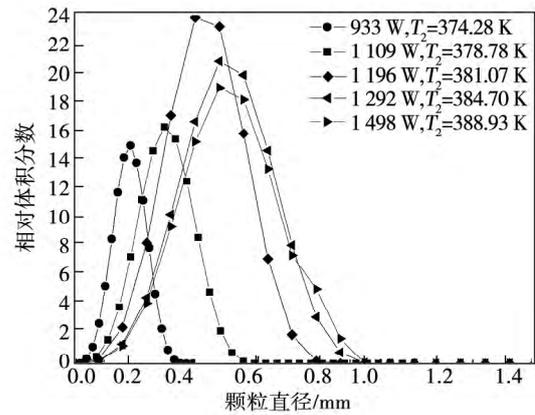


图 10 气泡尺寸分布 ($Q_m = 3.49 \text{ kg}/(\text{m}^2 \cdot \text{s})$)
Fig. 10 Distribution of the dimensions of air bubbles ($Q_m = 3.49 \text{ kg}/(\text{m}^2 \cdot \text{s})$)

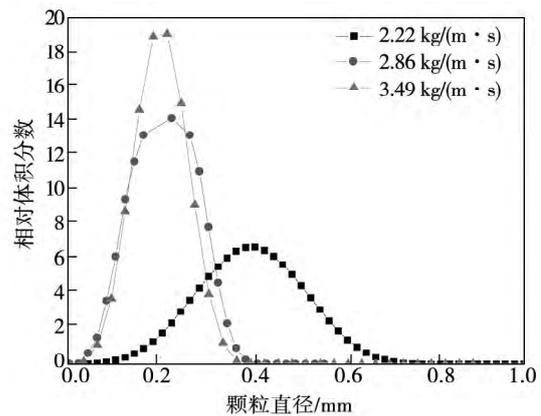


图 11 工况 1 的气泡尺寸分布
Fig. 11 Distribution of the dimensions of air bubbles under the operating condition No. 1

表 2 为超声法测得气泡中位径 D_{50} 。在一定流量下, 随着加热功率、出口温度和压力的增加, D_{50} 增大, 在同一工况下, 随着流量增大, D_{50} 减小。

表 2 超声法测量的气泡中位径 D_{50}
Tab. 2 Medium diameter of the air bubbles D_{50} by using the ultrasonic method

工况	气泡中位径/mm		
	$2.22/\text{kg}\cdot(\text{m}^2\cdot\text{s})^{-1}$	$2.86/\text{kg}\cdot(\text{m}^2\cdot\text{s})^{-1}$	$3.49/\text{kg}\cdot(\text{m}^2\cdot\text{s})^{-1}$
1	0.398 0	0.199 8	0.173 6
2	0.477 0	0.276 4	0.251 1
3	0.597 0	0.388 6	0.355 3
4	0.677 6	0.558 3	0.434 3
5	0.716 4	0.629 0	0.513 2

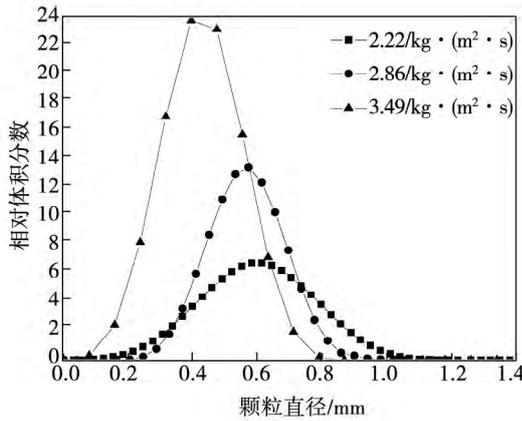


图 12 工况 3 的气泡尺寸分布

Fig. 12 Distribution of the dimensions of air bubbles under the operating condition No. 3

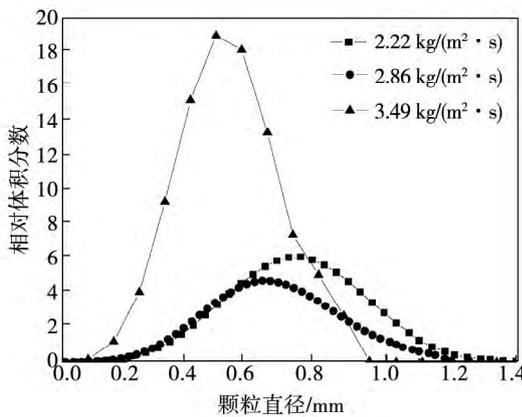


图 13 工况 5 的气泡尺寸分布

Fig. 13 Distribution of the dimensions of air bubbles under the operating condition No. 5

通过式(6)算出测量区域内气液两相流的含气率,并与气液分离法(Gas-Liquid Separation Method, GLSM)比较,如表3所示。

从表3可知:在一定的流量下,气液两相流的含气率随着工况参数增大而增加,说明在提高加热功率后,窄通道内水从过冷沸腾到泡状流,对流传热增强,随着热流密度的增加,流体局部换热系数也增大,产生的气泡量增大;在工况相当条件下,随流量增大,气液两相流含气率减小,这是因为过冷液体量增加,如要产生相同沸腾,必须提供更大的功率以保证出口温度和绝对压强的提高。超声衰减法与气液分离法比较,最大相对偏差为4.5%,说明超声测量结果基本可信。

表 3 用超声法与气液分离法所测气液两相流含气率比较

Tab. 3 Comparison of the air content measured by using the ultrasonic method with that by using the gas/liquid separation method

工况	超声衰减法	气液分离法	相对偏差/%
1-1	0.323	0.335	3.6
1-2	0.215	0.216	0.5
1-3	0.196	0.204	3.9
2-1	0.416	0.425	2.1
2-2	0.298	0.312	4.5
2-3	0.281	0.287	2.1
3-1	0.532	0.549	3.1
3-2	0.406	0.413	1.7
3-3	0.335	0.339	1.2
4-1	0.568	0.556	2.2
4-2	0.502	0.512	2.0
4-3	0.396	0.392	1.0
5-1	0.595	0.588	1.2
5-2	0.536	0.542	1.1
5-3	0.485	0.466	4.1

4 结 论

(1) 在一定的流量下,随着加热功率等工况参数的提高,超声衰减法增加,气泡尺寸分布向大气泡方向偏移,气液两相流的含气率增大;在工况相当情况下,随着流量增大,气泡尺寸分布向小气泡方向偏移,气液两相流的含气率减小。

(2) 超声衰减法对气液两相流含气率的实验测量结果与气液分离法比较,相对偏差最大为4.5%,测量结果基本可信,说明超声衰减法可用于气液两相流的含气率非接触测量。

致谢:感谢上海理工大学制冷与低温工程研究所黄理浩博士对本研究提供的帮助。

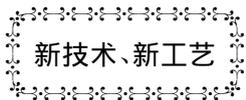
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(丛 敏 编辑)



熔盐菲涅尔光热发电技术示范取得突破

DOI:10.16146/j.cnki.rndlgc.2015.02.005

5月5日,Areva 太阳能宣布其与 Sandia 国家实验室合作建设的菲涅尔式光热发电熔盐储热技术实验示范项目正式投入运行,项目测试结果成功证明了菲涅尔技术直接采用熔盐作工质的可行性。9月份,Novatec 太阳能公司和熔盐厂商 BASF 宣布在西班牙 PE1 项目上合作成功建设了另一个熔盐为传热工质的菲涅尔光热发电示范系统。这两个示范系统的建设对研究熔盐菲涅尔技术具有重要意义,采用熔盐作为传热和储热介质,可增加菲涅尔光热电站的年运行小时数,降低 LCOE,提升电能质量和电网可调节性。但不幸的是 Areva 其后剥离了光热业务。

(吉桂明 摘译)

ture at the outlet 9.6%. **Key Words:** gas turbine ,swirler ,NO_x ,numerical simulation

三联供系统中综合性能评价方法的应用研究 = **Study of the Applications of the Method for Evaluating the Comprehensive Performance of a Trigeneration System** [刊, 汉] / SUN Peng , YOU Shi-jun , ZHANG Huan (College of Environment Science and Engineering , Tianjin University , Tianjin , China , Post Code: 300072) , LI Xu (China Northwest Architecture Design Research Institute Co. Ltd. , Xi'an , China , Post Code: 710018) // Journal of Engineering for Thermal Energy & Power. - 2015 , 30(2) . - 187 - 192

In the light of the problem that the influence of dynamic loads are currently ignored during the design of a gas cooling , heating and power trigeneration system and excessively large capacities given in the models of the equipment items chosen in the configuration of the system may result , with the reference capacity and operation strategies for the internal gas combustion engine serving as the design variables and the comprehensive performance indexes , including the total annual operation expenses , amount of primary energy sources consumed and the quantity of carbon dioxide emissions serving as the target functions for optimization , established was a method for designing and optimizing a system. By using the method thus established , an analysis and design of a trigeneration system for a building of a hotel in Tianjin city were conducted. The optimization results are given as follows: the reference capacity of the inner combustion engine should be chosen as 975 kW and when the system is operating according to the strategy of “determining heat generation on the basis of power demand” , as compared with any single supply system , the trigeneration system can save expenses by 3.6% , an amount of energy by 28.9% and reduce the carbon dioxide emissions by 44.7%. **Key Words:** cooling , heating and power trigeneration system , comprehensive performance index , system configuration , operation strategy

泡状流中含气率和气泡尺寸分布的超声非接触测量方法 = **A Method for Ultrasonic Non-contact Measuring the Gas Content and Dimension Distribution of Bubbles in a Bubble Flow** [刊, 汉] / HU Bian (Hunan Wuling Electric Power Engineering Co. Ltd. , Changsha , China , Post Code: 410004) , SU Ming-xu , CAI Xiao-shu (Particle and Two-phase Flow Measurement Research Institute , Shanghai University of Science and Technology , Shanghai , China , Post Code: 200093) // Journal of Engineering for Thermal Energy & Power. - 2015 , 30(2) . - 193 - 199

Set up was a set of supersonic non-contact measurement device for performing an on-line measurement of the gas content and bubble dimensions of a gas-liquid two-phase bubble flow in a circulation system. For a vertical rectangu-

lar narrow channel outlet with a cross section of $20 \text{ mm} \times 3 \text{ mm}$, under the condition of the supercooling state in which the pressure was normal and the inlet temperature was 313 K , the ultrasonic attenuation spectrum method was used to measure the gas content and dimension distribution of bubbles in a vertical rising gas-liquid two-phase bubble flow arisen from the boiling of a water flow and analyze the influence of the heating power and the mass flow rate on the gas content, bubble dimensions and their distribution of a bubble flow. The test results show that when the mass flow rate is constant, with an increase of the heating power, the medium diameter of the bubbles D_{50} will increase, the distribution of dimensions will broaden and the gas content of the gas-liquid two-phase flow will also increase. Under the condition of the operating conditions being roughly equivalent (which can be judged from the outlet temperature T_2 and the outlet absolute pressure P_2), with an increase of the mass flow rate, the medium diameter of the bubbles D_{50} will decrease, the distribution of dimensions will narrow and the gas content will decrease. When the gas content measured by using the ultrasonic method is compared with that measured by using the gas-liquid separation method, the maximal relative deviation reaches 4.5% , indicating that the measurement results obtained from the test are basically reliable. **Key Words:** gas content, dimension distribution of bubbles, gas-liquid two-phase flow, supersonic attenuation spectrum, rectangular narrow channel

CuO-H₂O 纳米流体强化换热的数值模拟 = Numerical Simulation of the Intensified Heat Exchange of CUO-H₂O Nano-fluid [刊 汉] SUN Chao-jie, SUN Bao-min, ZHONG Ya-feng, JIANG Jia-zong (Education Ministry Key Laboratory on Power Plant Equipment Condition Monitoring and Control, North China University of Electric Power, Beijing, China, Post Code: 102206) // Journal of Engineering for Thermal Energy & Power. - 2015, 30(2). - 200 - 204

By using the numerical simulation method, studied were the natural convection-based heat exchange characteristics and of CUO-H₂O nano-fluid inside a rectangular cavity and the mechanism governing the heat exchange. The emphasis was placed on an analysis of the influence of volumetric fraction and particle size of the nano-fluid on the temperature and speed field inside a two-dimensional enclosed cavity at various Ra numbers formed when the CUO-H₂O nano-fluid is undergoing the natural convection and an investigation of the influence of Brownian movement of nano-fluid on the heat exchange. The numerical simulation results show that for a given Ra number, the heat exchange efficiency of the nano-fluid will notably enhance. When Ra number is relatively small, the heat exchange is mainly regarded as the heat conduction. With an increase of Ra number, the heat exchange will gradually become a convection-based heat exchange. Brownian movement of the nano-particles will become an important factor influen-